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Land Cover Change and Its Eco-environmental Responses in Nepal

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Preface

Nepal is a neighbouring country of China, located at the south of Himalayas, and characterized by the typical mountainous landscapes. Its land is commonly divided into three ecological belts—mountains, hills, and the terai plain, running east–west and vertically intersected with Nepal's major, north-to-south-flowing river systems. Each belt has different natural resources, and ecological and sociocultural environments. In past decades, owing to the anthropologic disturbances and climate change, land use/cover such as glaciers has been reported a lot of changes, causing significant impacts on the eco-environment in Nepal. Especially after the 4.25 big earthquake in 2015, the contradiction between human and land is arising extensive concerns among the scientific communities.

China and Nepal have a long history of bilateral exchanges and cooperation. Under the background of the China's international regional economic cooperation strategy of "the Belt and Road Initiative," in recent years, the two sides have signed a series of memorandum of understanding or cooperative agreements in the field of science and technology, economy and culture, especially for enhancing the cooperation on environment-related fields in the face of global climate change and sustainable development. The Institute of Mountain Hazards and Environment (IMHE), of Chinese Academy of Sciences (CAS), is a state nonprofit academic institution and the unique institute that especially focuses on mountain science studies including mountain hazards, mountain environment, sustainable mountain development and digital mountain & remote sensing application. As a leading role in this field, IMHE attaches great importance to international cooperation and has signed cooperative agreements with the International Centre for Integrated Mountain Development (ICIMOD) and Tribhuvan University (TU) of Nepal to perform continuous science and technology cooperation. It is also authorized the secretariat office of the China Committee of ICIMOD. Under this framework, joint studies have been conducted in the fields including but not limited to land use/cover change and its environmental effects, transboundary water resources managements and water hazard prevention and control, mountain eco-environmental evolution and livelihood security by scientists from both sides.

In September 2013, CAS launched an International Cooperation Key Project named “Comparison study on typical mountain ecosystems in China and Nepal based on remote sensing technologies”, under the granted number GJHZ201320. The aid project on Science and Technology for developing countries from Ministry of Science and Technology of China also partly sponsored related studies. After more than three years of efforts, the projects have achieved remarkable progresses in key remote sensing technologies in oversea land cover monitoring, land cover mapping, land cover change and its driving forces analysis, and eco-environmental responses analysis in Nepal. Especially in the 2015 Nepal earthquake, the project quickly started an emergency response to investigate earthquake-induced geohazards based on data archives, to efficiently assist and effectively support the Nepal scientific disaster relief teams from CAS and international organizations. Most important of all, a joint cooperative team has been formed during the cooperating. The friendship is being built up for all involved scientists between the two countries, and subsequently, it should lay a solid foundation for future cooperation.

Based on the above achievements, we initiated this book in 2015 to consolidate the authors from TU, ICIMOD, IMHE, and China-Nepal Joint Research Center for Geography, to jointly achieve the successful goal. This book collects recent researches which address four key topics related to LUCC, eco-environmental change, livelihoods and adaptation, geohazards, 4.25 earthquake and its impacts, totally including 20 chapters. Its main purpose is to analyze and identify the land use and land cover change in Nepal at different temporal and spatial scales to enable a deeper understanding about the fact and potential consequences of eco-environmental changes. This book can also be supplied as a very useful literature for related governments or organizations to make decisions for some actions to enhance the sustainable development and eco-environment protection in Nepal.

We would like to express our thanks to all the contributors for their sincere cooperation during this book preparation. Each author has provided his unique contribution to this book. The appendix of this book presents dozens of photographs that are the precious records, showing international activities and field investigations during bilateral and multilateral communications. Meanwhile, this book would not be successfully published without scientific leadership by the International Scientific Committee. We are grateful to the members who offered their valuable time and expertise through reviewing the manuscripts to ensure the high academic standard of this book. We believe that it also introduces a success case of bilateral or multilateral scientific and technological cooperation in the field of land resources and environment for both countries and even the South Asia, and will surely be benefit to “the Belt and Road Initiative.”

Chengdu, China Prof. Ainong Li
November 1, 2016

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Chapter 1
Land Use/Cover Change and Its Eco-environmental Responses in Nepal: An Overview

Ainong Li and Wei Deng

Abstract Nepal is a typical mountain country. Its eco-environment has been reported highly sensitive to land use/cover change (LUCC) related to human activities, natural disasters, and climate change. This book collected joint studies from both China and Nepal scientists, and concluded the issue of eco-environmental responses to LUCC in Nepal from different aspects, including LUCC spatial-temporal pattern, eco-environmental changes, livelihood and adaptation, and mountain geo-hazards. It is supported by the China-Nepal Joint Research Center for Geography and the regional science and technology cooperation framework such as the cooperation agreements signed by Institute of Mountain Hazards and Environment (IMHE), Chinese Academy of Sciences with Tribhuvan University (TU), and International Center for Integrated Mountain Development (ICIMOD). It should be a valuable and comprehensive literature for scientific community and local government to support the land resources use, environment security protection as well as the decision making for sustainable development in Nepal.

Keywords Mountain · LUCC · Eco-environment · Livelihood · Geo-hazard

In general, land use/cover pattern is an outcome of natural and socioeconomic factors and their utilization by man in time and space. Information on land use/cover is essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare, but also plays an important role on land surface eco-environment variation, which would directly influence

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ecosystem services. Therefore, quantitatively obtaining land use/cover change (LUCC) information is very essential for better understanding of landscape dynamic during a known period to achieve sustainable managements. Usually, LUCC is a widespread and accelerating process, not only closely associated with human activities, but also directly or indirectly influenced by terrestrial ecosystems, which in turn drive changes that would impact natural ecosystem, such as the impacts on land surface processes related to surface energy exchange, water cycle, and mass transfer. Meanwhile, it has been pointed out that LUCC is highly associated with the occurrences of geo-hazards, such as debris flow and landslides in the mountainous areas, which greatly threats the life and property of local people. Many sustainable development issues are related to LUCC. Therefore, understanding landscape patterns, changes, and interactions between human activities and natural phenomenon is very important for proper land management and decision improvement, to help solve the existing conflicts between human and natural environments.

Agriculture is the mainstay industry in Nepal. Compared with the regions or countries experiencing rapid industrial expansion and urban growth, the LUCC pattern and its effects in Nepal are more special and typical. During the past half-century, due to population growth and agricultural expansion, aggravated over the long term by harvesting for fuel and timber, Nepal has experienced a continuous deforestation. The forestry area, which was 45% in 1966 and 37% in 1986, had declined considerably to 29% in 1994 (DFRS 1999). Although recent studies have revealed that Nepal's total forest coverage and condition are significantly improving due to the community forestry (CF) intervention (FAO 2009), the area change of forest lands greatly impacts the forest resources, forest ecosystem, and biodiversity in Nepal. In addition, due to excessive agricultural activities, coupling with global change and population growth, LUCC shows great impact on the natural ecosystem, soil and water resources, and poverty reduction undertaking in Nepal, leading to severe land degradation, water and soil hazards, and difficulties in livelihood improvement.

Regarding all these issues, under the supports from the China-Nepal Joint Research Center for Geography and the regional science and technology cooperation framework such as the cooperation agreements signed by Institute of Mountain Hazards and Environment (IMHE), Chinese Academy of Sciences with Tribhuvan University (TU), and International Centre for Integrated Mountain Development (ICIMOD), scientists from China and Nepal jointly conducted researches on land use/cover change and its eco-environmental responses in Nepal. It is meaningful to natural resources and environment security analysis and decision making for sustainable development in Nepal.

1.1 Geographic Background of Nepal

Nepal is officially abbreviation of the Federal Democratic Republic of Nepal. It is a beautiful landlocked mountainous country, with Kathmandu as the capital, surrounded by India to the south, east, and west and China to the north (Fig. 1.1). It is located between the latitudes 26° 22′–30° 27′N and the longitudes 80° 04′–88° 12′E and occupies a total area of 147,181 km^2, with the east to west average length of 885 km and the north to south width ranging from 145 km to 241 km.

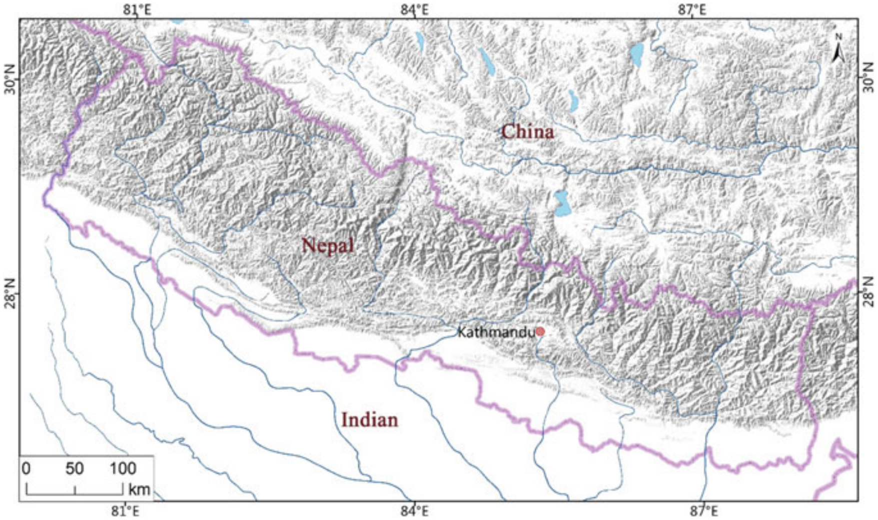

Fig. 1.1 The geographic location of Nepal

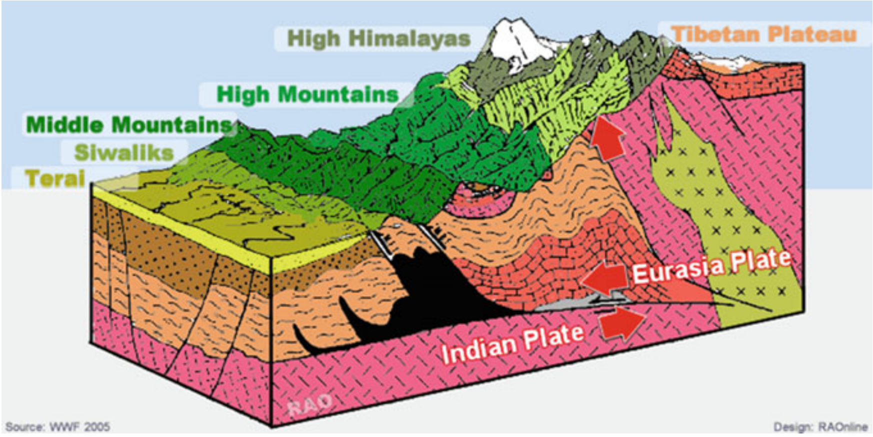

Fig. 1.2 Cross section of Nepal's topography (*Source* Thomas and Rai 2005)

1.1.1 Topography

In Nepal, about 86% of total land area is occupied by high mountain and rolling hills. Physiographically, Nepal can be divided into five ecological regions: Terai Plain, Siwaliks, Middle Mountains, High Mountains, and High Himalayas (Fig. 1.2) (WECS 1986). Terai Plain is the northern part of Indo-Gangetic plain. It extends nearly 800 km from east to west and about 30–40 km from north to south. The average elevation is below 750 m. Siwaliks is commonly referred to as the Churia Hills; the elevation ranges from 700 to 1,500 m. For the Middle Mountains, the elevation is from 1,500 to 2,700 m. It is cut in many places by antecedent rivers such as Koshi, Gandaki (Narayani), Karnali, and Mahakali. They are the first great barrier to monsoon clouds, and the highest precipitation occurs on the southern slope of this range. High Mountains ranges from 2,200 to 4,000 m. This region consists of phyllite, schists and quartzite, and the soil is generally shallow and resistant to weathering. High Himalayas range from 4,000 to above 8,000 m. Eight of the highest peaks in the world and the world's deepest gorge, 5,791 m in the Kali Gandaki valley, are located in this region.

1.1.2 Climate

Because of the enormous range of altitude within such a short north–south distance, Nepal has remarkable climatic variability conditions. The presence of the east–west-trending Himalayan range to the north and the monsoonal alteration of wet and dry seasons also greatly contribute to local climatic variations. Generally, five climatic zones can be separated in Nepal based on altitude: the tropical and subtropical zone of below 1,200 m in altitude; the cool, temperate zone of 1,200–2,400 m in altitude; the cold zone of 2,400–3,600 m in altitude; the subarctic climatic zone of 3,600–4,400 m in altitude; and the arctic zone above 4,400 m in altitude.

In terms of precipitation distribution pattern, Nepal has the average annual precipitation about 1,530 mm, decreasing progressively from southeast to northwest. About 64% of rainfall turn into runoff, and 36% forms snow precipitation or seep into underground (Sharma and Awal 2013). Eighty percent of the precipitation in Nepal comes in the form of summer monsoon rain, and winter rains are more common in the western hills. As the occurrence of monsoon rains is dominant in the temporal distribution of precipitation, the season can be defined as: monsoon (June–September), post-monsoon (October–November), winter (December–February), and pre-monsoon (March–May). Summer precipitation is subject to the advancement of Indian Ocean southeast monsoon. Monsoon normally starts from the second week of June (10 June) and retreats in the fourth week of September (23 September). Monsoon is the wettest season and is the main source of precipitation in Nepal. Monsoon season contributes on an average 79.8% of the total annual precipitation of the country (DHIM 2015). During the monsoon season, depressions form in the Bay of Bengal and move west-northwest causing heavy rain in its path. Therefore, the rainfall decreases progressively from southeast to northwest. Winter precipitation is caused by the westerly disturbances originating in the Mediterranean, which affects areas in the northwest and contributes greatly to the annual total precipitation in these areas. Winter precipitation plays a key role in water balance in glaciers in western Nepal. Most of winter precipitation is in the form of snow, feeding glaciers, and accumulating snow.

Similar as the precipitation variation in Nepal, the spatiotemporal distribution of temperature is directly related to the variation of season and altitude. Usually, winter has the lowest temperature and temperature increases as spring advances due to increase in solar insolation. The temperature will reach its maximum value of the year in the pre-monsoon season, which induces May or early June to be the hottest months. The temperature starts decreasing from October and reaches the minimum in December or January. The hottest part of the country is the southern Terai belt, and the coldest part lies in the high mountain or the Himalayas in the north.

1.1.3 Vegetation

As a Himalayan country, Nepal represents one of the world's richest pockets in plant diversity. The presence of extreme ranges of altitude, precipitation, temperature, and soil within a small geographic area has created a striking vertical zonation in natural vegetation and diversity in flora, with 75 vegetation types and 35 forest types. It is estimated that about 7,000 species of flowering plants exist in Nepal. So far, about 6,000 species of flowering plants and over 4,000 species of non-flowering plants have been enumerated from the country. About 5% of its flowering plants are endemic.

Nepal is floristically influenced from six adjoining floristic regions, namely Central Asiatic in the north, Sino-Japanese in the northeast, Southeast Asia-Malaysian in the southeast, Indian in the south, Sudano-Zambian in the southwest, and Irano-Turranean in the west. Stainton (1972) recognized 35 forest types classified into ten major groups which have been widely adopted in later works. The ten major groups are: subtropical pine forest (1,000–2,200 m), lower temperate mixed broad-leaved forest (1,700–2,200 m), upper temperate broad-leaved forest (2,200–3,000 m), tropical moist lowland Indo-Malayan forest (below 1,000 m [to 1,200 m in Churia hills]), subtropical broad-leaved evergreen forest (1,000–2,000 m), upper temperate mixed broad-leaved forest (2,500–3,500 m), temperate coniferous forest (2,000–3,000 m), subalpine forest (3,000–4,100 m), alpine scrub (above 4,100 m), and perpetual snow (above 5,200 m).

1.1.4 Society

Nepal is known as the "Eastern Switzerland." The population of Nepal in 2015 is estimated to be about 28.5 million as reported by worldometers, with a population growth rate of 1.2%. The population density in Nepal is 201 cap/km^2, 18.6% of the population is living in urban, and the median age is about 23.4 years.

Nepal has many different languages. According to the 2001 national census (CBoS 2012), 92 different living languages are spoken in Nepal, and most of them are evolved from three major language groups: Indo-Aryan, Tibeto-Burman languages, and various indigenous language isolates. The major languages of Nepal (percent spoken as native language) according to the 2011 census are Nepali (44.6%), Maithili (11.7%), Bhojpuri (Awadhi Language) (6.0%), Tharu (5.8%), Tamang (5.1%), Nepal Bhasa (3.2%), Bajjika (3%) and Magar (3.0%), Doteli (3.0%), Urdu (2.6%), and Sunwar.

About the religion, it is not just a set of beliefs and accompanying rituals handed down from generation to generation in Nepal; rather, it is a complex intermingling of traditions, festivals, faiths, and doctrines that have permeated every strata of Nepalese Society in such a way as to become the very heartbeat of the nation. Religion occupies an integral position in Nepalese life and society. It is reported by the 2011 census that 81.3% of the Nepalese population was Hindu, 9.0% Buddhist, 4.4% Muslim, 3.0% Kirant/Yumaist, 1.42% Christian, and 0.9% followed other religions or no religion. Buddhist and Hindu shrines and festivals are respected and celebrated by most Nepalese.

1.2 LUCC

LUCC is not only a data-intensive research, but also an important database related to scientific exploring. Based on Landsat TM/ETM+/OLI images, IMHE conducted land cover change monitoring for the whole Nepal during 1990–2015 and produced five land cover data sets (1990, 2000, 2005, 2010, and 2015). These data sets consist of 8 primary classes and 32 secondary classes. The overall classification accuracy of secondary classes is 87.17%, and Kappa coefficients are 0.85. Because they can accurately reflect the temporal and spatial pattern of Nepal land cover, they are currently the best open land cover products with the 30-m spatial scale (see Chap. 2).

According to statistics, near 25% Nepal's land areas are used for farming, with an area of 36,901.96 km^2. Croplands concentrate in the Terai Plain, low mountains, and hills. Area proportion of paddy fields to dry lands is approximately two to three. Paddy fields mainly produce rice, and a handful of places practice triple-cropping rice agriculture. Dry lands grow corns, wheats, potatoes, beans, and other food and cash crops. Planting patterns of cultivated lands include plain terraces, sloping terraces, and valley reclamation. Forty percent of arable lands have no irrigation facilities. Their agricultural production depends in large part on natural climate conditions, and there are little mechanized modern managements, resulting in a slower growth in the farm crop yield.

Woodland is still Nepal's main land cover class, with a total area of 60,009.27 km^2, accounting for 41% of the total land area. Besides, shrub, grassland, and permanent snow/glaciers are in an area of 12,811.13 km^2, 15,898.78 km^2, and 8,160.79 km^2, respectively, accounting for 8.68, 10.77, and 5.53%, respectively. Relative to the rest of land cover classes, wetlands and artificial surfaces take smaller proportion of land cover classes.

There is an obvious zonality for land use in Nepal, as shown in Table 1.1, which lists main land use types in different landscape areas.

During 1990–2015, there had been a decreasing trend in areas for forests, wetlands, permanent snow/glaciers, whereas croplands, artificial surfaces, and bare lands increased. Shrubs and grasslands did not display any obvious fluctuation (see Chap. 3). Significant changes in land cover occurred mainly in the Terai Plain, low

Table 1.1 Area ratio of land cover classes in different regions

Regions	Paddy field (%)	Arid lands (%)	Grassland (%)	Sparse forests (%)	Jungle (%)	Bare land (%)
Terai Plain	43.7	14.9	4.2	2.1	24.6	10.6
Siwalik Hills	35.3	8.4	5.3	6.8	41.2	3.1
Middle Mountains	8.0	16.6	17.0	36.9	19.9	1.5
High Mountains	1.4	5.5	40.4	29.4	14.7	8.3
High Himalayas	–	–	27.2	2.4	2.4	67.9

hills, Kathmandu valley, and Nepal 4.25 strong earthquake stricken region. The most typical land cover change type was that of forest converted to cropland, with the area of about 215.36 km^2. A lot of wetlands changed to croplands with net change 145.3 km^2. Other land cover change types were a relatively small in amount. From south to north, the intensity of land cover change reduced with an increasing elevation.

This book introduces researches on driving forces of land cover change in Siwalik Hills, Koshi Basin, western hill areas, and entire territory of Nepal (see Chaps. 4, 5, 6, and 14). It has been found that climate changes, natural disasters, population growth and migration, regional poverty, land shortages, and policy influences in Nepal are major driving factors of land cover changes. It will prepare for further researches characterized by multi-topic intersection and multiple temporal and spatial scales. Due to native woodlands decreasing and arable land expanding, it was bound to affect these areas on soil and water conservation function, vegetation carbon sequestration levels, and soil and water incubation conditions for disasters. Simultaneously, it also brought more uncertainties about ecological services and security to these areas as well as their surroundings.

1.3 Eco-environmental Changes

LUCC affects terrestrial ecosystem biodiversity, water, carbon and nitrogen cycles, and surface energy balance. This book addresses major eco-environmental changes in Nepal and their consequences, covering topics related to vegetation growth and biomass monitoring, carbon cycle, and soil erosion.

To quantitatively acquire information about the eco-environment in Nepal, Earth observation (EO) technologies have been applied a lot in recent decades for eco-environmental monitoring and assessment at various scales. A review study was conducted in Chap. 7 to get the idea about the status of EO-based assessment of key ecosystem components, including forests, rangelands, agroecosystems, and wetlands in Nepal. It also provided the discussion about the current information gaps and potential use of upcoming satellite technology developments.

Vegetation growth and carbon cycle changes in Nepal acting as indicators of global change have a significant meaning. However, the responses of vegetation to global change varied a lot at different altitudes for different vegetation types. To clearly address this issue, the spatiotemporal variation of the net primary production (NPP) in Nepal was analyzed based on MODIS NPP product (see Chap. 8). The result indicated that the NPP value in Nepal is close to that in the middle reaches of the Yangtze River in China, with the average annual value about 497 gC/m^2. From 2001 to 2015, there was an increasing trend for NPP in this area with the average annual growth about 1.60 gC/m^2. The NPP change characteristics varied at different altitudes. The decreasing trend can be observed in low-altitude areas because of the intensive human activities, such as agricultural development and urbanization. In the middle to high-altitude areas, the trend of NPP variation was positive, and the increasing trend was very obvious in the middle reaches of the Sun Koshi River and Arun River basin. In addition to the variation induced by climate change and human activities, it was found that the influence from 2015 Nepal earthquake on vegetation growth is significant, especially for the earthquake fault zone when compared with surrounding areas.

The vegetation monitoring results indicated that the high sensitivity of mountain ecosystem is vulnerable to human activity and global change (see Chap. 9). Land degradation has become a very serious environmental issue in Nepal due to deforestation, poor management of natural resources, and inappropriate farming practices. It affected a far greater proportion of the population and had the worst consequences for economic growth and individuals' livelihoods. Regarding this issue, this book introduces the related studies from different scales.

At the regional scale, Chap. 10 presents a study which used RKLS and Revised Universal Soil Loss Equation (RUSLE) to estimate the potential and actual soil loss for a typical agricultural watershed in Nepal (KhadoKhola). Results showed that this region suffered from soil loss about 27.9 million ton/year with the potential erosion of 253.1 million ton/year. It was indicated that soil erosion rate is closely related to land cover types, surface slope, and soil bareness level. The degraded forest contributed significantly as of 64% total potential soil loss. Agriculture as a lifeline of livelihood of rural communities spatially concentrated in 74.31% of the watershed areas and contributed significantly as of 28% of the total potential soil loss and 65% of actual total soil loss in the study area.

At the site scale, the dynamics of soil erosion, organic carbon, and total nitrogen in terraced fields and forestland was analyzed by using the ^{137}Cs tracing method in the Middle Mountains of Nepal (see Chap. 11). Soil samples were collected at approximately 5- and 20-m intervals along terraced field series and forestland transects, respectively. The results indicated that both tillage erosion and water erosion are major erosion processes on terraced fields lacking field banks, resulting in serious soil erosion on the upper section of each terrace and soil accumulation at the lower section of each terrace. For the forestland site, with the exception of soil erosion at the top of slope, spatial variation in soil erosion was similar to the "standard" water erosion model. It should be noted that significantly higher soil erosion rates were found in terraced fields than the forestland site, which indicated that terraces lacking field banks are not effective enough in limiting water erosion and would result in increased tillage erosion rates due to their short slope lengths.

1.4 Livelihoods and Adaptation

Nepal is composed of 75 administrative districts, including 16 districts in mountains, 39 districts located in hilly areas, and the remaining 20 districts located in the Terai Plains. It is a typical mountain country, with mountain population accounting for the major part of the total population. By 2015, the total population was about 28,520,071, with mountainous and hilly county population accounting for 49.7%. Livelihoods of mountain people in Nepal depend on agriculture and animal husbandry; however, the rugged terrains limit arable lands and greatly restrict mountain residents for subsistence from natural resource conditions. Meanwhile, there also exists several adverse natural factors in mountainous and hilly areas, including poor climate conditions, short growing season in contrast to a relatively long crop growing period, extreme weather, droughts and floods, and geological disaster prone. Furthermore, relatively isolated community, inaccessible to traffic, limited irrigation and other infrastructures, all bring considerable pressures on livelihood maintenance. Currently, poverty and development in mountains have drawn extensive concerns from inside and outside of the local society.

To conduct livelihoods study, it first needs to make scientific understanding of poverty, which is the prerequisite for solving poverty problem. In this regard, this book analyzed the spatial variation of poverty in Nepal and further deduced the relationship between poverty and environment (see Chap. 12), and it would provide an effective method for exploring the poverty-driven mechanism. This study disclosed that poverty level in midwestern and western regions of Nepal was higher than those in other regions, but the difference was relatively minor. Comparing the Lorenz curves of poverty distribution, it was discovered that poor people concentrates in central, western, and midwestern regions, but in western regions poor population is relatively evenly distributed. In the hidden poverty regions, local governments maintained a relative good macroeconomic situation through obtaining the stable income from tourism, while local residents just can have little opportunity to participate in tourism business. In the specific low-poverty regions, political factors and government caused economic downturn, motivating a large number of locals for foreign employment.

Due to a low level of urbanization and industrialization in Nepal, human disturbance behaviors on ecological environment mainly lie in land use behavior of households. As to the use structure of cultivated lands, it is mainly planting food crops in mountains, including rice, wheat, corn, millet, buckwheat, and barley. Among them, rice, wheat, and corn are main crops. Cash crops include fruits, vegetables, beans, cardamom, and coffee, but the planting area of economic crop and its household proportion were relatively low. At present, researches on livelihoods and land use in Nepal Mountains mainly focus on the effects of specific kinds of livelihood activities on land use, land use patterns, but often ignore the differences in land utilization patterns incurred by varied household livelihood strategies and combined livelihoods. How to optimize farmers' livelihood strategies in order to achieve rational use of land resources? It has become the key issue for poverty-stricken areas to improve regional poverty and to adhere to sustainable development (see Chaps. 13 and 14).

The agriculture-based livelihood mode is subject to climate change, extreme weather, and geological disasters. To respond such influences, it is not enough to rely on individual behavior, but needs to constantly adapt and adjust measurements at the policy level (see Chaps. 9 and 15). The so-called adaptation is actually a social learning process, including perception on climate trends and their impacts, as well as development of appropriate programs and policies, so as to minimize risks associated with these changes. By analyzing the variations of temperatures, rain, snow, and vegetation coverage at different altitudes in mountain watershed Seti Khola during 1972–2015, it was found that floods and landslide disasters caused damages to arable lands, accompanying by food shortages, and finally impaired local livelihood conditions. Local measures to fight against climate change and natural disasters included crop diversification, conservation of plant species, and early warning systems construction. However, these measures still needed to be strengthened, and attentions should be paid to a number of inherent issues at the local and community level, such as the shortage in related knowledge and technologies, regulations and enforcement support, and the lack of coordination and cooperation between villagers. Moreover, the infrastructure and economic support were also weak.

Livelihood diversification is an important method to reduce livelihood risk and solve poverty issue. It primarily focuses on the problem of living stress and family stress of mountain inhabitants. The analysis of livelihood strategies was conducted through questionnaires, interviews, seminars, and field observations. Studies suggested that strategy optimization requires attentions on multiple aspects, such as deepening the institutional reform of farmland, accelerating the transferring rate of land resources, mobilizing the enthusiasm of farmers' production, and raising the education level of households. Besides, according to the market demands, farmers should be given advices to adjust the planting structure, to improve the farming technologies, to increase the irrigation inputs, to increase the land productivity, and to improve the infrastructure constructions such as roads. In particular, the promotion of non-farming livelihood activities could lead to non-agricultural employment with reasonable and orderly transfer of surplus rural labors, and as a result, to reduce land pressure. On the one hand, non-farming livelihood activities have several advantages, such as reducing livelihood risks and livelihood vulnerability, dropping down the dependence of farmers on land and reclamation rate, promoting changes in land ownership and land redistribution, and finally improving agricultural productivity, but on the other hand, non-agricultural industry may inevitably increase the risks of land degradation and environmental pollution (see Chaps. 12, 13, and 16).

1.5 Mountain Geo-Hazards, 4.25 Earthquake, and Its Impacts

1.5.1 Brief Profiles of Mountain Geo-Hazards in Nepal

The Himalayas are characterized by unstable geological environment due to intense geological tectonic activities, relatively loose land surface materials, neotectonic movement, and flow erosion. Because of the fragile geological environment, as well as high concentration of precipitation during monsoon, Nepal is very prone to mountain hazards, which include landslide, rock fall, debris flow, and floods. Moreover, the recent increasing anthropogenic activities such as deforestation and road construction in the high mountain regions also caused the instability of slope and exacerbated the occurrence of geo-hazards. According to the Nepal Disaster Report (Government of Nepal Ministry of Home Affairs Government of Nepal Ministry of Home Affairs 2014), statistics showed that 6,025 people died in the past 20 years due to floods and landslides, which caused a direct economic loss of about 1.186 trillion rupees. In recent years, the frequency of geological disasters has a tendency to increase.

In Nepal and its surrounding regions, landslides are characterized by wide distribution, large volume, and frequent occurrence. The number of landslide accounts for the largest proportion to all geo-hazard types. Larger-scale landslides often evolve into landslide-dammed lakes, causing outburst flood disasters, or develop into debris flows, forming a chain of geo-hazard events. Taking Koshi River basin as an example (see Chaps. 17 and 18), there are 5,739 landslide hazards to be identified. These landslides brought about high damages including threat or damage to buildings, destruction of farmland and roads, blocking rivers (19% of total), forming debris sources (49% of total), causing serious soil erosion. Currently, the frequency of buildings destroyed by landslide is relatively low, but once the hazard happens, the destruction will be quite heavy. For example, the Zhangmu landslide with a large area of 1.48 km^2, and about 9,793.16 m^3 in volume, is now still threatening hundreds of buildings. The research on the Koshi River area had designed a framework for geo-hazards risk management in transboundary basin. As for the typical transboundary areas, a suggestion was given out that cooperation at academic and government (decision-making) levels should be simultaneously launched to joint response to transboundary disasters. First of all, the disaster information and technologies need be put into sharing mechanism. As long as transboundary disasters occur, geo-hazard data, rapid risk assessment, and mitigation solutions should be shared and exchanged by relevant countries at the academic level, and the consulted countermeasures will be submitted to functional divisions for disaster disposal. Accordingly, governments can accept the suggested measures to reduce or avoid risk.

1.5.2 4.25 Earthquake and Its Impacts

The earthquake and its secondary disasters are widely distributed in Nepal. Since 1900, a total of 8 large earthquakes have hit Nepal. On April 25, 2015, Ms 8.1 earthquake with focal depth about 20 km took place in Pokhara area, where it is about 80 km away from northwest of Kathmandu. Within one month after the earthquake, there were over 265 times aftershocks with magnitude larger than Ms 4.0, and the largest aftershock was Ms 7.3. Earthquake rupture zone extended from west to east along the fault surface, causing huge damages. According to the reports, the earthquake caused 8,790 people die, 22,300 injured, and more than 300 missing. In total, 507,017 houses were completely destroyed, as well as 269,190 houses partially damaged in the disaster. The earthquake-affected population accounted for one-third of Nepal's total population, across over 31 districts, where 7 were hardest hit areas, 7 hard-hit areas. And 17 adjacent counties were mild affected. Earthquake-induced hazards such as landslides, rock falls, and dammed lakes were prevalent in the high-intensity areas. As compared with 5.12 Wenchuan earthquake in 2008, China, there were relatively small quantity of landslides induced by these earthquakes, which was deduced to attribute to the regional geological characteristics and less surface rupture, and it mainly happened on woodlands and arable lands (see Chap. 19).

The earthquake has considerable impacts on regional ecological environment and socioeconomy. Survey in Tamakoshi watershed illustrated this subject (see Chap. 20). According to the field investigation done by ICIMOD, more than 3,000 landslides with serious surface ruptures occurred in Tamakoshi valley. Almost the entire watershed was blanketed by sliding rocks and rolling stone, with a close size of 3.0 × 2.4 × 1.8 m. Large-size landslides with areas over 20 ha concentrated in the north of basin. The field investigation revealed that 50% inhabited sites in northern and central valley were completely destroyed. Only 5% housing sites kept safe due to the fair good building structure, which mainly located in the south of basin. Clearly, the poor families suffered greater losses. According to an assessment report on building damage, 52.6% of completely damaged houses were stone structure, 10.2% adobe structure, 6.2% brick and cement structure. Under the double impacts of the earthquake and monsoons, economic status within the basin went back to those of decades ago. As opposed to situation before the earthquake, almost all the economic development stagnated, which posed serious challenges to local livelihoods (such as income, education, and life) in the disaster areas.

1.6 Summary

Nepal is a typical mountain country located at the southern Himalayans. In recent years, there is an increasing demand in Nepal to promote socioeconomic development. However, the controversy between human and land is also increasingly highlighted. Under the driving factors from climate change, natural disasters, and human activities, land use and land cover in Nepal had undergone continuous change over the past few decades. The responses of eco-environment in Nepal to LUCC presented high variation regarding different types and different regions. Obviously, deforestation and agricultural expansion not only weaken the soil and water conservation ability and vegetation productivity, but also increased the risk of geo-hazards occurrence and posed high pressure on mountain livelihood improvement. This book includes joint studies from both China and Nepal scientists concerning on the impacts from LUCC and it eco-environmental responses, a hot topic relevant to mountain environment and development. It reflects both parties in-depth cooperation in data building and sharing, method developing, decision-making consulting, and collaborative mechanism, and it will lay a solid foundation for further comparative study of cross-borders. In the meantime, it also introduces a success case of bilateral or multilateral scientific and technological cooperation in the field of resources and environment in South Asia.

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Part I
Land Use/Cover Change

Chapter 2
Land Cover Mapping and Its Spatial Pattern Analysis in Nepal

Guangbin Lei, Ainong Li, Xiaomin Cao, Wei Zhao, Jinhu Bian, Wei Deng and Hriday Lal Koirala

Abstract Nepal, located in a unique transition zone spanning from plains to mountains and then to the plateau, is characterized by diverse and complex land cover. Based on an object-oriented method and decision tree classifier, a land cover product covering the whole of Nepal in 2010 (hereinafter referred to as the NepalCover-2010) was produced using 30 m-resolution Landsat TM images, consisting of 8 classes at Level I and 31 classes at Level II. The accuracy of the NepalCover-2010 product at Level II was validated using samples collected from high-resolution Google Earth images. The result showed that the overall accuracy of the product was 87.17%, with a Kappa coefficient of 0.85, making it the most accurate product among similar land cover products. The product can accurately reflect the spatial patterns of land cover in Nepal. Forests are the main land cover classes, accounting for 41% of the land, followed by croplands covering about 25%. The areal proportion of paddy fields to dry farmlands was approximately two to three. Topographical and meteorological factors presented as the determining effects on the spatial patterns of land cover in Nepal. With elevation uplift from south to north, land cover classes showed a vertical zonality ordered thus: paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. Land cover mapping in Nepal contributes significantly to the basic data collection in this country, and can also be of a benefit to China's international regional economic cooperation strategy entitled "the Belt and Road Initiative".

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2.1 Introduction

The Hindu–Kush–Himalayan (HKH) region has an area of approximately 4.3 million km^2, related to eight countries including Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan, which is also the major research object of the International Center for Integrated Mountain Development (ICIMOD). Diverse and complex land cover in the HKH region directly or indirectly affect the livelihoods of 1.3 billion downstream residents and maintains the stability of local ecosystems (Molden et al. 2013). Under the background of global climate change and rapid economic development, the land cover in the HKH region has witnessed tremendous changes over the past decades.

Nepal, as an essential part of the HKH region, is a typical, mountainous landlocked south Asian country (Bhattarai et al. 2009), and is located in a unique transition zone spanning from plains to mountains and then to the plateau. The temperature and precipitation of this country varies with the vertical terrain. The specific topographical, meteorological, and socio-economic conditions breed diverse and complex land cover in Nepal (Bhattarai et al. 2009). Currently, a large number of land cover products on various scales have been produced based on remote-sensing technologies, such as IGBP DISCover (Loveland et al. 2000), UMD land cover (Hansen et al. 2000), and GlobeLand30 (Chen et al. 2015) on a global scale, and Africover (Kalensky 1998) and ChinaCover (Wu et al. 2014) on the national scale. These land cover products were characterized by their different advantages due to their differences in data sources, classification systems, mapping methods, and application requirements. However, similar land cover mapping projects in Nepal have not been conducted since 1986, resulting in shortages of available land cover data for usage (Uddin et al. 2015).

Supported by an international cooperation key project of the Chinese Academy of Science (CAS), named "Comparison study on typical mountain ecosystems in China and Nepal based on remote sensing technologies (No. GJHZ201320)", land cover in 2010 over the whole of Nepal (NepalCover-2010) was produced by the Institute of Mountain Hazards and Environment (IMHE), CAS. This work not only reveals the detailed spatial patterns of land cover in Nepal, but also has a great scientific and practical significance for land resource management, ecosystem protection, and even sustainable economic and social development (Liu et al. 2014). Simultaneously, it is of benefit to the China's international regional economic cooperation strategy entitled "the Belt and Road Initiative" (Liu 2015).

This chapter comprehensively introduces the method of mapping used to generate the NepalCover-2010 product and also its validation scheme. The 2012 Statistical Yearbook data and an existing product named GlobeLand30-2010 (Chen et al. 2015) are further used to evaluate product quality. Finally, the relationship between topographical and meteorological factors and spatial patterns of typical land cover classes are analyzed and discussed.

2.2 Study Area

Nepal is located in the north of the Indian subcontinent and the south of the middle section of the Himalayas. It is bordered by China to the north and by India to the east, west, and south, and lies between latitudes 26°22′–30°27′ N, and longitudes 80°4′–88°12′ E (Fig. 2.1). Nepal exhibits a considerable variation in elevation from north to south, with the Himalayas at a maximum elevation of 8844 m standing to the north, numerous conspicuous mountains distributed in its middle section, and the Terai Plain with an average elevation below 400 m located in the south. This tremendous altitudinal gradient forms five ecological regions: Terai Plain, Siwalik, Middle Mountain, High Mountains, and High Himalaya. Temperature and precipitation in Nepal are obviously affected by its steep topography and the India Ocean southeast monsoon. The land cover in Nepal mainly includes broadleaf forests, needleleaf forests, mixed broadleaf and needleleaf forests, croplands, shrubs, grasslands, bare lands, as well as permanent ice/snow (Wang 2004).

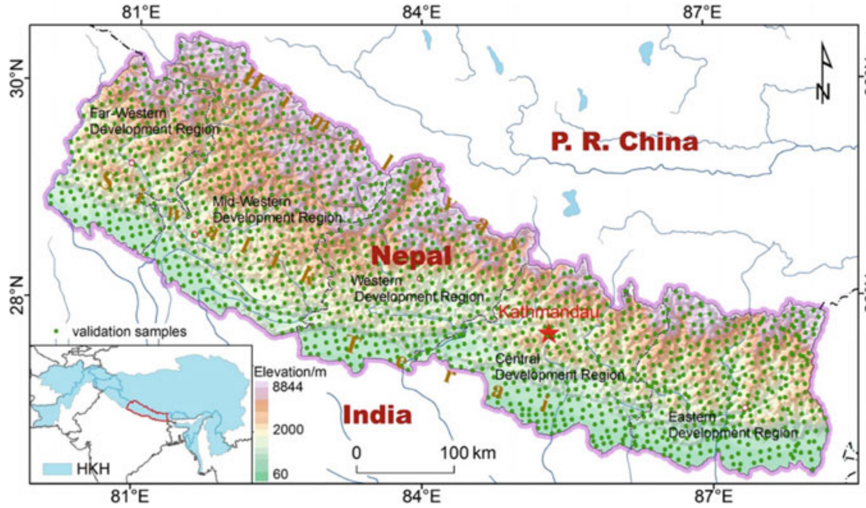

Fig. 2.1 Geographical location of Nepal and spatial distribution of the land cover validation samples

2.3 Data and Methods

2.3.1 Data

A total of 32 scenes of Landsat TM images with 30 m resolution were acquired to produce the NepalCover-2010 product (Fig. 2.2). These were downloaded from a scientific data-sharing platform of the US Geological Survey, USGS (http://glovis.usgs.gov/). To explore the potential of multi-temporal satellite images for land cover mapping, both growing and non-growing seasonal images were acquired in each satellite path/row (Fig. 2.2). For a path/row without high-quality satellite images (cloud coverage below 5%) in 2010, a number of high-quality satellite images in 2009 or 2011 were acquired. All acquired Landsat TM images were L1T products, which had been radiometrically and geometrically corrected. The LEDAPS pre-processing package (Wolfe et al. 2004) was further used for atmospheric correction on each image in this study.

Besides the remote-sensing images, topographical data including elevation, slope, and aspect, and meteorological data including temperature and precipitation, were used as auxiliary data in land cover mapping and subsequent analyses. The 30 m-resolution ASTER GDEM data was adopted. Slope and aspect were calculated from the GDEM data using ERDAS software. Temperature data at meteorological stations were downloaded from the US National Climatic Data Center (NCDC http://www.ncdc.noaa.gov/). Based on the acquired temperature data, the annual average temperature over the whole of Nepal was interpolated using ANUSPLIN software. Precipitation data used in this study were the monthly TRMM 3B43 products with a spatial resolution of 0.25° × 0.25° (ftp://disc2.nascom.nasa.gov/data/s4pa/TRMM_L3/TRMM_3B43/).

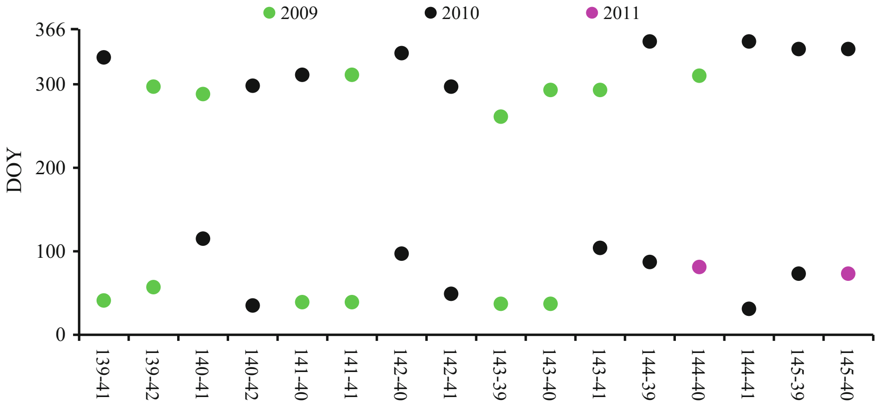

Fig. 2.2 The acquisition time of Landsat TM images used to produce the NepalCover-2010 product

2.3.2 *Land Cover Mapping*

2.3.2.1 Land Cover Classification System

The land cover classification system adopted by the NepalCover-2010 product was formed by taking into full consideration the existing classification systems (De Fries et al. 1998; Hansen et al. 2000; Zhang et al. 2014) and the actual land cover situation in Nepal. The classification system adopted consists of 8 classes at the first level (Level I) and 31 classes at the second level (Level II), which is detailed in Table 2.1.

2.3.2.2 Land Cover Classification Method

The object-oriented classification method was used to produce the NepalCover-2010 product, and its flowchart is shown in Fig. 2.3. The multi-temporal satellite images were firstly collected and pre-processed. After object-oriented, multi-resolution segmentation, a series of rules for each path/row were built by decision tree algorithm (See 5.0) and were then used to produce preliminary classification results. Finally, post-processing of classification was used to further improve the quality of the classification results. This chapter mainly introduces four critical steps: (1) image segmentation, (2) training sample collection, (3) automatic classification via a decision tree algorithm, and (4) error checking and revising. Details are given in Fig. 2.3 and the following text.

Image segmentation: Image segmentation represents the foundation of the object-oriented classification method. It groups homogenous neighboring pixels into meaningful objects based on the principles of homogeneity and heterogeneity (Benz et al. 2004). In this study, a widely used, multi-resolution segmentation algorithm (Benz et al. 2004; Zhang et al. 2014), embedded in the eCognition 8.7 platform, was adopted to segment satellite images. Scale, shape, and compactness are three critical parameters. The optimal values of these parameters are determined by trial-and-error along with visual assessment of the segmentation results. In this study, the scale parameter was set as 25, the shape parameter was set as 0.1, and compactness as 0.7.

Training samples collection: Training samples were collected from high-resolution Google Earth images. The sample size of each path/row was not less than 1000, and the sample size of each land cover class was at least 50.

Automatic classification with a **decision tree algorithm**: The total number of features used for classification was 28, including mean value and standard deviation of the reflectance value of each band, texture features, shape features, topographic features (including elevation, aspect, and slope), as well as the Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI, Xu 2005), and Normalized Difference Building Index (NDBI, Chen et al. 2006).

Table 2.1 Land cover classification system adopted in the NepalCover-2010 product

Level I		Level II		Classification rules
Name	Code	Name	Code	
Forest	1	Evergreen broadleaf forest	11	Natural or semi-natural vegetation, evergreen, rounded tree canopy, $C > 60\%$, $H > 5$ m
		Deciduous broadleaf forest	12	Natural or semi-natural vegetation, deciduous in winter, rounded tree canopy, $C > 60\%$, $H > 5$ m
		Evergreen needleleaf forest	13	Natural or semi-natural vegetation, evergreen, needle leaf, $C > 60\%$, $H > 5$ m
		Mixed broadleaf and needleleaf forest	14	Natural or semi-natural vegetation, $C > 60\%$, $H > 5$ m, 25% < needleleaf broadleaf < 75%
		Tree garden	15	Artificial vegetation, around artificial surface, $C > 60\%$, $H > 5$ m
Shrub	2	Evergreen broadleaf shrub	21	Natural or semi-natural vegetation, evergreen, rounded tree canopy, $20\% < C<40\%$, 0.3 m $< H<5$ m
		Deciduous broadleaf shrub	22	Natural or semi-natural vegetation, deciduous in winter, rounded tree canopy, $20\% < C<40\%$, 0.3 m $< H<5$ m
		Evergreen needleleaf shrub	23	Natural or semi-natural vegetation, evergreen, needleleaf, $20\% < C<40\%$, 0.3 m $< H<5$ m
		Shrub garden	24	Artificial vegetation, around artificial surface, $20\% < C<40\%$, 0.3 m $< H<5$ m
Grassland	3	Meadow	31	Natural or semi-natural vegetation, aquatic, $C > 20\%$, 0.03 m $< H<3$ m
		Steppe	32	Natural or semi-natural vegetation, xerophyte or mesophyte, $C > 20\%$, 0.03 m $< H<3$ m
		Tussock	33	Natural or semi-natural vegetation, $C > 20\%$, 0.03 m $< H<3$ m
		Lawn	34	Artificial vegetation, around artificial surface, $C > 20\%$, 0.03 m $< H<3$ m

(continued)

Table 2.1 (continued)

Level I		Level II		Classification rules
Name	Code	Name	Code	
Wetland	4	Herbaceous wetland	41	Natural or semi-natural vegetation, freshwater marsh with mainly seasonal floating plants, $C > 20\%$, $0.03\ \text{m} < H<3\ \text{m}$
		Lake	42	Natural water surface, still water, water conservation
		Reservoir/pond	43	Artificial water surface, still water, water conservation
		River	44	Natural water surface, linear flow
		Canal/channel	45	Artificial water surface, flowing, functions of water distribution, flood diversion, flood drainage and water supply
		Flood plain	46	Naturally formed, around rivers, inundated in flood season and emergent in dry season
Cropland	5	Paddy field	51	Artificial vegetation, disturbed soil, mainly aquatic plants and partly paddy-upland rotation, harvesting process
		Dry farmland	52	Artificial vegetation, disturbed soil, mainly xerophytes and drought-resistant crops, harvesting process
		Tree orchard	53	Artificial vegetation, economic benefit, $C > 60\%$, $H > 5\ \text{m}$
		Shrub orchard	54	Artificial vegetation, $20\% < C<40\%$, $0.3\ \text{m} < H<5\ \text{m}$
Artificial surface	6	Residential land	61	Hard artificial surface, residential buildings
		Industrial land	62	Hard artificial surface, manufacturing buildings
		Transportation land	63	Hard artificial surface, linear ground objects
		Mining field	64	Mining pits, stairs and outdoor man-made channels
Bare land	7	Sparse vegetation	71	Natural or semi-natural vegetation, $4\% < C<20\%$, $0.03\ \text{m} < H<3\ \text{m}$
		Bare rock	72	Naturally formed, bare hard surface, non-vegetative
		Bare soil	73	Naturally bare soil texture sheets, sparse vegetation
Permanent ice/snow	8	Permanent ice/snow	81	Naturally occurring, solid reservoir, at the covered surface

NOTE C is short for coverage/canopy density (%); *H* is short for vegetation height (m)

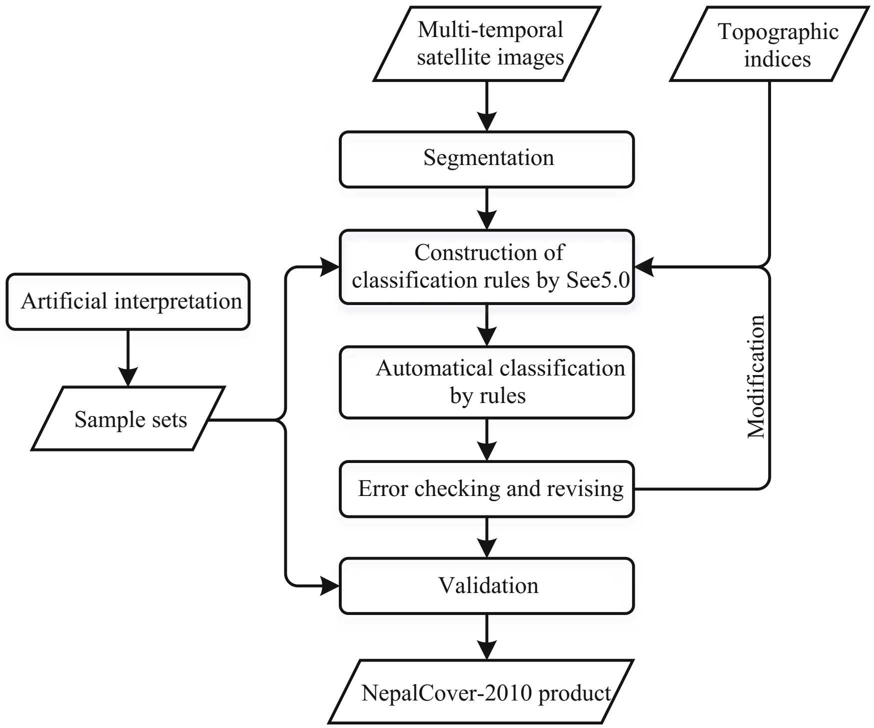

Fig. 2.3 The flowchart of the proposed object-oriented classification method

The essential part of classification using a decision tree algorithm is to establish the classification rules (Jia et al. 2011). This study used decision tree classifier See 5.0 (Friedl et al. 1999) to train collected samples and features, and then to form corresponding classification rules. Finally, the classification results were derived following these rules. Figure 2.4 shows a typical classification rule set used for the Terai Plain (path/row: 141/41, WRS2).

Generally, the differences in the NDVI, between vegetation and non-vegetation, are evident in the non-growing season. Therefore, the NDVI in the non-growing season was used to distinguish between them. The MNDWI, derived from the same season, was chosen to identify open water misclassified as vegetation, because it is very sensitive to water. Vegetation was subdivided into forests, shrubs, grasslands, croplands, and herbaceous wetlands, while non-vegetation was subdivided into artificial surfaces, bare lands, permanent ice/snow, and open waters. The T2_B2_Mean feature was used to identify croplands, grasslands, and forests with significant spectral differences among them during the non-growing season. Considering the “absorbing valley” of forests in the red band, the T1_B3_Mean feature was adopted to distinguish between forests and shrubs. The T2_NDVI_Mean feature was used to differentiate croplands from grasslands due to the difference in the NDVI in the non-growing season. Open waters had noteworthy

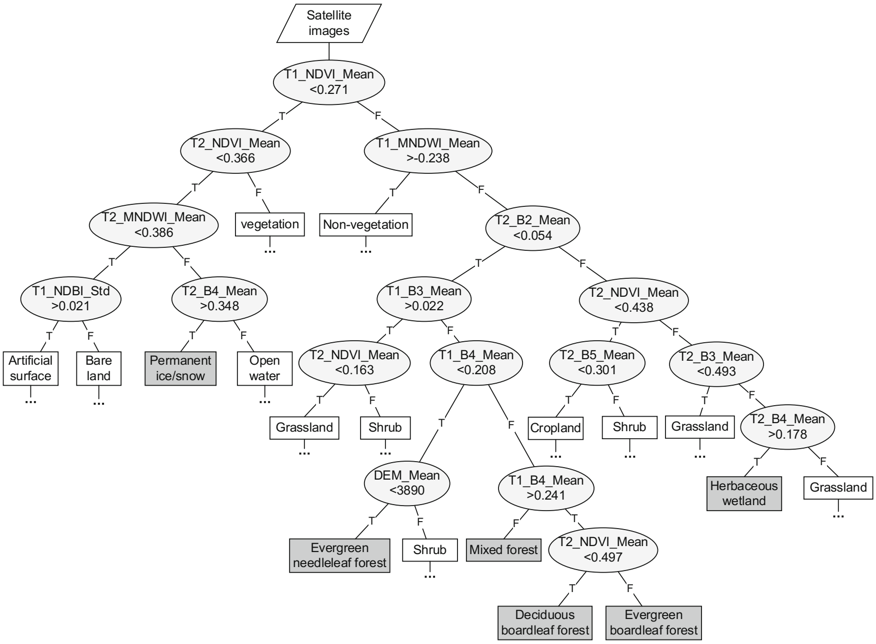

Fig. 2.4 Typical classification rules used for producing the land cover map of the Terai Plain (*path/row*: 141/41, WRS2). *T1* represents Landsat TM images in the growing season (2009-03-10), *T2* represents Landsat TM images in the non-growing season (2009-11-07), *Bx* represents the band *x* of the Landsat TM image, *Std* represents standard deviation, and the *ellipsis* represents a land cover class which needs to be further subdivided

absorption in the near-infrared band, therefore, the T2_B4_Mean feature was adopted to differentiate open waters, permanent ice/snow, as well as herbaceous wetlands. Artificial surfaces and bare lands were distinguished using the mean value of the NDBI. Finally, above land cover classes were further subdivided. Taking the forests subdivision as an example, broadleaf forests, needleleaf forests, and mixed broadleaf and needleleaf forests were distinguished using the near-infrared band (T1_B4_Mean feature) and the NDVI (T2_NDVI_Mean feature). Similar approaches were conducted for the subdivision of shrubs, grasslands, croplands, artificial surfaces, open waters, and bare lands.

Error checking and revising: Error checking and revising mainly deals with problems such as cloud and cloud shadow areas, spatial discontinuity phenomena of classification results, as well as certain regions and land cover classes with relatively low classification accuracy. Due to the limitations of the interpretation abilities of satellite images and classification methods, some linear land cover classes, like rivers and roads, were discontinuous in the automatic classification results, and some other land cover classes, like industrial lands and mining fields, were not easily classified automatically. To solve these problems, artificial modification was needed. The evergreen and deciduous characteristics of forests were

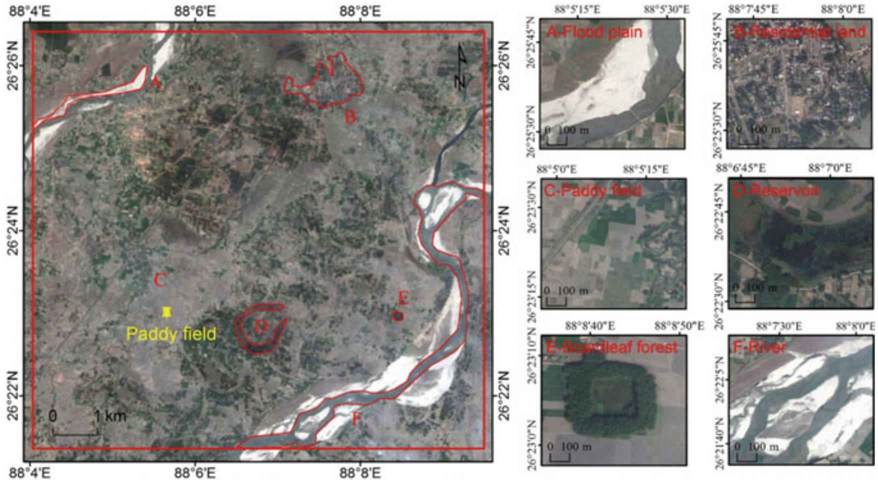

Fig. 2.5 A diagram depicting the method used for selecting validation samples from high-resolution Google Earth images. The red box represents a 10 km × 10 km grid

automatically distinguished using the differences in the NDVI between growing and non-growing season images (Lei et al. 2014). For cloud and cloud shadow regions, spatial autocorrelation[1] and multi-temporal satellite images were adopted to fill the gaps caused by clouds. The spatial discontinuity phenomena of land cover often occurs at the overlap regions of neighboring paths/rows, which are mainly caused by the differences in the acquisition phase of selected satellite images and the cognitive level of mappers. Therefore, spatial consistency verification (Lei et al. 2016) is indispensable when removing the spatial discontinuity phenomena which exists in the NepalCover-2010 product (Tobler 1970).

2.3.2.3 Accuracy Validation

Accuracy validation is an essential part of land cover mapping. An error matrix was calculated by comparing the classification results with the validation samples, which were collected from high-resolution Google Earth images – a method proved as successful by Chen et al. (2007). The study area was divided into a series of 10 km × 10 km grids. Land cover classes were visually interpreted in each grid, based on high-resolution Google Earth images. The land cover class with the largest area in each grid was selected as a validation sample. For an example, as shown in Fig. 2.5, the grid contains at least six land cover classes, and the area of paddy

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[1] The First Law of Geography, according to Tobler (1970), is “everything is related to everything else, but near things are more related than distant things.”, which is the foundation of the fundamental concepts of spatial dependence and spatial autocorrelation.

fields is much larger than that of the other land cover classes, therefore, a validation sample was collected from the geometric center of the polygon of paddy fields. In addition, validation samples of some land cover classes which did not occupy large areas, such as rivers, flood plains and residential land, were also collected.

2.4 Results and Analysis

2.4.1 The NepalCover-2010 Product and Its Accuracy

Described in the method above, the NepalCover-2010 product was generated, and its land cover map is shown in Fig. 2.6.

A total of 1528 validation samples were collected as shown in Fig. 2.1, and Table 2.2 lists the error matrix of the NepalCover-2010 product. The overall accuracy of Level I in the NepalCover-2010 product was 94.83%, with a Kappa coefficient of 0.94, whilst the overall accuracy of Level II reached 87.17%, with a Kappa coefficient of 0.85. The producer and user accuracy for most of the land cover classes exceeded the overall accuracy of Level II in the NepalCover-2010 product (87.17%), like deciduous broadleaf forests, paddy fields, dry farmlands, flood plains, residential lands, and permanent ice/snow.

Table 2.2 shows that paddy fields and dry farmlands are relatively easy to be misclassified, which frequently occurred in the Terai Plain and the mountainous valley areas. As a consequence of the fact that the tillage technologies at these areas are mainly paddy–upland rotation and mixed cropping, the boundaries between

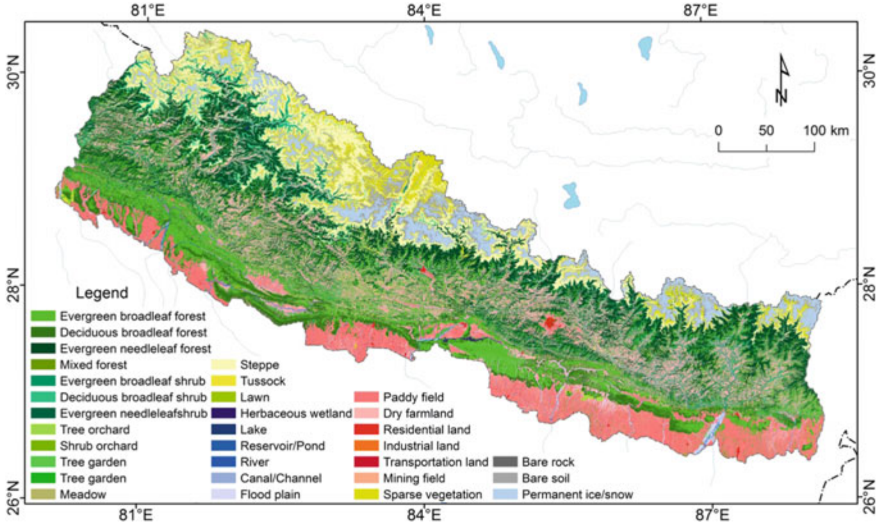

Fig. 2.6 The final NepalCover-2010 product

Table 2.2 Error matrix of the NepalCover-2010 product

Classification results																			
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total	PA (%)
Validation samples	A	188		8	3	4							1					204	92.16
	B		85	2	1	1												89	95.51
	C	27	1	163	3	1												195	83.59
	D	4		1	21								6					32	65.63
	E	2	6			33			2				3					46	71.74
	F					3	12	1	2									18	66.67
	G							11										11	100.00
	H								134				5		6		3	148	90.54
	I									13		2						15	86.67
	J										12							12	100.00
	K	3									1	142	14					160	88.75
	L	11	4	4		5		2	3	2		16	328					375	87.47
	M											1		26				27	96.30
	N							1	9						39		1	50	78.00
	O														3	16	4	23	69.57
	P			1		1	1	2	7						2		109	123	88.62
	Total	235	96	179	28	48	13	17	157	15	13	161	357	26	50	16	119	1528	
	UA (%)	80.00	88.54	91.06	75.00	68.75	92.31	64.71	85.35	86.67	92.31	88.20	91.88	100.00	78.00	100.00	93.16		

Total accuracy 87.17%, *Kappa coefficient* 0.85

Note A Evergreen broadleaf forest; *B* Deciduous broadleaf forest; *C* Evergreen needleleaf forest; *D* Evergreen broadleaf shrub; *E* Deciduous broadleaf shrub; *F* Evergreen needleleaf shrub; *G* Meadow; *H* Steppe; *I* River; *J* Flood plain; *K* Paddy field; *L* Dry farmland; *M* Residential land; *N* Sparse vegetation; *O* Bare soil; *P* Permanent ice/snow; *PA* Producer accuracy; and *UA* User accuracy paddy fields and dry farmlands on satellite images are often difficult to distinguish. Terrain shadows and cloud shadows are inevitable in mountain areas, which led to a few misclassifications between broadleaf forests and needleleaf forests. The accuracy of shrubs is the lowest among all Level I classes in the NepalCover-2010 product. The misclassification of shrubs comes about due to the fact that their growth is usually mixed within croplands and forests. Mixed pixel is especially prominent on the 30-m-resolution satellite images, which is a non-negligible factor for classification errors. Meanwhile, the background noise and differences in soil properties also affect NDVI values of vegetation, which might cause confusion among shrubs, croplands, and forests. In future research, the soil-adjusted vegetation index (SAVI) and an improved soil-adjusted vegetation index (Li et al. 2015) will be further used. Simultaneously, higher resolution remote sensing imagery will also be incorporated to reduce classification errors in regions with relatively low accuracy.

This study also conducted a comparative analysis to further evaluate the quality of the NepalCover-2010 product. The data used in the comparative analysis included 2012 Statistical Yearbook data and an existing product named GlobeLand30-2010 (Chen et al. 2015). The comparison result is shown in Fig. 2.7. The orders of areal ratios for each land cover class in the three products were consistent: forests > croplands > grasslands > shrubs > bare lands > permanent ice/snow > wetlands > artificial surfaces. However, in terms of a single land cover class, the areal ratios in each of the three products were different. Areal proportion of forests in the NepalCover-2010 product was almost in line with that of the GlobeLand30-2010 product, about 1% higher than that of the Statistical Yearbook data. For croplands, the areal ratio in the NepalCover-2010 product was about 2% lower compared to the other two products, but much closer to the report (32,510 km^2) published by Nepal's Central Bank website (http://www.NRB.org.NP/). For grassland, the areal ratio in the NepalCover-2010 product was almost identical to the data in the Statistical Yearbook, which was about 11%, while the areal ratio of grasslands in the GlobeLand30-2010 product reached 16%. In terms

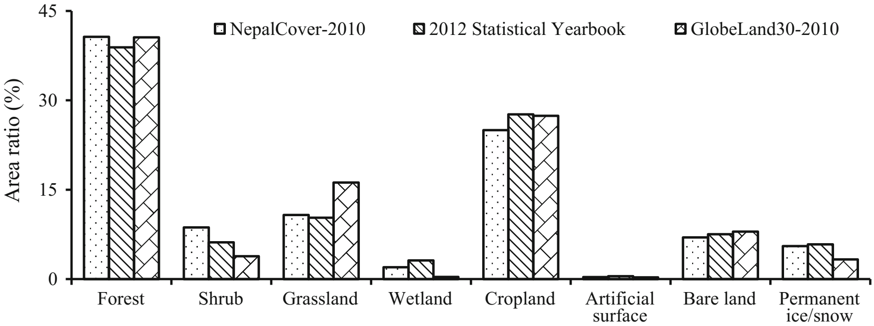

Fig. 2.7 The areal ratio of each land cover class for the NepalCover-2010 product, 2010 Statistical Yearbook of Nepal, and GlobeLand30-2010 product

of permanent ice/snow, the areal ratio in the NepalCover-2010 product was almost consistent with the data in the Statistical Yearbook, which was about 6%, and almost 3% higher than that of the GlobeLand30-2010 product. The difference in areal ratio of bare lands and artificial surfaces among these three products was quite small. According to the above comparison results, the NepalCover-2010 product was the most accurate in general.

Based on the 1528 validation samples, this study compared the accuracy of the NepalCover-2010 product with that of the GlobeLand30-2010 product. The comparison results showed that the overall accuracy of the NepalCover-2010 product at Level I was 14.72% higher than that of the GlobeLand30-2010 product. The producer accuracy of forests, shrubs, grasslands, wetlands, croplands, artificial surfaces, and permanent ice/snow in the NepalCover-2010 product was higher than that of the GlobeLand30-2010 product. For example, the producer accuracy of shrubs and wetlands was 40% higher, permanent ice/snow was about 26% higher,

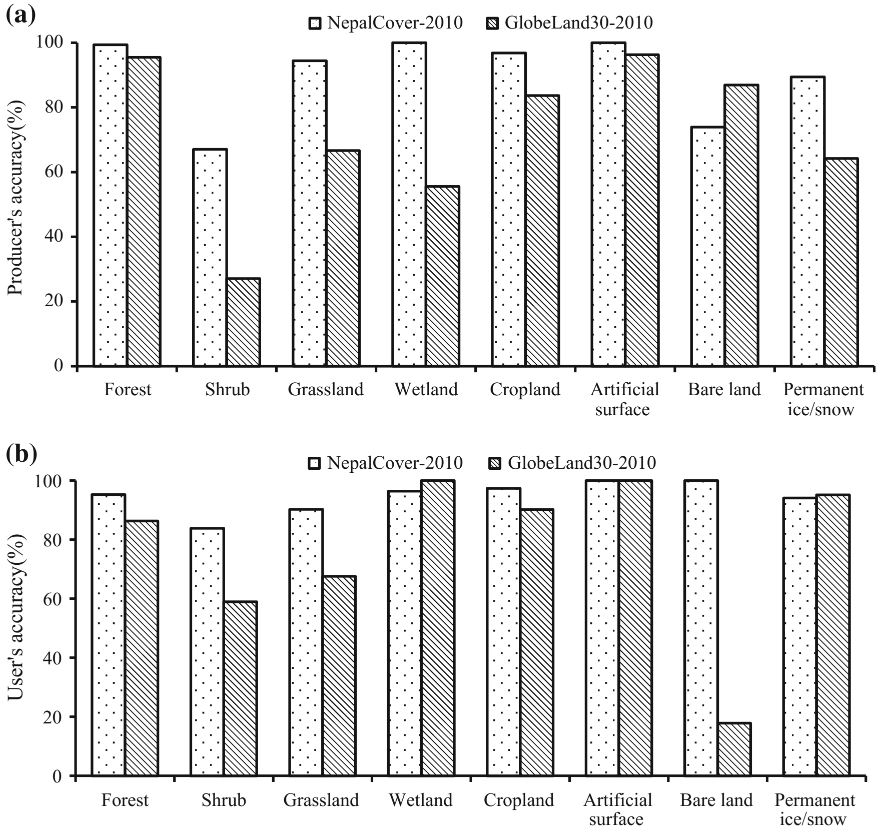

Fig. 2.8 Comparison of producer accuracy **a** and user accuracy **b** between the NepalCover-2010 product and the GlobeLand30-2010 product

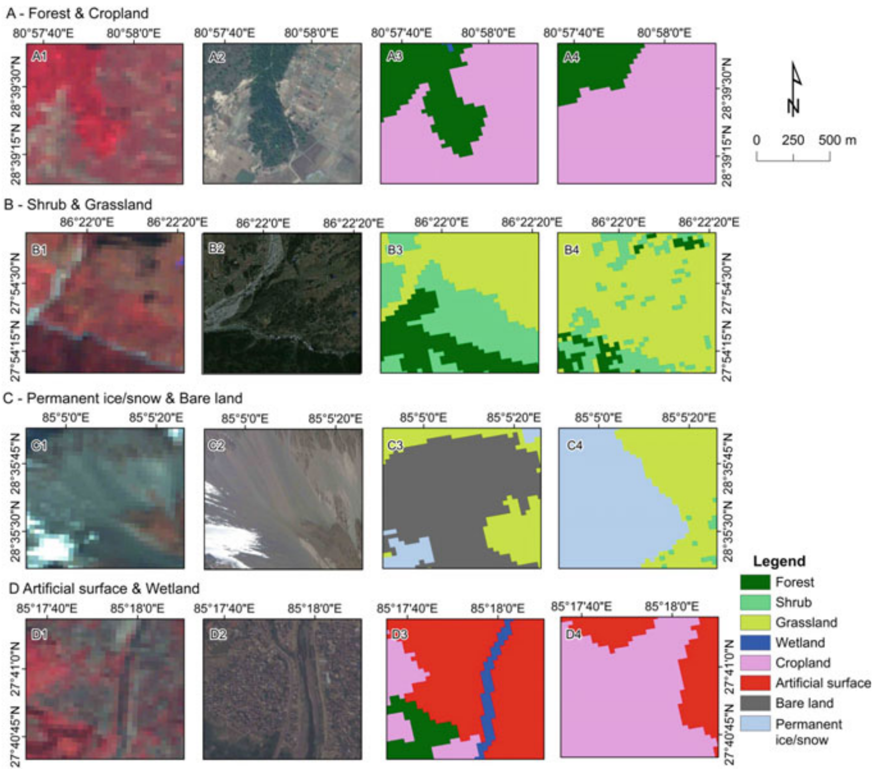

Fig. 2.9 Comparison of the NepalCover-2010 product with the GlobeLand30-2010 product over four typical regions: *A1*, *B1*, *C1*, and *D1* represent Landsat TM images; *A2*, *B2*, *C2*, and *D2* represent high-resolution Google Earth images; *A3*, *B3*, *C3*, and *D3* represent the NepalCover-2010 products; and *A4*, *B4*, *C4*, and *D4* represent the GlobeLand30-2010 product

farmlands was about 13% higher, forests and artificial surfaces was about 4% higher (Fig. 2.8a). The user accuracy of forests and croplands in the NepalCover-2010 product was about 8% greater than that of the GlobeLand30-2010 product, shrubs and grasslands was about 24% higher, and bare lands accuracy was about 80% higher (Fig. 2.8b).

Meanwhile, the NepalCover-2010 product better reflected spatial distribution patterns of land cover in the transition areas than did the GlobeLand30-2010 product (Fig. 2.9a, b). To precisely distinguish permanent ice/snow from bare lands in the NepalCover-2010 product (Fig. 2.9c), two satellite images—one in the growing/warm season and the other in the non-growing/cold season—were used in each path/row. In addition, the NDVI, MNDWI, and NDBI were also applied in order to generate the NepalCover-2010 product, which greatly eliminated the effects of vegetation and open waters on extraction of artificial surfaces (Fig. 2.9d). In conclusion, the overall quality of the NepalCover-2010 product was better than that of the GlobeLand30-2010 product, which can accurately reflect the spatial patterns of each land cover class in Nepal.

2.4.2 The Statistical Analysis of Land Cover in Nepal

Administratively, the whole land of Nepal is divided into five development regions, namely the Eastern, Central, Western, Mid-Western and Far-Western Development Regions (Fig. 2.1). The areal proportions in each development region are 19.34, 18.52, 19.98, 28.82, and 13.33%, respectively. The area and areal proportions of each land cover class in Nepal, according to the statistics of the NepalCover-2010 product, are listed in Table 2.3 and the areal proportions of each land cover class within the different development regions is presented in Fig. 2.10.

Forests were mainly distributed in the Terai Plain, Siwalik Mountains, and Mahabharata Mountains, covering 60,009.27 km^2, which accounted for 40.66% of the land. Among these, evergreen broadleaf forests and evergreen needleleaf forests were the main forest classes. The areal proportion of forests in the Central and Western Development Regions were larger than in other regions, due to the fact that there are three national forest parks (Rara National Park, Shey–Phoksundo National Park, and Royal Bardia National Park) and one hunting reserve (Dhorpatan Hunting Reserve) in these regions.

The area of croplands was 36,901.96 km^2, accounting for 25.01% of the land. They were mainly distributed in the Terai Plain, Kathmandu Valley, Pokhara Valley, Koshi River Basin, Gandaki River Basin, and Carl River Basin. The areal proportion of paddy fields and dry farmlands was approximately two to three. Almost three-quarters of paddy fields were located in the Terai Plain, and two-thirds of dry farmlands were situated in mountainous valleys. The areal ratio of croplands in the Eastern and Central Development Regions were the largest, covering 52.1% of the overall cropland area, which was closely related to those regions increasing populations, rapid development of agriculture, abundance of water resources, and appropriate growth environment for crops.

Shrubs were mainly distributed around croplands and at the high Himalayan region with an area of 12,811.13 km^2, which accounted for 8.68% of the land. The areal ratio of shrubs in the Eastern and Western Development Regions were the largest, accounting for 55.63% of the total shrub area. Native shrubs were mainly distributed in highland areas, while secondary shrubs grew in hill and mountain valleys, resulting from the damaging effects of human activities on native forests.

Grasslands were mainly located in the high Himalayan region with an extent of 15,898.78 km^2, which accounted for 10.77% of the land. Steppes were the main grassland classes, accounting for 87.3% of the total grassland area. The areal proportion of grasslands in the Mid-Western Development Region was the largest, nearly half of the total grassland area.

The area of permanent ice/snow was 8160.79 km^2, accounting for 5.53% of the land. It was mainly distributed in the high Himalayan areas where 8 of the 10

Table 2.3 The area and areal proportions of each land cover class in Nepal according to the statistics of the NepalCover-2010 product

Level I	Area (km^2)	Ratio (%)	Level II	Area (km^2)	Ratio (%)
Forest	60,009.27	40.66	Evergreen broadleaf forest	26,794.78	18.16
			Deciduous broadleaf forest	8965.31	6.08
			Evergreen needleleaf forest	23,803.30	16.13
			Mixed broadleaf and needleleaf forest	440.75	0.3
			Tree garden	5.14	0
Shrub	12,811.13	8.68	Evergreen broadleaf shrub	5271.21	3.57
			Deciduous broadleaf shrub	6224.20	4.22
			Evergreen needleleaf shrub	1314.64	0.89
			Shrub garden	1.07	0
Grassland	15,898.78	10.77	Meadow	1533.97	1.04
			Steppe	13,880.24	9.41
			Tussock	475.67	0.32
			Lawn	8.9	0.01
Wetland	2945.41	2	Herbaceous wetland	101.56	0.07
			Lake	71.77	0.05
			Reservoir/pond	42.08	0.03
			River	1057.57	0.72
			Canal/channel	17.05	0.01
			Flood plain	1655.37	1.12
Cropland	36,901.96	25.01	Paddy field	13,938.75	9.45
			Dry farmland	22,846.88	15.48
			Tree orchard	114.9	0.08
			Shrub orchard	1.43	0
Artificial surface	512.67	0.35	Residential land	427.35	0.29
			Industrial land	4.61	0
			Transportation land	79.07	0.05
			Mining field	1.65	0
Bare land	10,329.96	7	Sparse vegetation	6978.82	4.73
			Bare rock	373.14	0.25
			Bare soil	2978.01	2.02
Permanent ice/snow	8160.79	5.53	Permanent ice/snow	8160.79	5.53

highest peaks in the world, with elevations above 8000 m, are gathered, including Mount Everest, Kanchenjunga, Lhotse, Makalu, Cho Oyu, Dhaulagiri, Manaslu, and Annapurna peak. Bare lands, with an extent of 6978.82 km^2, are mainly

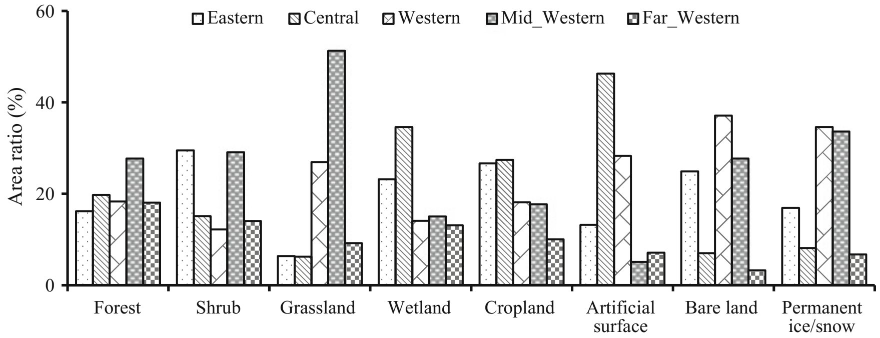

Fig. 2.10 The areal proportions of each land cover class in different development regions according to the statistics of the NepalCover-2010 product

distributed near permanent ice/snow, which accounts for 4.73% of the land. Both bare lands and permanent ice/snow are more widely distributed in the Western and Mid-Western Development Regions than in other regions. This is because nearly one-third of these regions are located in Himalayan mountainous areas—unsuitable conditions for the growth of plants at such high-altitudes with severe cold weather. Thus a spatial pattern of bare lands and permanent ice/snow has formed.

The extent of wetlands and artificial surfaces were relatively small compared to the rest of the land cover classes. Wetlands accounted for 2% of the land. Artificial surfaces were mainly distributed in agricultural areas, accounting for only 0.35% of the land.

2.4.3 Relationships Between Spatial Patterns of Typical Land Cover Classes and Topographical Factors

As shown in Fig. 2.11a, with an increase in elevation, land cover classes showed a distinctively vertical zonality ordered by paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. Among these, almost all paddy fields were distributed in the Terai Plain, where the elevation is below 400 m, because such flat and rich (in terms of water resources) land is suitable for rice cultivation. Evergreen broadleaf forests, dry farmlands, and evergreen broadleaf shrubs were mainly distributed in river valleys and hilly areas with elevations below 3000 m. The areal proportions of evergreen broadleaf shrubs increased with elevation, and some of their distribution regions (secondary shrubs) overlapped with those of dry farmlands (Pandit 2011).

There are three types of pattern for spatial distributions of land cover classes and terrain slopes: Type I, areal proportion gradually decreases with increase of slope; Type II, "peak-valley" pattern; and Type III, "peak" pattern (Fig. 2.11b). The spatial

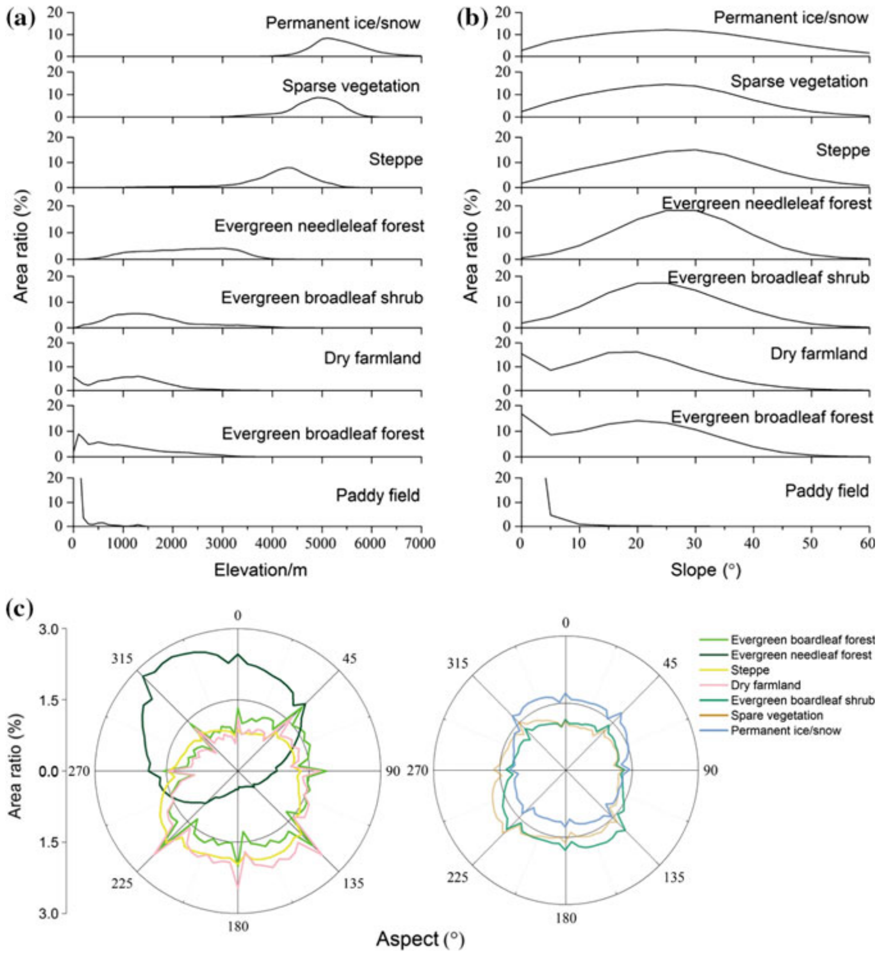

Fig. 2.11 Relationships between the spatial patterns of typical land cover classes and topographical factors, including **a** elevation, **b** slope, and **c** aspect

distribution of paddy fields belongs to Type I. Paddy fields are almost all distributed in areas where the slope is less than 10°, because irrigation facilities are not well developed in Nepal. The spatial distribution of evergreen broadleaf forests and dry farmlands belongs to Type II, with two inflection points appearing at 5 and 20°, respectively. The distribution pattern of the rest of the land cover classes belong to Type III, which are mainly distributed in areas where the slope was below 50°—steep slopes being unconducive to vegetation growth (Wang 2004; Higaki et al. 2005).

This study used two aspect diagrams to present the relationship between spatial patterns of typical land cover classes and aspect (Fig. 2.11c). The areal proportion of dry farmlands on sunny slopes was far greater than on shady slopes, because crops in Nepal are mainly corn, wheat, rapeseed, and other light-demanding crops.

The areal proportion of evergreen broadleaf forests, grasslands, sparse vegetation, and evergreen broadleaf shrubs was slightly larger in sunny and half-sunny slopes. The light in these areas is sufficient to meet the needs of vegetation growth. Evergreen needleleaf forests and permanent ice/snow were mainly distributed in shady and half-shady slopes. The temperature is relatively low in these areas, which is explains the distribution of permanent ice/snow. Light is relatively scarce in shady and half-shady slopes compared to sunny and half-sunny slopes, therefore, needleleaf forests find it easier to grow on shady slopes compared to the broadleaf forests which prefer sunny slopes (Wang 2004).

2.4.4 Relationships Between Spatial Patterns of Typical Land Cover Classes and Meteorological Elements

With an increase in annual average temperature, land cover classes appeared in the following order: grasslands, evergreen needleleaf forests, evergreen broadleaf shrubs, dry farmlands, evergreen broadleaf forests, and paddy fields (Fig. 2.12a). This is opposite to the order of vertical zonality determined by the elevation. The areal proportion of dry farmlands and evergreen broadleaf shrubs reached a maximum value with an annual average temperature of 21 °C, while the areal proportion of paddy fields and evergreen broadleaf forests reached a maximum value with an annual average temperature around 25 °C; this can be simply explained by recognizing that the growth of different vegetation types requires different amounts of energy (Xu et al. 2003).

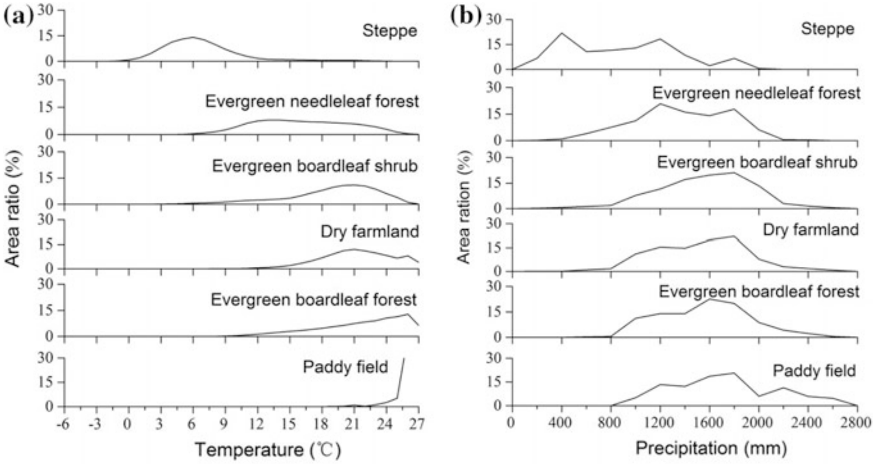

Fig. 2.12 Relationships between the spatial patterns of typical land cover classes and meteorological elements, including **a** annual average temperature and **b** annual precipitation

The spatial distribution of annual precipitation in Nepal is mainly affected by the towering Himalayas, which block the Indian Ocean's southeast monsoon generating significant monsoon rains. Therefore, the rainfall in Nepal is abundant but demonstrates an uneven spatial distribution (Wang 2004). The spatial distribution of typical land cover classes appeared as multiple peaks aligned to the increase of annual precipitation. The distribution ranges of these land cover classes partly overlapped. It was found that 1200 mm was the optimal precipitation for evergreen needleleaf forests, and 1800 mm was the optimal precipitation for paddy fields, dry farmlands, and evergreen broadleaf forests (Fig. 2.12b).

2.5 Conclusion

This chapter introduced the method used to produce the NepalCover-2010 product and its validation scheme. The NepalCover-2010 product, with 30 m resolution, consists of 8 classes at Level I and 31 classes at Level II. The classification accuracy of the NepalCover-2010 product at Level II reached 87.17%, with a Kappa coefficient of 0.85, which makes it the most accurate land cover product among similar products. It therefore accurately reflect the spatial patterns of land cover in Nepal. Forests were the major land cover classes in Nepal, accounting for 41% of the land, which is mainly distributed in mountainous areas and the nature reserves of the Eastern and Western Development Regions. Croplands covered 25% of the land, mainly distributed in the Eastern and Central Development Regions, where the population continues to grow and agriculture develops rapidly. The ratio of the areal proportion of paddy fields to dry farmlands was approximately two to three. This product will contribute significantly to basic data collection in Nepal, and also will be of benefit to China's international regional economic cooperation strategy of, known as "the Belt and Road Initiative".

Topographical and meteorological factors presented themselves as the determining effects on the spatial patterns of land cover in Nepal. With elevation uplift from south to north, land cover classes showed a vertical zonality ordered by paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. These relationships provide a potential foundation for predicting the trends in land cover change whilst considering global climate change and increasing human activities.

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Chapter 3
Land Cover Change and Its Driving Forces in Nepal Since 1990

Ainong Li, Guangbin Lei, Xiaomin Cao, Wei Zhao, Wei Deng and Hriday Lal Koirala

Abstract Nepal is a typically mountainous landlocked country. In recent years, land cover in Nepal has changed significantly due to climate changes, population growth and economic development. This study used four periods of land cover change data (1990–2000, 2000–2005, 2005–2010 and 2010–2015) produced by the object-oriented change detection method, to reveal the spatial patterns of land cover change and its driving forces in Nepal since 1990. The result showed that the total change area from 1990 to 2015 in Nepal is 1665.58 km^2, accounting for 1.13% of the land. Among these changes, forests, wetlands and permanent ice/snow presented a trend of decrease, whereas croplands, artificial surfaces and bare lands had been continuously increasing. The prominent land cover changes included mutual transformation between wetlands and croplands, wetland class inner shifts and the conversion of forests to croplands. These changes varied among different development regions and during different periods. In general, the intensities of land cover change in Eastern and Central Development Regions were higher than in other development regions. The annual change area was 59.26 km^2/year during 1990–2000, reached to 98.44 km^2/year during 2000–2005 and turned to slowly decline after 2005. The analysis and discussion indicated that major driving forces of land cover change in Nepal include climate changes, natural hazards, population growth, urbanization, economic development and government policy implementation. A comprehensive understanding of the relationships between land cover change and various driving forces in Nepal was given in this study, which would be valuable for policymaking, land planning, resource development and protection. Simultaneously, it could be also benefit to China's "Belt and Road Initiative."

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3.1 Introduction

Land Use/Cover Change (LUCC) is an important content of global change research (Niyogi et al. 2009) and is also closely related to biodiversity, material and energy cycles, the natural ecological processes and the development of human society (Field et al. 1996; Li 1996; Fu et al. 1999). Understanding LUCC processes and associated driving mechanisms is essential to policymaking and land planning at regional and national scales.

The Hindu Kush–Himalayan (HKH) region occupies a total area of 4.3 million km^2, encompassing all or parts of eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan (Fig. 3.1). There are rich in water resources and biodiversity, which directly or indirectly provides the fresh water and ecosystem services for 1.3 billion downstream residents and 210 million mountainous residents (Molden and Sharma 2013). However, affected by rugged terrains, climate changes and human activities, land covers in this region are complicate and highly vulnerable. Although in recent years, a growing number of scientists and organizations have realized the importance of the HKH region and conducted a lot of relevant studies (Bajracharya et al. 2010), the spatial scales and land cover classification systems in these researches were generally not consistent. Land cover and its change information with the high quality in this region was still lacking for usage.

Nepal, located in the transition zone from Indo-Gangetic Plain to the Qinghai–Tibet Plateau, is a typical mountainous landlocked country with diverse and complex land covers. In recent years, Nepal has witnessed substantial changes in its land cover due to climate changes, population growth and economic development (Paudel et al. 2016). For example, global warming has significantly affected this region by increasing its average surface temperature at a rate of 0.15–0.6 °C every decade in the past 30 years (IPCC 2007). The total population has been growing at an annual rate of 0.52% and has reached 28.51 million in 2015 (Paudel et al. 2016). Economy in Nepal grew rapidly, its GDP increased from US $508 million in 1960s to US $20,881 million in 2015 and its economic structure also gradually shifted from agriculture dominant to that the proportion of non-agricultural products was gradually increasing (Wang 2004).

Currently, available land use/cover data in Nepal included global-scale data and regional-scale data. The global-scale data are generally in a coarse spatial resolution (i.e., ≥ 300 m), which could not meet the requirements for national land cover change analysis. Regional-scale data focused on either small areas such as a watershed (Virgo and Subba 1994; Thapa 1996; Gautam et al. 2003; Paudel et al. 2016) or a single land cover class, such as forest (Fox 1993), glacier (Bolch et al. 2012), urban area (Thapa and Murayama 2012). Uddin et al. (2015) have conducted

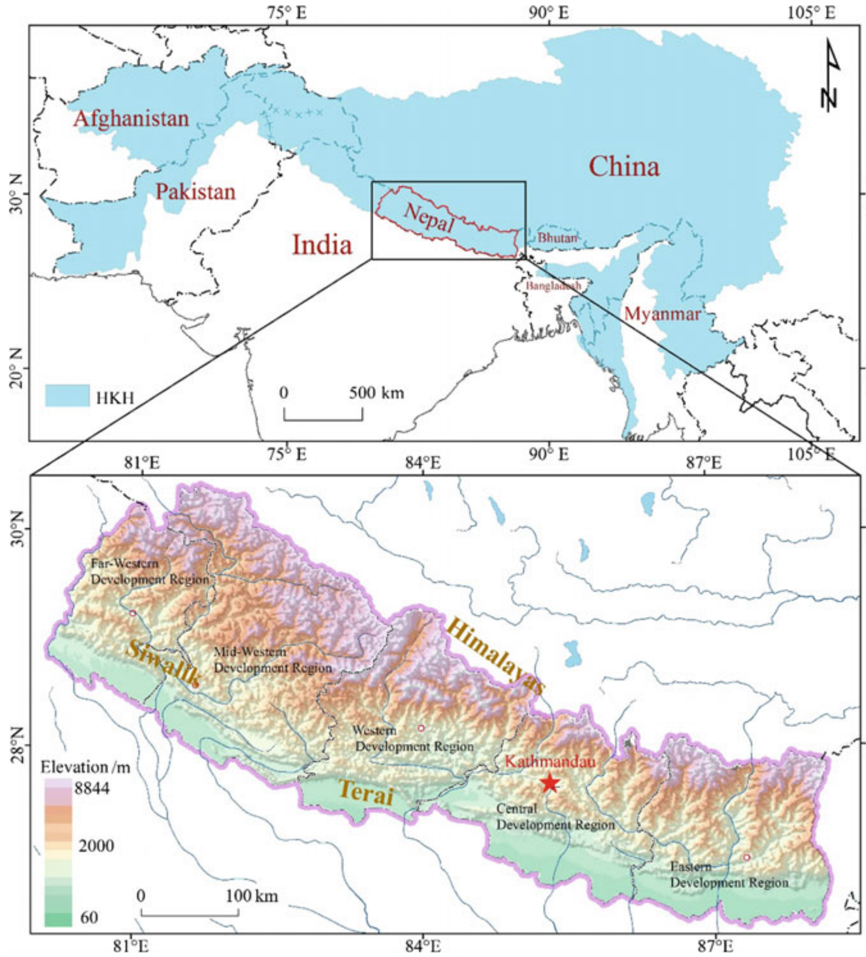


Fig. 3.1 Geographical location of Nepal

a national-scale land cover mapping in Nepal in 2010, but it was a one-time land cover data and lack of land cover change monitoring over a relative long period.

Under the support of the international cooperation key project of Chinese Academy of Sciences, named "Comparison study on typical mountain ecosystems in China and Nepal based on remote sensing technologies (No. GJHZ201320)," land cover change monitoring in Nepal since 1990 was conducted by the Institute of Mountain Hazards and Environment (IMHE), CAS. This work attempts to reveal the detailed spatial patterns of land cover changes in Nepal and to understand the correlations between land cover changes and associated driving forces. It can be surely benefit to policy makers and planners for better managing Nepal's natural resources and may also be useful for China's international regional economic cooperation strategy entitled “Belt and Road Initiative.” This chapter introduces the method for producing land cover change data sets in Nepal since 1990. Based on these data, the spatial patterns of land cover change and its driving factors at the national scale are comprehensively analyzed and discussed.

3.2 Study Area

Nepal is located in the south middle of the Himalayas, with a total area of 147,600 km^2, and lies between latitudes 26° 22′–30° 27′N and longitudes 80° 4′–88° 12′E (Fig. 3.1). It contains some of the most rugged terrain. Within a distance of 200 km from north to south, elevation drops from 8844 m down to 60 m. There are five ecological regions: High Himalaya, High Mountains, Middle Mountain, Siwalik and Terai Plain distributed along such huge elevation gradient. Annual average temperature in Nepal is significantly different between north and south. Annual precipitation is abundant, but its distribution, both spatially and temporally, is uneven (Devkota 2014). Farming is the primary economic activity, and almost 80% of the population in Nepal are engaged in farming. The industrial foundation is very weak with small scale and low level of mechanization (Wang 2004).

3.3 Data and Method

3.3.1 Data

In this study, we used Landsat TM/ETM+/OLI images with a 30-m spatial resolution at 5-year intervals from 1990 to 2015 except that in 1995, in which the acquired images cannot cover the whole land of Nepal. Among them, the data in 1990, 2005 and 2010 are only Landsat TM images, the data in 2000 are Landsat TM and ETM+ images, and the data in 2015 are Landsat OLI images. All acquired satellite images met the condition of cloud coverage less than 5%. When there is a lack of high-quality images at a certain year, the acquisition time of satellite images was expanded to before or after one year. A total of 96 satellite images (Fig. 3.2) were acquired, all of which were downloaded from the USGS data sharing platform (http://glovis.usgs.gov/). The Landsat TM/ETM+/OLI images are L1T products, which had been conducted radiometric and geometric correction. The atmospheric correction had further been conducted for each image by the LEDAPS preprocessing package (Wolfe et al. 2004).

Topographic data including altitude, slope and aspect, and meteorological data including annual average temperature and annual precipitation were also used as key variables for determining land cover changes in this study. ASTER GDEM data with spatial resolution of 30 m were adopted. Slope and aspect were calculated

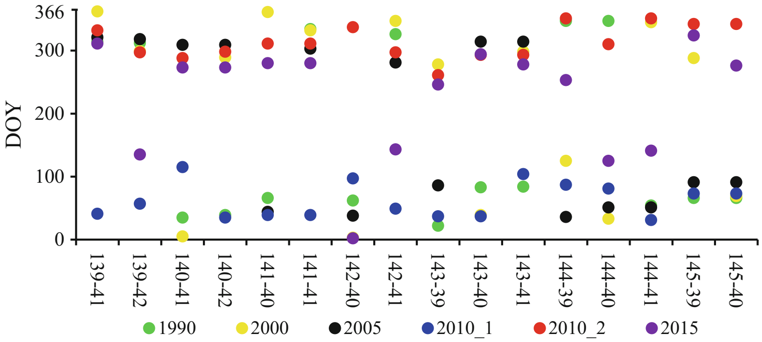


Fig. 3.2 Acquisition time of satellite images adopted to monitor land cover change in Nepal since 1990

from the GDEM data by the ERDAS software. Meteorological data were acquired from the national climatic data center NCDC (http://www.ncdc.noaa.gov/). Interpolation was conducted with ANUSPLIN software for downscaling of meteorological data into 30-m spatial resolution.

3.3.2 Land Cover Change Detection

The four periods of land cover change data (1990–2000, 2000–2005, 2005–2010 and 2010–2015) were generated by the object-oriented change detection method. Land cover map in 1990, 2000, 2005 and 2015 was produced by combining four periods of land cover change data and the NepalCover-2010 product (see Chap. 2, and Cao et al. 2016). The flowchart of the proposed change detection method is shown in Fig. 3.3. Firstly, multi-temporal satellite data (including reference image and detected image), change indices and topographic indices were segmented into image objects by multi-resolution segmentation algorithm. Simultaneously, the training samples were collected by artificial visual interpretation. Subsequently, a series of rules were built by decision tree classifier (See 5.0), to detect the changed polygons between the reference image and the detected image. In order to identify the feature of changed polygons, an automatic classification method was adopted to recognize the land cover class in the detected image. Finally, we further checked and revised the potential errors existed in the change detection results. This chapter mainly introduces three critical steps: samples collection, setting rules for detecting change polygon, and error checking and revising.

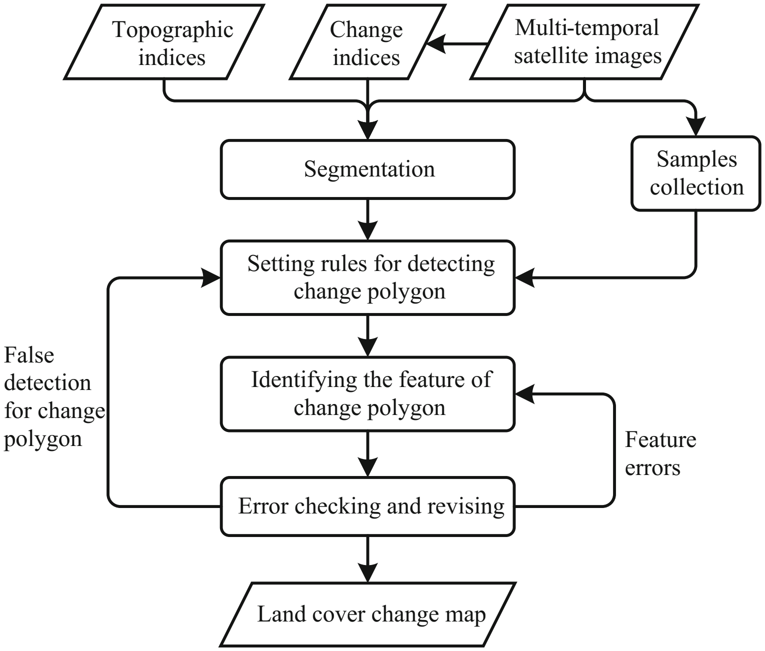


Fig. 3.3 Flowchart of the object-oriented change detection method

3.3.2.1 Samples Collection

Samples are considered as the "true" data of the ground and the foundation for building the change detecting rules by the decision tree method. Taking the change detecting between 2005 and 2010 as a case, both the changed samples and the unchanged samples were collected from satellite images in 2005 and 2010 by artificial visual interpretation. Those polygons with obvious spectral changes between the reference image and detected image were found out and taken as changed samples. The number of the sample size for each change type was not less than 20. To assure the robustness of the rules for detecting changed polygons, almost all change types existed in a path/row need to be contained in the samples. For the unchanged samples, the sample size needs to keep consistent with that of changed samples, and these samples should be distributed as uniformly as possibly.

3.3.2.2 Setting the Rules for Detecting the Change Polygons

In this study, a total of 32 indices were selected to build the rules for detecting the changed polygons. They were spectral reflectance (b_i), spectral indices (NDVI, MNDWI and NBR), temporal differences in spectral reflectance (Δb_i) and spectral indices (ΔNDVI, ΔMNDWI and ΔNBR) between reference image and detected

Table 3.1 Published indices used for detecting the change polygons in this study

Indices	Calculation methods		Illustration	References
	Equations	Parameters		
CVI	$CVI = \sqrt{(g_1 - h_1)^2 + (g_2 - h_2)^2 + \cdots (g_n - h_n)^2}$	g_i and h_i represent the surface reflectance of reference image and detected image in band i, respectively	Capturing the absolute value of total spectral change between reference image and detected image	Nackaerts et al. (2005)
VS	$VS = \frac{\sum g_i h_i}{\sqrt{\sum g_i^2} \cdot \sqrt{\sum h_i^2 \cdot \left(\left\| \frac{\sqrt{\sum g_i^2}}{\sqrt{\sum h_i^2}} - 1 \right\| \right) + 1}}$		Calculating the similarity of vectors formed by reference image and detected image	Li et al. (2009)
NDVI	$NDVI = (b_4 - b_3)/(b_4 + b_3)$	b_i represents the surface reflectance of satellite image in band i	Monitoring vegetation condition and vigor	Zha et al. (2003)
MNDWI	$MNDWI = (b_2 - b_5)/(b_2 + b_5)$		Enhancing liquid water information	Xu (2005)
NBR	$NBR = (b_4 - b_7)/(b_4 + b_7)$		Monitoring vegetation disturbances caused by fire	Miller et al. (2009)

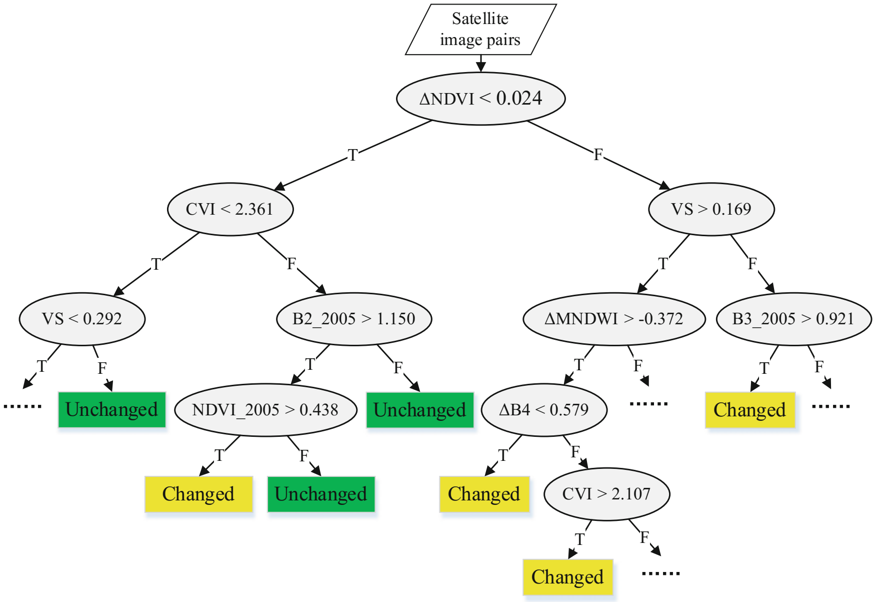


Fig. 3.4 A typical example of rules for detecting changed polygons in path/row of 143/41 (WRS2) in South Rapti. Bx_2005 represents the reflectance of satellite images in band x in 2005, ΔBx represents the temporal differences of spectral reflectance in band x between 2005 and 2010, *NDVI*_2005 represents the *NDVI* value in 2005, the representative meanings of the rest indices are shown in Table 3.1, and ellipsis means the object will be further subdivided

image, topographic factors (altitude, slope and aspect), as well as the change vector index (CVI) and the vector similarity (VS). Calculation methods and illustrations for these indices are listed in Table 3.1, and the relevant references can also be attached.

The rules used in change detection were constructed by decision tree classifier—See 5.0. Firstly, the training samples and 32 indices were input into the See 5.0, and the rules were built by an automatic training process. The changed polygons were then derived by carrying out these rules. Figure 3.4 shows an example of the derived rules in the South Rapti (path/row: 143/41, WRS2).

3.3.2.3 Error Checking and Revising

There exist two types of potential errors in change detection results. One is not the change, but was detected as the changed polygons because of the differences of image acquisition phase or cloud effect; the other is to identify a wrong feature to a detected change polygon. Here the artificial visual inspection was adopted to find out the errors of change detection. A logic checking method was then conducted to check the errors given a wrong feature. An example of the rules for the logic interpretation is listed in Table 3.2.

Table 3.2 Some typical rules for the logic interpretation of change processes

		Land cover after the change										
		1	2	3	4	5	6	7	8	9	10	11
Land cover before the change	1	×	×	✓	✓	✓	✓	✓	✓	✓	×	×
	2	×	×	✓	✓	✓	✓	✓	✓	✓	×	×
	3	✓	✓	×	✓	✓	✓	✓	✓	✓	×	×
	4	✓	✓	✓	×	✓	✓	✓	✓	✓	×	×
	5	✓	✓	✓	✓	×	✓	✓	✓	×	×	×
	6	✓	✓	✓	✓	✓	×	✓	✓	×	×	×
	7	✓	✓	✓	✓	✓	×	×	✓	✓	×	×
	8	×	×	×	×	✓	×	×	×	✓	×	×
	9	×	×	✓	✓	✓	×	✓	✓	×	×	✓
	10	×	×	×	×	×	×	×	×	×	×	✓
	11	×	×	×	×	×	×	×	×	✓	✓	×

Note 1 Evergreen broadleaf forest; *2* Evergreen needleleaf forest; *3* Deciduous broadleaf shrub; *4* Steppe; *5* River; *6* Paddy field; *7* Dry farmland; *8* Residential land; *9* Bare soil; *10* Bare rock; *11* Permanent ice/snow; symbol "✓" represents rational change process; symbol "×" represents irrational change process

3.3.3 Land Cover Change Analysis

This paper adopted the transfer matrix (Wu et al. 2014) and the change rate of land cover (Wang and Bao 1999) to quantitatively analyze the land cover change in Nepal since 1990. The transfer matrix can clearly depict the mutual changes of each land cover class and reflect the change direction of land cover classes under the interference of natural environment and human activities. The change rate of land cover was mainly used to reflect the change degree of each land cover class, and the formula is as follows:

$$D_i = \frac{A_{\mathrm{end}} - A_{\mathrm{start}}}{A_{\mathrm{start}}} \times 100$$

where D_i is the change rate of the ith land cover class, and A_{start} and A_{end} refer to the area of the ith land cover class at the start and end of monitoring period, respectively.

Meanwhile, in order to reveal the spatial patterns of land cover change in Nepal since 1990, the intensity map of land cover change was figured out with the grid resolution of 1 km × 1 km. It can describe the general change rate of the land cover at the 1-km scale.

3.4 Results and Analysis

3.4.1 Land Cover Change Pattern in Nepal Since 1990

The statistics showed that total land cover change in Nepal since 1990 is 1665.58 km^2, accounting for 1.13% of the land. Overall, the intensity of land cover change was relatively low. The spatial pattern and intensity of land cover change during 1990–2015 in Nepal were figured out and are shown in Fig. 3.5a. The changes mainly occurred in the Terai Plain, Siwalik, Middle Mountain, Kathmandu Valley and Nepal 4.25 earthquake-hit area. But generally, from south to north, the intensity of land cover change reduced with the increasing altitude. The intensity of land cover change was relatively low in most areas, and 82.18% of change intensity was below 10% (Fig. 3.6). The region with the change intensity exceed 50% only accounted for 2.69% of the land, which can be found at the places where human activities such as urbanization and tea plantation or natural driving forces like river diversion are very active (Fig. 3.5b–d).

Table 3.3 further shows that the prominent land cover changes include mutual transformation between wetlands and croplands (598.63 km^2), wetland class inner shifts (286.32 km^2) and the conversion of forests to croplands (215.36 km^2). Among changes, forests, wetlands and permanent ice/snow presented a trend of decrease, while croplands, artificial surface and bare lands had been continuously increasing. In addition, shrubs and grasslands did not display any obvious fluctuation. Change rates in artificial surfaces and wetlands reached as high as 9.94 and 5.41%, respectively (Fig. 3.7). Although change areas in croplands and forests were relatively large, their change rates were less than 1% because they covered a large proportion area.

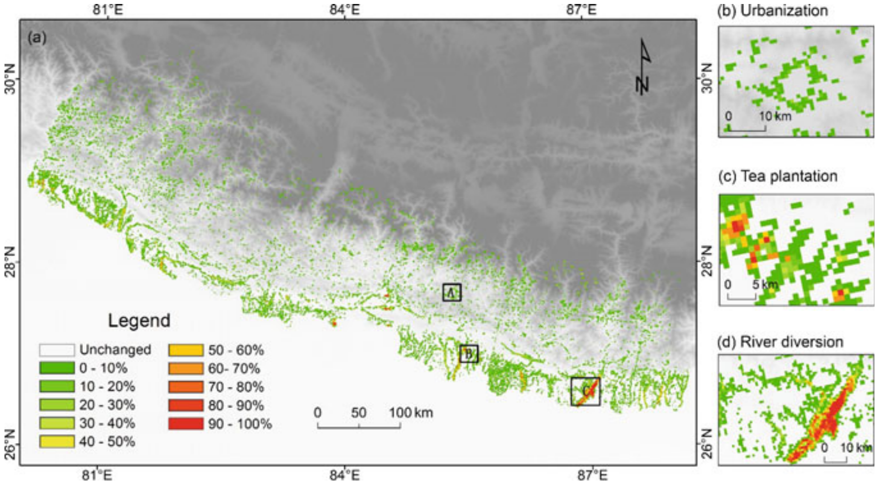


Fig. 3.5 Spatial pattern and intensity of land cover change since 1990 in Nepal

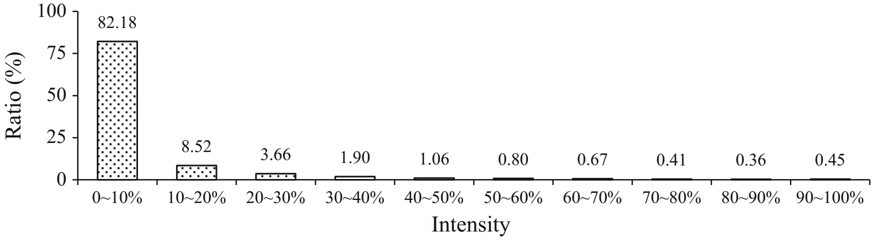


Fig. 3.6 Frequency distribution histogram of intensity of land cover changes from 1990 to 2015 in Nepal

According to Figs. 3.7 and 3.8, forests have lost 298.98 km^2 since 1990, and there is 89.87 km^2 other land cover converting into forests; therefore, the net loss of forests was 209.11 km^2, which accounted for 0.35% of the total forest areas. The reduced forests were mainly converted into croplands, due to the increasing demands for croplands in recent years. A catastrophic earthquake on April 25, 2015, also destroyed 11.86 km^2 forests. Wetland areas have a gain of 607.26 km^2 and a loss of 768.82 km^2, which resulted in a net decrease of 161.36 km^2 (5.41% of the total wetland areas) over the past 25 years. Changes in wetlands were mainly due to frequent river diversions in Terai Plain. Among of which, 226.68 km^2 croplands have been occupied by river diversions; At the meantime, 371.95 km^2 floodplains of rivers has been re-cultivated, and another 264.83 km^2 areas of wetlands has been mutually transformed between rivers and floodplains. Croplands have increased by 680.10 km^2 and decreased by 344.49 km^2, which resulted in a net increase of 335.62 km^2. Population growth and migration are the two major factors that lead to croplands increase. By comparing with other land cover classes, the change areas of croplands were the largest; however, its change rate was only 0.92% because croplands covered a huge areal proportion in Nepal. The permanent ice/snow has reduced by 58.55 km^2, with a change rate of 0.71%. It is well known that the land surface temperature has presented a trend of increasing in recent decades, which can lead to glacial recession and snow melting. In the past 25 years, the artificial surfaces in Nepal have increased by 47.02 km^2, but the change rate reached 9.94% because they only covered a small part of the land. Rapid urbanization and infrastructure construction were the major factors for the increasing artificial surfaces.

3.4.2 *Statistics of Changes in Different Development Regions*

Administratively, the whole land of Nepal is divided into five development regions —Eastern, Central, Western, Mid-Western and Far-Western Development Region (Fig. 3.1). These regions account for 19.35, 18.52, 19.98, 28.82 and 13.33% of the country area, respectively. Figure 3.9 shows that Eastern Development Region had

Table 3.3 Land cover transfer matrix from 1990 to 2015 in Nepal (km^2)

		2015								
		Forest	Shrub	Grassland	Wetland	Cropland	Artificial surface	Bare land	Permanent ice/snow	Total
1990	Forest		26.48	8.58	29.25	215.36	7.45	11.86		298.98
	Shrub	7.94		4.96	5.59	46.89	0.66	9.55		75.57
	Grassland	14.81	7.16		46.61	14.32	0.40	8.28	0.02	91.60
	Wetland	35.99	10.18	59.16	286.32	371.95	3.88	0.66	0.49	768.62
	Cropland	26.74	13.88	14.40	226.68	21.27	35.89	5.45		344.31
	Artificial Surface				0.36	0.90				1.26
	Bare land	4.40	4.57	2.96	2.75	9.41	0.01	0.97	0.45	25.52
	Permanent ice/snow		0.43	2.55	9.70			47.04		59.72
	Total	89.87	62.69	92.61	607.26	680.10	48.28	83.80	0.97	1665.58

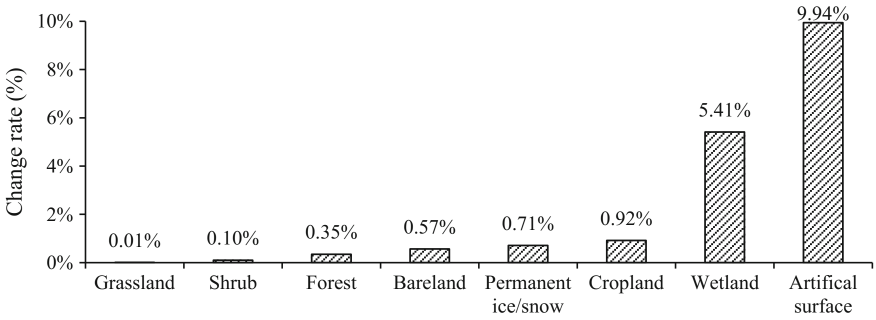
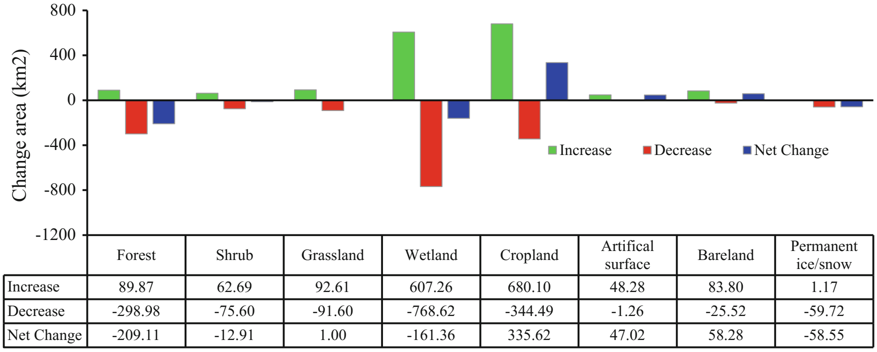


Fig. 3.7 Change rate of each land cover class in Nepal from 1990 to 2015



	Forest	Shrub	Grassland	Wetland	Cropland	Artifical surface	Bareland	Permanent ice/snow
Increase	89.87	62.69	92.61	607.26	680.10	48.28	83.80	1.17
Decrease	-298.98	-75.60	-91.60	-768.62	-344.49	-1.26	-25.52	-59.72
Net Change	-209.11	-12.91	1.00	-161.36	335.62	47.02	58.28	-58.55

Fig. 3.8 Area change of each land cover class in Nepal from 1990 to 2015

experienced the largest land cover change, with an area of 592.44 km^2, followed by Central Development Region 393.42 km^2. Change areas in Western, Mid-Western and Far-Western Development Regions were 172.83, 254.70 and 251.90 km^2, respectively. In terms of change rate of land cover, Eastern Development Region presented the fastest change at a rate of 2.08% among all regions, followed by the Central and Far-Western Development Region 1.44 and 1.28%, respectively. Change rate in Western and Mid-Western Development Regions were 0.59 and 0.60%, respectively. Generally, land cover changes in Eastern and Central Development Regions were more drastic than in other development regions since 1990.

The areal proportion of the plain and low hill is larger in Eastern and Central Development Regions than in other regions, where can create suitable conditions for specific land cover changes like river diversion. As for the social and economic conditions, Eastern and Central Development Regions are more developed compared with other development regions. For examples, the Koshi Zone in Eastern Development Region is an important industrial and trade center, and the Bagmati Zone in Central Development Region is the most developed zone of industry,

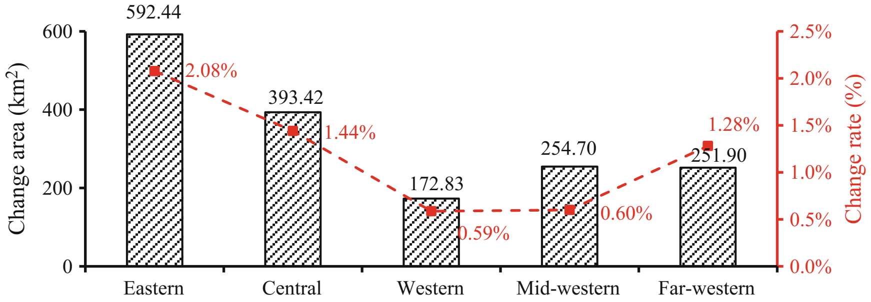


Fig. 3.9 Change area and change rate of land cover in different development regions from 1990 to 2015

commerce and transportation in Nepal (Wang 2004). Financial reports of the Central Bank of Nepal (http://nrb.org.np/ecorev/index.php) also showed that the economies of Eastern and Central Development Regions have grown rapidly in the last decades. Besides, in both two regions, agriculture, forestry and animal husbandry also had developed rapidly, and population growth rate and urban area density were much higher as well than in others (FAO 2000; Wang 2004). It proved that the superior natural environment and social and economic conditions are the driving factors for drastic changes of land cover in Eastern and Central Development Regions.

3.4.3 Statistics of Changes in Different Periods

Figure 3.10 presents that the annual change area was 59.26 km^2/year during 1990–2000 and increased to 98.44 km^2/year during 2000–2005 and turned to slowly decline after 2005, as 90.19 km^2/year during 2005–2010 and 82.28 km^2/year during 2010–2015. Meanwhile, the annual change area from 2000 to 2010 (87.95 km^2/year) was significant higher than that from 1990 to 2000 (59.26 km^2/year).

The economic structure transformation accelerated the land cover changes in Nepal; simultaneously, with improved management ability of the water sources, the frequency of river diversion caused by flooding obviously reduced during 2000–2015. These factors ultimately resulted in different change patterns of land cover in different periods. For instance, according to the World Development Indicators provided by the World Bank (http://data.worldbank.org/data-catalog/world-development-indicators/wdi-2013), Nepal's economic structure has undergone significant changes (Fig. 3.11); the proportion of agricultural output value to GDP has obviously dropped down from 51.63 to 32.79%; simultaneously, the service

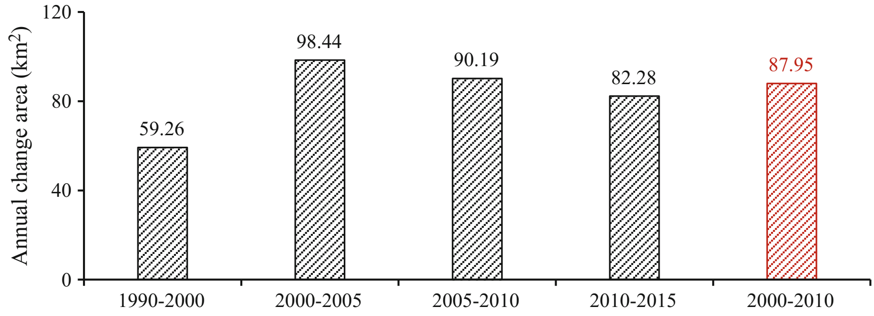


Fig. 3.10 Annual change area of land cover during different periods in Nepal since 1990

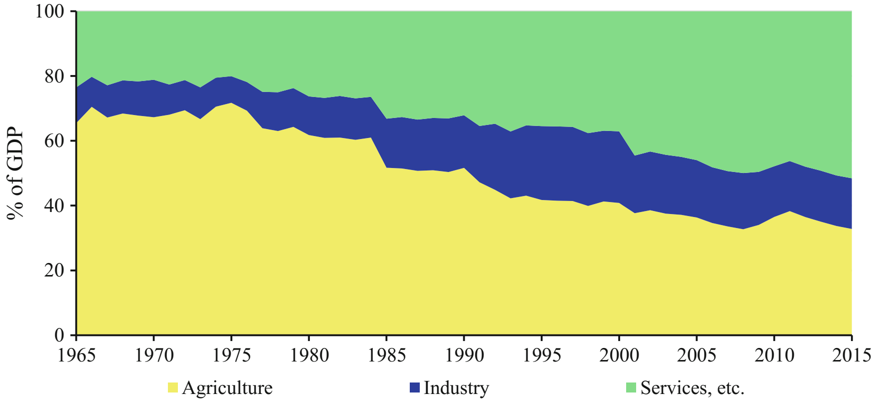


Fig. 3.11 Transformation processes of economic structure in Nepal from 1965 to 2015

output value has increased from 32.13 to 51.55% (Basnett et al. 2014). Changes in economic structure have direct effects on labor allocation and land use (Wang 2004).

3.4.4 Driving Forces of Land Cover Change

3.4.4.1 Climate Change

Global warming has caused the permanent ice/snow decreasing over the world, especially at the alpine or high mountain areas (IPCC 2007). According to this study, Fig. 3.12 also shows that a negative correlation exists between temperature and the area of permanent ice/snow in Nepal. In the past three decades, land surface temperature in Nepal has increased by 0.15–0.6 °C every decade (IPCC 2007), which may be the main reason causing the permanent ice/snow decreasing.

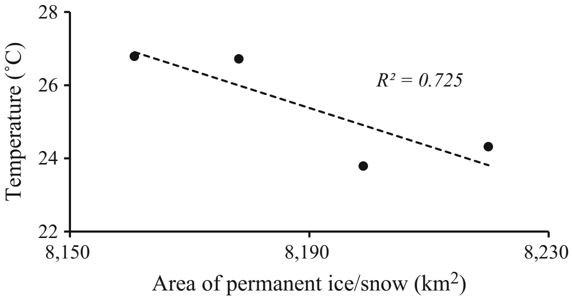


Fig. 3.12 Correlation between temperature and the area of permanent ice/snow in Nepal from 1990 to 2015

The report also recorded that residents in high altitude areas have been obviously aware of the glacier and snowline retreat, snow melting and ice lake expansion since 1980s, and those phenomena have become more prominent in recent years (Shrestha and Aryal 2010).

As the climate warming, the extreme weather like heavy rainfall and glacial lake outburst floods (GLOF) in high alpine areas also have become more frequent and severe in recent decades, which changed the river channels in the downstream and caused the mutual transformation between wetlands and croplands. The detailed discussion is followed as below.

3.4.4.2 Natural Disasters

Natural disasters in Nepal are frequent and devastating according to the statistics of the DesInventar data (http://www.desinventar.net/DesInventar/profiletab.jsp). A total of 20,374 natural disasters were recorded in Nepal during 1990–2013. Among them, many natural disasters were directly or indirectly related to land cover changes, like floods, landslides, forest fires and earthquakes (Table 3.4).

Floods and landslides were responsible for land cover changes with an area of 645 km^2 between 1990 and 2015 in Nepal. Frequent river diversions and bank breaches took place in Terai Plain due to the flooding and flat terrain. On the one hand, river diversion could submerge croplands, grasslands and forests along the rivers. For instance, a sever flood busted on August 18, 2008, in Koshi River basin (Shrestha et al. 2010), directly destroyed 46.48 km^2 croplands (Fig. 3.13). On the other hand, plentiful sediments deposited in the river channels which could lead to the reclamation of wetlands (floodlands) into croplands.

Aside from floods caused by heavy rainfall, GLOF followed by glacier retreat and snow melting are the other catastrophic disasters in Nepal. For instance, a GLOF from the Tam Pokhari Lake occurred on September 3, 1998, caused widespread damages to forests, croplands and residential areas in the downstream (ICIMOD 2011).

Droughts and forest wild fires are also common natural disasters in Nepal. During 1990–2013, there were about 200 forest wild fires and more than 150

Table 3.4 Part of disasters in Nepal from 1990 to 2013 (by the end of 2013)

	Event	Death Toll	Damaged Buildings	Damaged roads (Mts)	Economic loss (Nepalese Rupee)
Flood	3391	2871	89,424	20,382	5,965,207,636
Landslide	2854	3198	17,224	377,148	1,107,409,024
Drought	147	0	0	0	11,700,000
Forest fire	206	67	1808	3000	1,289,519,301
Earthquake	177	14	1464	0	578,453,700

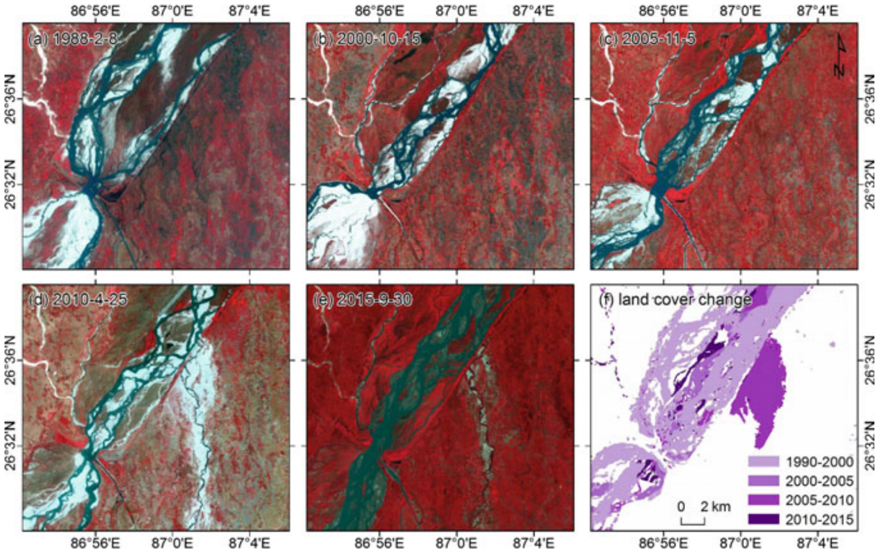


Fig. 3.13 A case of land cover change due to the river diversions in Koshi River basin. **a**–**e** showing the Landsat images in 1988, 2000, 2005, 2010 and 2015. **f** showing the spatial distribution of land cover changes during different periods

drought disasters in Nepal (MAC et al. 2009). Especially from the winter of 2008 to the spring of 2009, the persistent drought in Nepal not only caused serious damages to local agricultural production, but also induced massive forest wild fires in some areas (such as Myagdi District, Panchthar District); as a consequence, land cover classes in those areas have been changed obviously.

The statistics showed that well-recorded earthquakes in Nepal reach 177 times during 1990–2013. Earthquakes not only directly damaged infrastructures such as buildings and roads, but also caused secondary mountain hazards such as landslides, collapses and debris flows, which would ultimately result in land cover changes. For an example, 4.25 Nepal earthquake with a focal depth at 20 km and the secondary disasters triggered by this earthquake have resulted in land cover changes with an area of approximately 53 km^2 (Fig. 3.14), which mainly lie in the earthquake intensity zone IX, accounting for 63.29%.

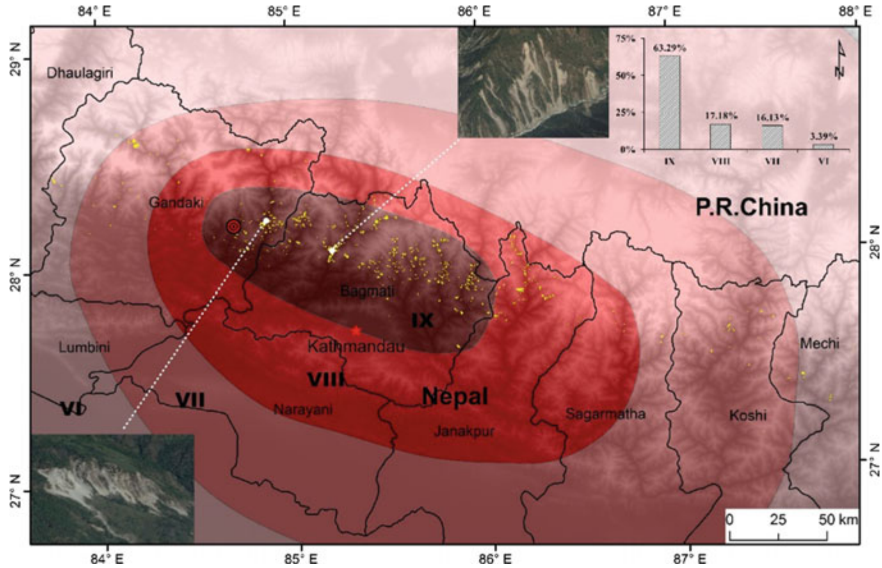


Fig. 3.14 Spatial distribution of land cover changes caused by 4.25 Nepal earthquake

3.4.4.3 Population Growth, Migration and Urbanization

Nepal's total population increased from 18.74 million to 28.51 million during 1990–2015, and its population density increased from 131 person/km^2 to 201 person/km^2 (Fig. 3.15). Meanwhile, the migrant population from remote mountain villages and towns into some big- and middle-sized cities has been continually increasing, and the total migrant population had reached 4 million until 2008 in Nepal (Gartaula et al. 2012). The increasing population can further intensify the conflicts between population and land supply and thus will inevitably lead to croplands expansion (Malla 2009). Simultaneously, the large amount of population migration will affect regional industrial structure, and land cover changes also may be followed by it.

According to the statistic, Fig. 3.16 also shows the close correlations between the population growth and area changes of forests, croplands and artificial surfaces. Forest area was negatively correlated with population growth ($r^2 = 0.9549$), artificial surface area was positively correlated to population growth ($r^2 = 0.9168$), and the correlation between cropland area and population growth was positive ($r^2 = 0.8696$).

To meet the requirements of wood, food and house for the growing population, deforestation, settlement expansion and infrastructure construction frequently occurred in Nepal (Kanel 1995; Bhattarai and Conway 2008; Bhattarai et al. 2009). During 1990–2015, about 298.98 km^2 forests were transferred to other land cover classes in Nepal. Figure 3.17 shows a case of land cover changes due to the deforestation in Terai Plain.

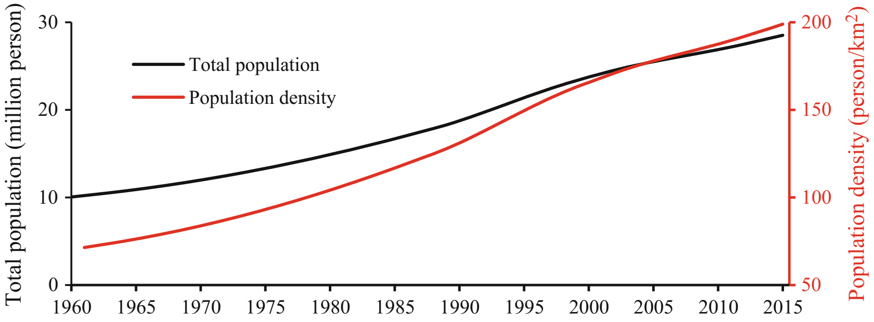


Fig. 3.15 Changes of total population and population density in Nepal between 1961 and 2015

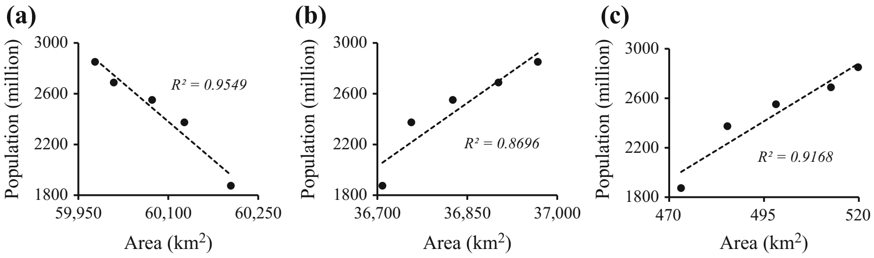


Fig. 3.16 Correlation between population growth and area change of three typical land cover classes: **a** forests, **b** croplands and **c** artificial surfaces

Urban expansion is another typical land cover change caused by continuous population growth and migration, among which the urban expansion in Kathmandu was the most typical. From 1981 to 2011, population in Kathmandu increased from 0.43 million to 1.74 million, with an annual growth rate of 4.76%; population density from 1069 person/km^2 increased to 4408 person/km^2. Urban expansion in Kathmandu mainly occupied its surrounding croplands, as shown in Fig. 3.18. The "ring" mode in Kathmandu city map indicated a gradual urbanization process, from core city area to marginal and surrounding rural areas. The similar result was also reported by Thapa and Murayama (2010), who divided Kathmandu into three annular regions in Nepal (core, marginal and rural) to analyze the process of urban expansion.

3.4.4.4 Socioeconomic Development

According to the statistics provided by the World Bank (http://www.worldbank.org/), from 1960s to 2015, Nepal's GDP has increased from US $508 million to US $20,881 million and per capita GDP from US $50.55 to US $732.30 (Fig. 3.19). The GDP

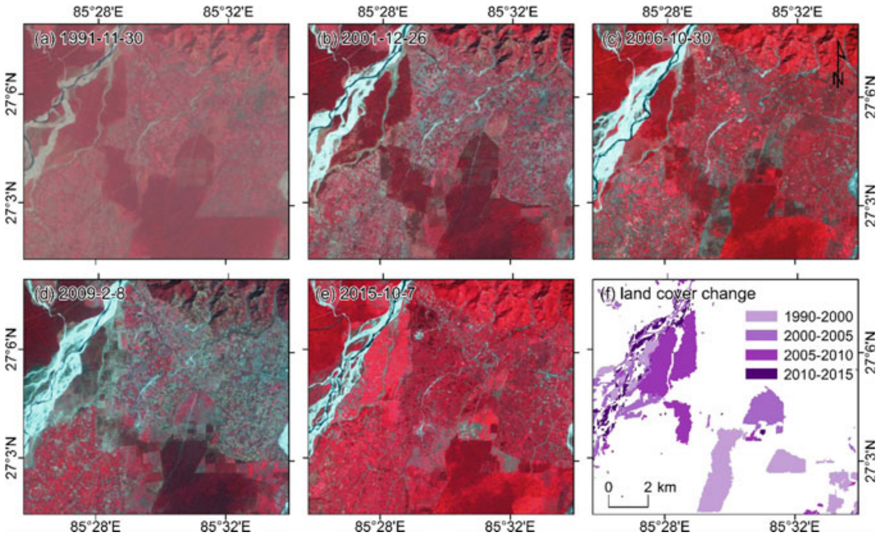


Fig. 3.17 A case of land cover changes due to the deforestation in Terai Plain. **a**–**e** showing the Landsat images in 1991, 2001, 2006, 2009 and 2015, respectively. **f** showing the spatial distribution of land cover changes during different periods

changes and area changes of forests, croplands and artificial surfaces were closely correlated (Fig. 3.20). Cropland area was positively correlated to GDP change (r^2 = 0. 9651), artificial surface area also positively correlated to GDP change (r^2 = 0.9265), whereas forest area was negatively correlated with GDP change (r^2 = 0.8904). To meet the needs of economic development, croplands and artificial surface areas have continuously increased, whereas natural forests were cut to meet the demands for timber and agricultural use.

Along with the socioeconomic development in Nepal, the government has gradually improved infrastructure construction, including roads, airports and hydropower stations. These infrastructures, on the one hand, have occupied large areas of land and on the other hand also have promoted trades and tourism, and stimulated economic development and industrial structure optimization, which would indirectly affect land cover changes. For instance, Gautam et al. (2004a) revealed that the decreased forest areas are more than increased forest areas at the range of 1–1.5 km of the highway. According to the statistics provided by the Department of Roads in Nepal (http://dor.gov.np/road_statistics.php), there was only 376 km highway in Nepal in 1955, and all were along the north-south direction. By 2014, road networks have extended to all directions, and highway mileage reached 24,000 km. Large hydropower stations have been built over the past decades (Shrestha et al. 2014), such as the Gusabani-Karnali Hydropower Station (10,800 MW), the Sapta Koshi River Hydropower Station (3600 MW) and the Gandaki Hydropower Station (600 MW). These hydropower stations improved the power generation capacity and agricultural irrigation and increased wetland

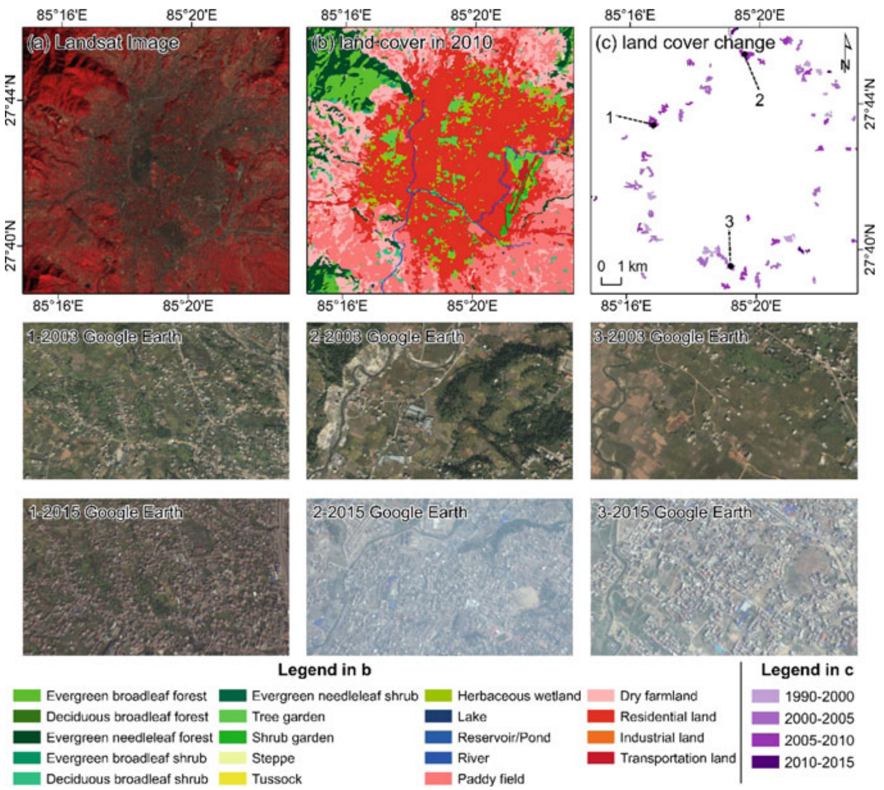


Fig. 3.18 A case of land cover change due to the urbanization in Kathmandu, Nepal. **a** showing the Landsat images in 2010, **b** showing the land cover map in Kathmandu in 2010 and **c** showing the spatial distribution of land cover changes during different periods, (*1*), (*2*) and (*3*) showing the high-resolution Google Earth images acquired at 2003 and 2015 in three typical regions

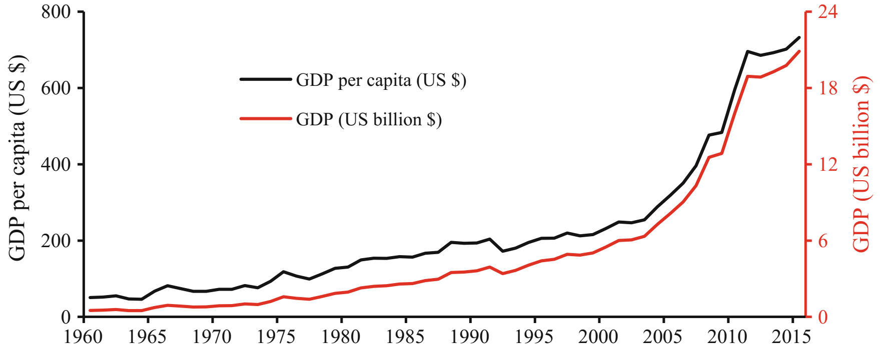


Fig. 3.19 Changes of the GDP and GDP per capita in Nepal between 1961 and 2015

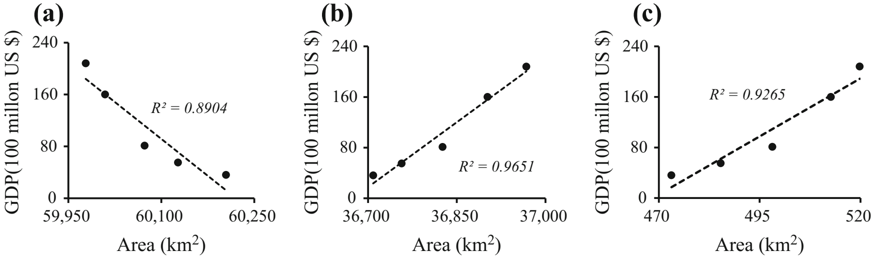


Fig. 3.20 Correlation between GDP change and area change of three typical land cover classes: **a** forests, **b** croplands and **c** artificial surface

areas significantly. In terms of water resource management, the dams, reservoirs and relevance irrigation infrastructures improved the ability of flood control, water supply and irrigation and decreased some types of land cover change, like river diversion.

3.4.4.5 The Implementation of Relevant Policies

The implementation of relevant government policies also directly or indirectly affected land cover. Forestry played an important role in Nepal's economy. The Nepalese government has put forward a number of forest conservation policies to ensure a sustainable use of natural resources. In 1956, the Nepalese government promulgated the *Forest Protection Law* to implement compulsory management measures for state-owned forests. However, this policy was not successful and led to a decrease in forest area. In 1993, the Nepalese government revised the *Forest Protection Law*, which divided forests into national and private forests. The national forests were categorized into community forests, leasehold forests, government-managed forests, religious forests and protected forests (Gautam et al. 2004b). Community forestry was given the highest priority over other forest types. The community forestry program has dramatically expanded in terms of both spatial coverage and number of forests handed over to local communities after the enforcement of the new legislation. Even more, some croplands that had been converted from forests were transferred back again. However, there are wide variations in the success of community-based forest management programs across the country (Shovit and Xie 2016).

For agriculture, the government promulgated the *Land Reform Law: 1964* to solve the problems that a handful of landlords held most of agricultural land in 1964. In addition, the government implemented a series of agricultural development measures to promote the increase in cropland areas, such as agricultural loans, promotion of fine varieties, expansion of irrigation systems, pesticide and fertilizer application.

In order to speed up the development of industry, the Nepalese government promulgated a series of industrial policies in 1992, such as *Industrial Policy in 1992* and *Foreign Investment and One-Window Policy*, to encourage both domestic and foreign investments to participate in industrial development. These actions have promoted the population migration and urban development and indirectly led to land cover change.

3.5 Conclusion

The spatial patterns of land cover change and its driving forces since 1990 in Nepal were comprehensively analyzed based on four periods of land cover change data (1990–2000, 2000–2005, 2005–2010 and 2010–2015). The results showed that total land cover change is 1665.58 km^2 in Nepal since 1990, accounting for 1.13% of the land. The intensity of land cover change was relatively low. Forests, wetlands and permanent ice/snow showed a trend of decrease, whereas croplands, artificial surfaces and bare lands have continuously increased. The prominent land cover changes were the mutual transformation between wetlands and croplands, wetland class inner shifts and the conversion of forests to croplands. There are significant differences of land cover change among different developing regions and during different periods. The intensities of land cover change in Eastern and Central Developing Regions were higher than in other regions. The annual change area is 59.26 km^2/year during 1990–2000, reaches to 98.44 km^2/year during 2000–2005 and turns to slowly decline after 2005. The main driving factors for land cover changes in Nepal included climate change, natural hazards, population growth, migration, urbanization, economic development and policy implementation. The comprehensive analysis on land cover changes at a national scale based on remote sensing technologies would be valuable to local government to design strategies and polices for resources and socioeconomic sustainable development, environmental protection and even climate change adaption.

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Chapter 4
Land Use Change and Its Driving Forces in the Koshi Hills, Eastern Nepal

Pushkar K. Pradhan and Puspa Sharma

Abstract In rural Nepal, development efforts often mean increasing the production and productivity of Arable land. Therefore, the land resources remain often changing its use. This paper intends to analyse the change in land use and land cover categories due to the intervention of different development activities in the eastern hills of Nepal during the past two and half decades. Both analogue and digital data have been used from three different sources including the Land Resource Mapping Project (LRMP, 1986), toposheets from 1996, and Landsat imagery from 2010. The spatial data generated was verified in the field via observation, a 'Reality Check Approach' (RCA), and consultation workshops held in the four districts such as Bhojpur, Dhankuta, Sankhuwasabha, and Terhathum. An attempt has also been made to identify the possible factors responsible for land use changes. Five broad categories of land uses, such as arable land, forest, shrubland, grassland, and others (water bodies, snow land, bare land, rock and ice, settlement built-ups, and roads), have been determined, based on 1996 toposheets. In the Koshi Hills, significant changes have occurred particularly in forest land, with it increasing consistently over the past 24 years, whereas cultivated land first increased during 1986–1996 and then decreased from 1996 onwards. In agriculture, while traditional subsistence cereal crops have been replaced with commercial vegetables and high-value crops such as large cardamom, ginger, seeds, and fruits, particularly around the roadsides, what has also happened is that patches of abandoned agricultural land have been observed due to a tendency of local youths migrating outwards to areas away from direct road access. The Community Forestry Program, the construction of roads, and the introduction of improved agriculture development programs have contributed to the internal trading between major land cover/use categories. These have brought benefits like nature conservation, national and international trade of local products, and improved living conditions for local communities. It is therefore possible to exhibit spatial relationships between development interventions and land use change on a GIS framework.

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Keywords Land use change · Koshi hills · Driving forces · Impacts

4.1 Introduction

Land is a fundamental natural resource in Nepal where agriculture is the main economic source for the majority of the population. However, the country has a major challenge where land resources were improperly used due to lack of a national land use act. Nepal lacks a land use plan and therefore there is no clear vision for the future development of districts, cities, or village areas. Additionally, this lack of regulation of land use means there is no way of preventing land use conflicts and safeguarding natural resources (FAO 1993).

Investment in a variety of development activities is increasing across Nepal, causing changes in land uses. There is urgency for integrated land use planning tools that combine interactive relations between different development activities and uses of environmental resources. In Nepal, a growing environmental awareness has inspired the government to promulgate the National Land Use Policy of 2013 and to set up a National Land Use Project in 2002. Since then the project has been making efforts to generate databases necessary to manage land use of the entire country. Land use and land cover change has been a core theme of this national project. Thus, this chapter intends to analyse land use change over a specified time period concentrating on the possible driving forces behind the land use change and their impacts on cultural landscapes in the Koshi Hills of eastern Nepal.

Land use is dynamic and frequently changes due to human intervention. Current land use patterns in specific areas are the result of centuries of human activity and are strongly influenced by natural conditions. Today's heterogeneous landscapes, with their mosaic of arable land, patches of natural vegetation, grassland, agro-biodiversed land, and conurbations, reflect the diverse land uses in an area. Studies have shown that external factors such as agricultural and forest conservation policies, transport development, hydroelectric dam works, etc., are frequently the driving forces behind changes in the use of land in rural areas (Lourenço et al. 1997). Similarly, social, economic and demographic changes affect land use patterns over time (Axinn and Ghimire 2011).

Land use represents an insightful reflection of human interaction with its environment in an area (Gautam et al. 2002; Virgo and Subba 1994; Thapa 1996; Jackson et al. 1998). Developmental interventions in the form of, for example, infrastructure, the introduction of new technology, and changes to policies, are likely to translate into changes in land use and socio-economic development. Land use studies generally are concerned with the spatial and temporal patterns of land conversion at different geographic scales by human activities as well as understanding the causes and consequences of these changes. They also attempt to explain the economic process—the human behavioral component that underlies land use change, i.e., causal relationships between individual choices and land use change outcomes (Axinn and Ghimire 2011). As human systems of production change, whether through shifting cultivation, subsistence agriculture, or commercial production, these changes alter the use of the land and the nature of the resulting land cover. Provisions of schools, health services, markets, and transportation services may all change social life and consumption patterns in terms of land. These changes in patterns of consuming land are likely to have important consequences for local land use and land cover.

Land use is a fundamental measure of how the environment is organized in a setting. Changes in land use are reflected in the relative magnitude of the land area devoted to agricultural and non-agricultural activities. Over time, as the population changes, as the economy grows, and as government infrastructure spreads, land use is likely to be transformed in many ways, for instance, the conversion of agricultural land to land for housing and other non-agricultural enterprises, the reduction of public forests and grazing lands, and the intensification of farming and therefore farm land expansion.

This chapter has a two-fold objective such as to establish a spatial database for mapping land use change and determining land use categories and their interpretations, and to identify factors responsible behind land use change in the Koshi Hills region of Nepal.

4.2 Data and Methods

4.2.1 Definitions and Classifications

Land use in the Koshi Hills region is defined with reference to the proportion of total land area shared by different land use categories. Five broad categories of land use such as arable land, forest, shrubland, grassland and other land have been determined. Arable land refers to the land being used for cultivation of cereal crops like rice, wheat, maize, millet, and vegetables, tea, fruit trees, etc. Forest lands include all lands having permanent forests and woodlands or trees with more than 10% crown cover (DRFS 1999). Shrub refers to bush, or degraded forest or secondary growth forest, where there are scattered trees standing, or to land with less than 10% crown cover. Grassland comprises meadows and pastures. Other lands include conurbations, roads, barren or bare land, water bodies, snow covered land, rock and ice. This definition broadly includes the social and economic purposes and contexts for whether lands are managed or left unmanaged. Change in land use type refers to those which occurred in three different mapping years: 1986, 1996, and 2010. The driving forces of land use change in the Koshi Hills include those factors which influence human activity, including local culture, economics, environmental conditions, and land policy and development.

The five broad categories of the land use as stated above have been based on the land use types found in the 1996 toposheet, defined by the Survey Department, a government agency of Nepal. Similar land use categories were also identified from the 1986 LRMP map sheet (KESL 1986), and 2010 Landsat images. These works were designed to calculate and compare changes in land use categories by location, over specified time periods. The rationale behind considering those broad land use types is that each of them has significant role to play in development and natural conservation in Nepal. For instance, forest contributes to rural development by providing forest products such as firewood, fodder, timber, and herbs to rural communities, as well as regulating atmospheric conditions. In addition, forests are also essential for sustaining agriculture and livestock (buffaloes, cows, and goats) rearing in the Koshi Hills. Arable land is a fundamental resource required to support the lives of majority of rural people. There is a close link between agriculture and forest resources. The former derives products from the latter such as fodder, leaf-litter, etc., to maintain nutrient levels and soil structure. Grassland has an immense role to contribute, not only to raising livestock such as cows, sheep, and yaks in the high mountains, but also to maintain the watershed.

This study has drawn data from both analog and digital map sources for those three mapping years. The 1986 map data has been considered as a benchmark year in terms of a spatial database of land use and land use change. As these different map sources have different map scales, such as 1:50,000 and 1:25,000, whereas Landsat imagery has 30-m resolution, a scale of 1:25,000 has been set as the base map for this study. In so doing, all map scales have been converted to this scale, i.e., 1:25,000.

As no analog data before the year 1986 was available at the district level in Nepal, the data from 1986 has been considered as the benchmark year for the spatial database and land use change. It is important to note that LRMP is the only available map data for the entire country. These analog map sheets prepared at 1:50,000 scale contain three datasets: land utilization, land capability, and land suitability. For the purpose of this study, land utilization was used. The 1996 data sets, prepared using two scales of 1:25,000 (for the Tarai and urbanized hill districts) and 1: 50,000 (for the mountain and rural hill districts) include *nine* digital data layers: land use and land cover, administrative boundary (VDC, municipality, and district), hydrography, contour, transportation, building footprints, utilities/facilities, national parks and protected areas, and place names. The imagery data was acquired from ICIMOD, Kathmandu, Nepal. Further, the Koshi Hills region also lacks reliable baseline household data, which is needed to comprehensively capture the complex relationships between land use change and its impacts on social and economic conditions.

4.2.2 GIS Mapping Approach

The GIS mapping approach to land use change in the Koshi Hills consists of four broad components of spatial data transformation: (i) preparation of digital data, (ii) processing of data, (iii) output (layers and tabular data), and (iv) interpretation. Here, map units refer to land mapping units or spatial units (polygon, line, and point) and each map unit refers to an area that possesses a degree of homogeneity in its physical characteristics.

The base map for the Koshi Hills study has been set at the 1:25,000 scale with all the map data of different scales, such as the LRMP data at 1: 50,000, the toposheet data at 1:50,000 and 1:25,000, as well as the 30-m resolution Landsat images being adjusted to the base scale of 1:25,000. The map unit at this base scale is approximately 2.5 ha. Therefore, the area of the mapping units below this threshold polygon were not detected for computation. However, an appropriate GIS function was used to carefully calculate these mapping units. Below is a description of the data transformation process adopted in this study:

- The LRMP analog datasets were scanned and processed into a compatible data form by adopting all the basic steps: geo-referencing, digitizing (missing features), topology building, editing, edge matching, appending, and map layouts in ArcGIS format.
- The 1996 toposheet digital data features such as river levels, road types, and contours required for the study were raw (unrefined) and therefore they were duly defined and edited.
- The ortho-corrected Landsat imagery from 2010 was processed thus re-projecting to the modified Universal Transverse Mercator coordinate system (adopted by the Survey Department of Nepal) through a re-sampling of <0.5 pixel resolution (equivalent to approximately 10–15 m), selection of training sites (based on in situ assessment provided by ground truthing work), creation of multiple signatures, identification and classification of land use and land cover by a maximum likelihood classifier, post-reclassification assessment (based on the existing land use, digital elevation model, and field data), and refinement of classification by filtering. The classification accuracy as explained by the Kappa statistics was 85.3%, which is above the minimum level of classification accuracy. The classification accuracy for land use and land cover data of other data sources was nearly 80% (NLUP 2016).
- Verification of land use type and land use change and its associated factors in the field was carried out across the Koshi Hills, but this field verification was limited only to areas accessed by roads. The attribute data available over time, from records or base data at district level, were limited and inconsistent. Field verification was carried out in two steps. First, consultation with personnel representing different district line agencies at each headquarters of the four districts was made to determine whether there was any change in land use types from those displayed on the GIS land use color maps generated in 2010. In advance of that, data and reports available from the districts were also acquired. Second, key features such as newly built feeder roads, commercial vegetable growing areas, cardamom and *Amreso* lands (broom grass), abandoned arable land patches, hāt (weekly) bazaars, health services, and place names were verified by location visits. Verification was assisted by using GPS equipment with 3-m resolution, toposheets from 1996 (in color as reference maps), as well as by talking to people from the local area by using RCA. Changed land use features on land use layouts were updated via computer. Final layouts to the district level were prepared for viewing on a GIS platform.

- The spatial attribute data on the population and the production of major agriculture crops including off-season vegetables, cardamom, and ginger as well as other materials such as non-timber forest products (e.g., herbs) and wood, were gathered for GIS from different sources (publications, documents, reports, statistical and digital data, and maps) from the districts, municipalities, and from non-governmental and private organizations. Integration of the attribute data related to land use at the district level was made based on a standard coding system from the Central Bureau of Statistics (CBS). These were made to spot changes in the land use pattern and identify gaps to help explain the key factors responsible behind land use change, in addition to changes in the social and economic conditions of the people of the study region.
- The GIS overlay function was also used to determine changes and relationships in the selected features such as land use, population versus altitude, and facilities versus distance.
- Change in land use categories was computed using the overlay function between a two consecutive years, such as: (i) 1986 and 1996 and (ii) 1996 and 2010. The magnitude of change in land use categories was determined at four levels (as a percentage), such as: <25, 26–50, 51–75, and >75, based on the mappable polygon size.
- The map layouts of land use category for three years, i.e., 1986, 1996, and 2010, were prepared following standard colors, and other GIS functions such as buffer and overlay were employed wherever feasible and suitable. Therefore, the land use study of the Koshi Hills was also based on these three data point years: 1986, 1996, and 2010. The dot method was used to depict the distribution of population, with one dot representing 50 people. The location of the dots was placed carefully on the map, with respect to population and area of VDCs and municipalities within each district, but avoiding water bodies, forests, rocky areas, sloppy, and snowy area. The relationship between altitude and population concentrations was obtained by defining the altitudes at contour intervals of 1,000 m and population distribution by representative dots for two years: 1986 and 2010. The population censuses of 1981 and 2001 were used accordingly.

4.2.3 Background Description of the Study Area: The Koshi Hills of Nepal

The physical settings of the study region offer a starting point for land use analysis. Spatial extent of administrative districts, and therein social and economic factors, and facility infrastructure accessibility also either directly or indirectly affect land use change.

4.2.3.1 Administrative and Physical Settings

The Koshi Hills comprises four districts considered as administrative units: Bhojpur, Dhankuta, Sankhuwasabha, and Terhathum, all belonging to the eastern region of Nepal (Fig. 4.1). This region covers 6557 km^2: 3480 km^2 for Sankhuwasabha; 679 km^2 for Terhathum; Bhojpur (1507 km^2); and Dhankuta (891 km^2). The region shares 4.4% of the country's total land area (147,181 km^2). The Koshi Hills neighboring districts are Morang and Sunsari in the south Tarai (Plain) region and Ilam and Khotang, both hilly regions, in the east and west respectively. These neighboring districts have linkages to land use change in the Koshi Hills.

The Koshi Hills region has rugged topography that presents a maze of spurs and valleys; the elevation of which ranges from 300 to over 8000 masl. The hills consist of *Mahabharat Lekh* and *Pahar* traversing from east through to west (Fig. 4.2). In between these are a number of narrow longitudinal river valleys such as the *Arun* and the *Tamur* and several *Tars*, which are extensively cultivated through terrace farming. The main mountains or Himalayas are confined to its northern part, extending up to the Tibetan border, and include most of northern Sankhuwasabha. This belt also consists of rolling pastureland, known as "*Kharka*" where sheep and

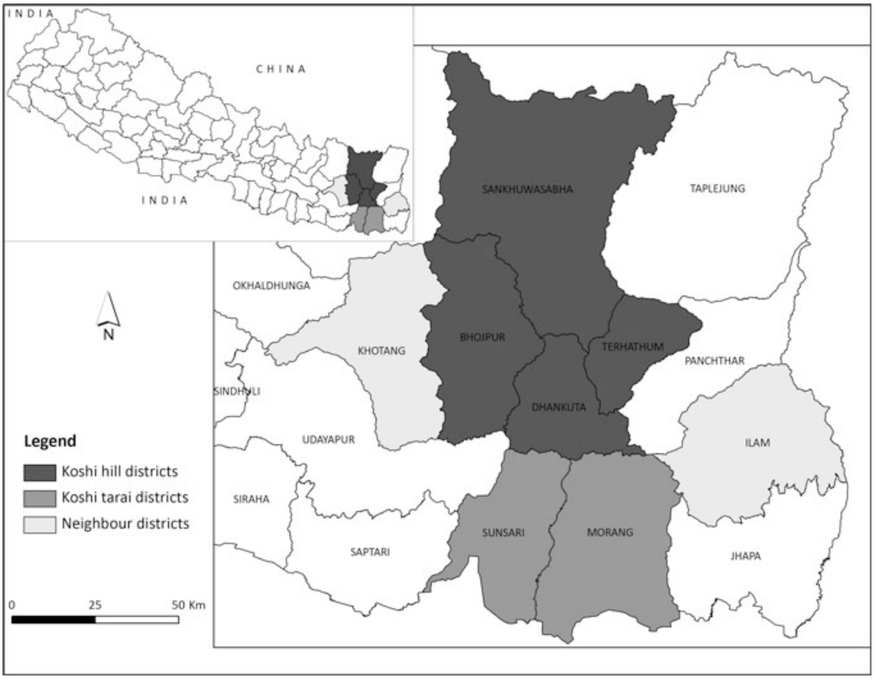

Fig. 4.1 Koshi Hills region, Eastern Nepal

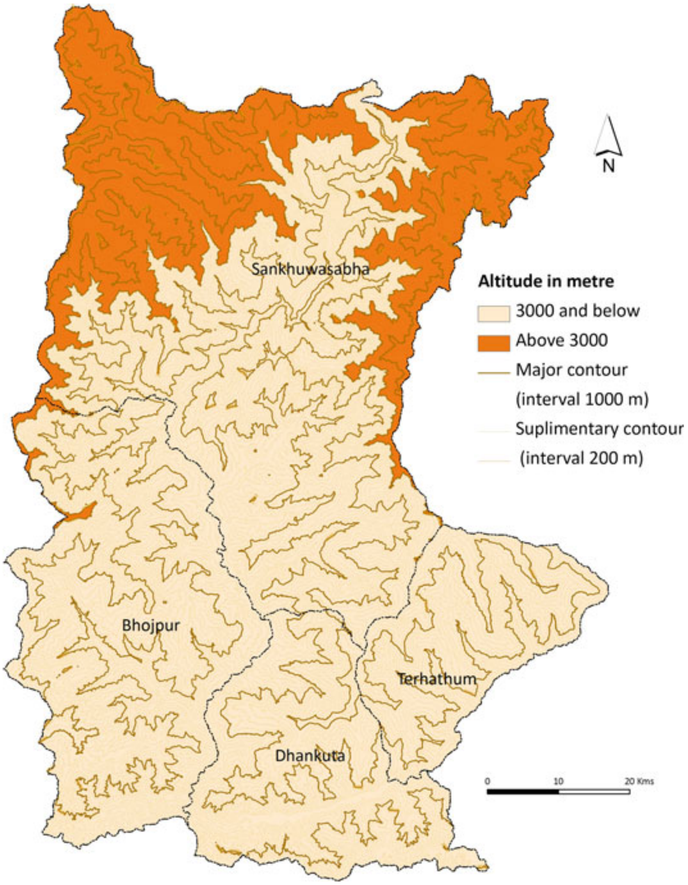

Fig. 4.2 Relief (contours) across the study area

yaks graze. There are historically important trading routes leading to Tibet through the passes.

The Koshi River, the largest river in Nepal, drains the study region. It is composed of three main tributaries such as the Arun, the Sunkoshi, and the Tamor (Fig. 4.3). Of these, the Arun has largest catchment area. Over 80% of the annual precipitation of 1500 mm occurs during the monsoon season (June–September). Broadly speaking, the mean temperature increases from north to south and the rainfall decreases from east to west. While the moist sub-tropical climate prevails in the southern half of the Koshi Hills, a temperate climate and tundra-type climate are found in the northern part of the Koshi Hills.

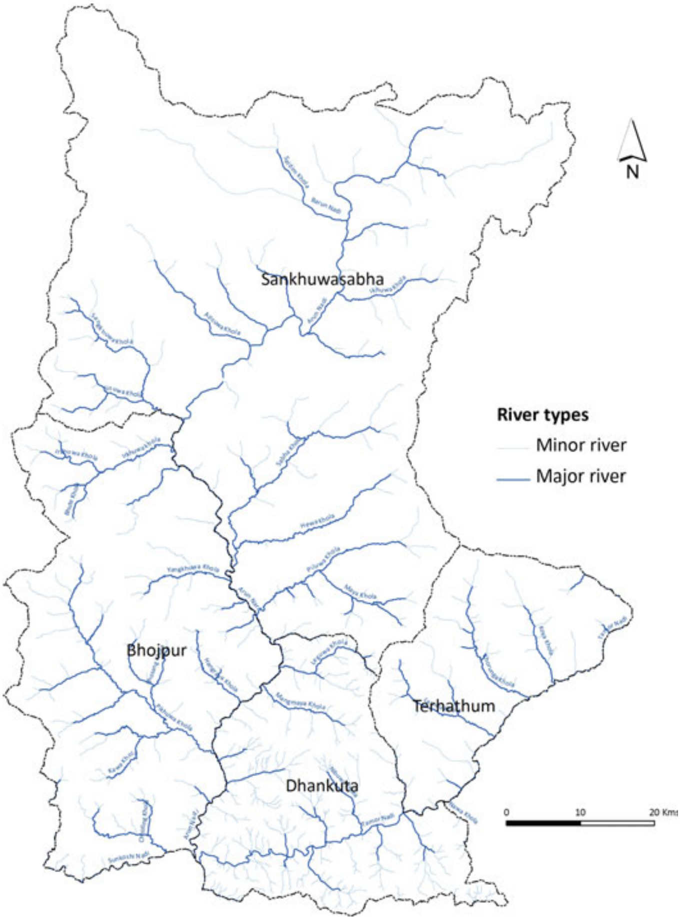

Fig. 4.3 Drainage systems of the study area

4.2.3.2 Demographic Settings

The 2011 census provided a total population of 609,407 to the Koshi Hills, accounting for 2.3% of the country's total population. There is overall a negative growth rate of −0.52%, unlike the national population growth rate of 1.4% during 2001–2011. This is seen primarily in three districts—Bhojpur, Dhankuta, and Terhathum. The average population density of the Koshi Hills is 93 people per square kilometer. The distribution of population across the Koshi Hills is concentrated in the low terraces, river valleys, and along the roads. There has not been remarkable change in the population distribution patterns between 1991 and 2001 (Figs. 4.4 and 4.5). Females surpass males and over half the population fall within the 15–59-year age group, something which has been consistent since 1971.

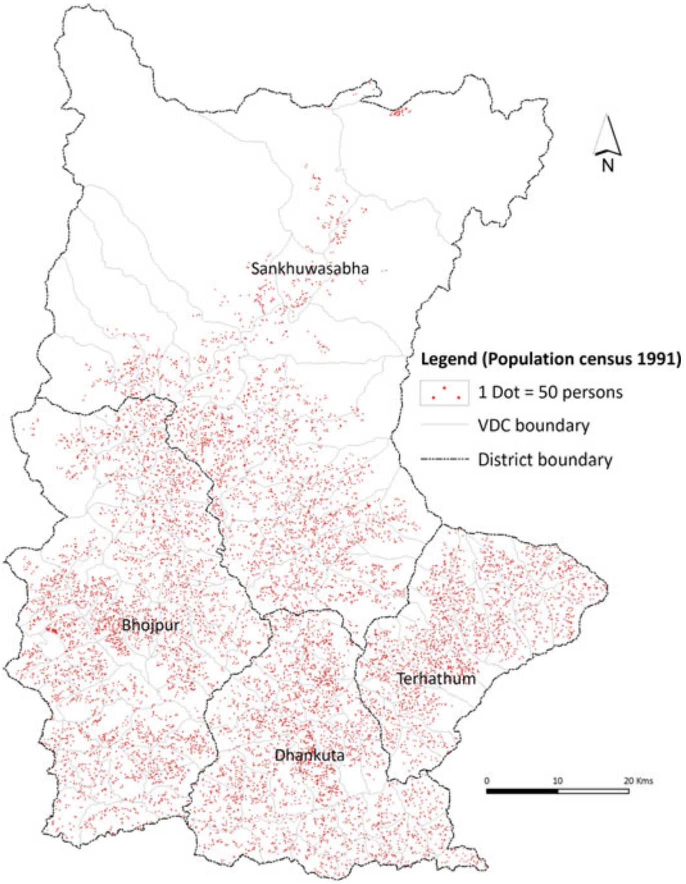

Fig. 4.4 Population distribution in 1991

The Rais and the Limbus are the indigenous inhabitants of the region and other major groups are Chhetri, Bahun, and Tamang.

Historically, there has been a tendency of flow of people from the hills to the Tarai in the eastern region. For example, the 1981 census recorded a net loss of 0.68 million from the hills and mountains, while the Tarai gained 0.69 million. During the same census year, 67% of in-migrants in the eastern Tarai were born in the eastern hills. In the Koshi Hills, the population migrating out (absent population) has increased from 3.1% in 1991 to 8.4% in 2001.

4.2.3.3 Economic Settings

Agriculture is the predominant activity in the Koshi Hills, though the population engaged in this sector has decreased from 98% in 1971 to 76% in 2001, which is far

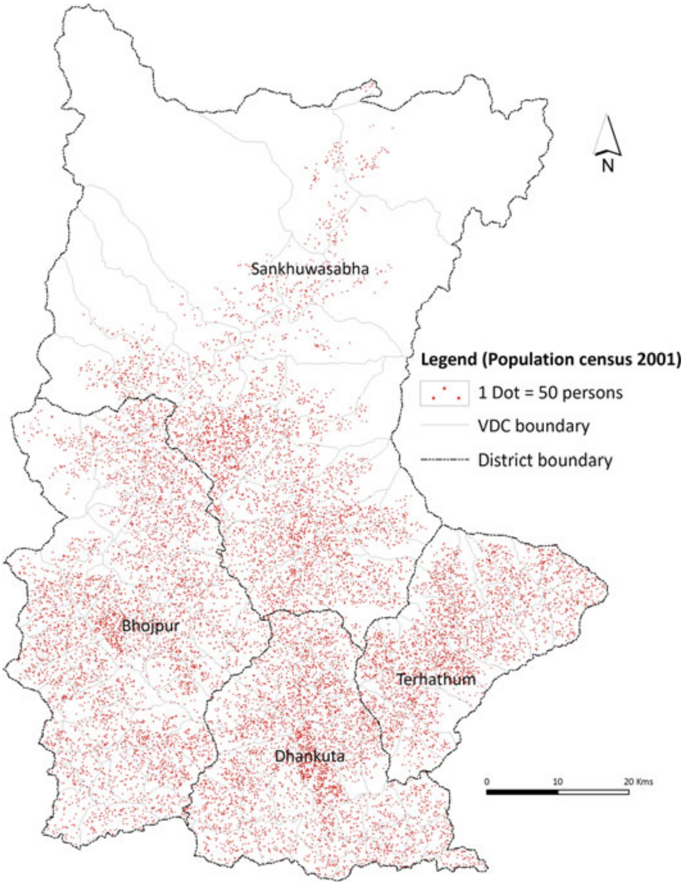

Fig. 4.5 Population distribution in 2001

higher than the national average (60% in 2001). The agricultural system is predominantly of subsistence in nature, except in few areas accessed by roads where intensive cultivation of vegetables is being practiced.

According to the Nepal Living Standard Surveys (NLSS), poverty has declined from 38.9% in 1995/1996 to 21.4% in 2010/2011 in the eastern region, which is the lowest among other regions (Central, Western, Mid-Western, and Far Western) of Nepal. Studies reveal that one of the main drivers of poverty reduction is the rise in the number of households (about 56%) receiving remittance, as well as increased remittance amounts. The NLSS III indicated that the number of people in poverty actually increased by 19% in the rural eastern hills area in 2010/2011, as compared to 42.9% in 2003/2004 and 36.1% in 1995/1996.

The manufacturing sector in the Koshi Hills is primarily based upon local raw materials and products. Each of the four districts of the Koshi Hills is characterized by its unique products such as tea from the tea estates in Dhankuta, Dhaka (cotton cloth) in Terhathum, Allo (a kind of NTFP) in Sankhuwasabha, and paper in Bhojpur. In 2011, a total of 1774 products were registered, mostly the indigenous products such as textiles (*Dhaka*, *Allo* cloths) and handicrafts (bamboo products, embroidery products). The Dhankuta and Terhathum districts were included within "Tea Zones" by the government in 1982. Government policies in recent years have been concerned with treating tea as an export commodity. In addition, various user groups and associations related to milk, vegetables, live animals, retail outlets, wholesale, etc., have emerged in recent decades promoting internal marketing systems. However, market access has been the main hurdle due to limited market places and a lack of access roads and price and market information network, etc.

Highways have opened up links for local produce with the large cities of Dharan and Biratnagar in the Tarai as well as with other places across the country and also with India. Yet, the economic structure of the towns in the Koshi Hills is dominated by the agricultural sector, engaging 55–67% of the active population, while only 13–16% is engaged in the commercial sector (in 2001).

Trading activity is conducted through two market centers in the Koshi Hills. First is the network system of temporary traditional market places, locally known as hāt bazaars (Fig. 4.6), which are located at convenient distances from the villages across the region. They operate markets for basically local products as well as imported goods and are open all days of the week. These markets appear to be crucial to the articulation of rural societies, as well as to act as a stimulus for integrated regional market network systems. Hāts are by far the most important marketing agents in terms of volume of trade. The distribution of *hāts* exhibits a spatio-temporal pattern, i.e., *hāts* are held at different places, as well as on different days of a week. There are altogether some 66 hāts across the Koshi Hills, with a density of 1 hāt for every 100 km^2. This density is changing due to improvements in roads and transport, commercialization of agricultural production, increases in population density, etc. However, settlement distribution is quite dispersed, with 2.1 settlements for every 100 km^2. Approximately 70% of the population live at an elevation zone between 1000 and 2000 m. The authors feel that this needs to be changed towards an agglomeration at feasible places for delivering basic infrastructure and therefore improving commercial activities.

The second type of market system are the permanent market centers with various hierarchical levels ranging from district headquarters towns to small centers, all mostly connected by roads. Their growth can be categorized under two broad factors such as external trade and internal trade. The former is greatly affected by the geographical position of Nepal with respect to its neighboring countries. This in turn affects internal trade, with the change in growth of the commercial sector being made in terms of a national trade policy, trade patterns, town and market centers, and marketing structures for local products.

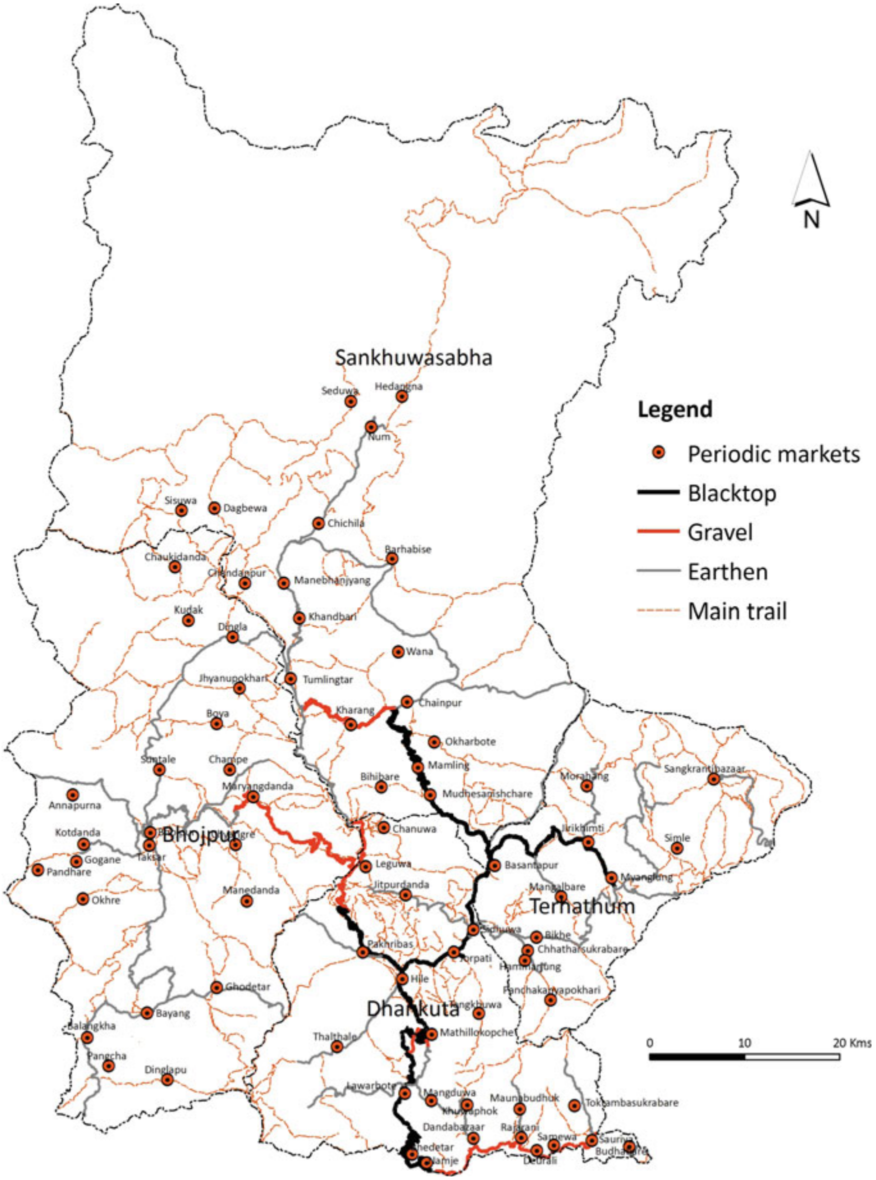

Fig. 4.6 Location of hāt bazaars

4.2.3.4 Accessibility of Facilities

The Koshi Hills saw roads for the first time in 1982 and only in 2007 were all four district headquarters connected by a network totaling 934 km. The Koshi Highway, also known as the Dharan-Dhankuta Highway, is the main thoroughfare that

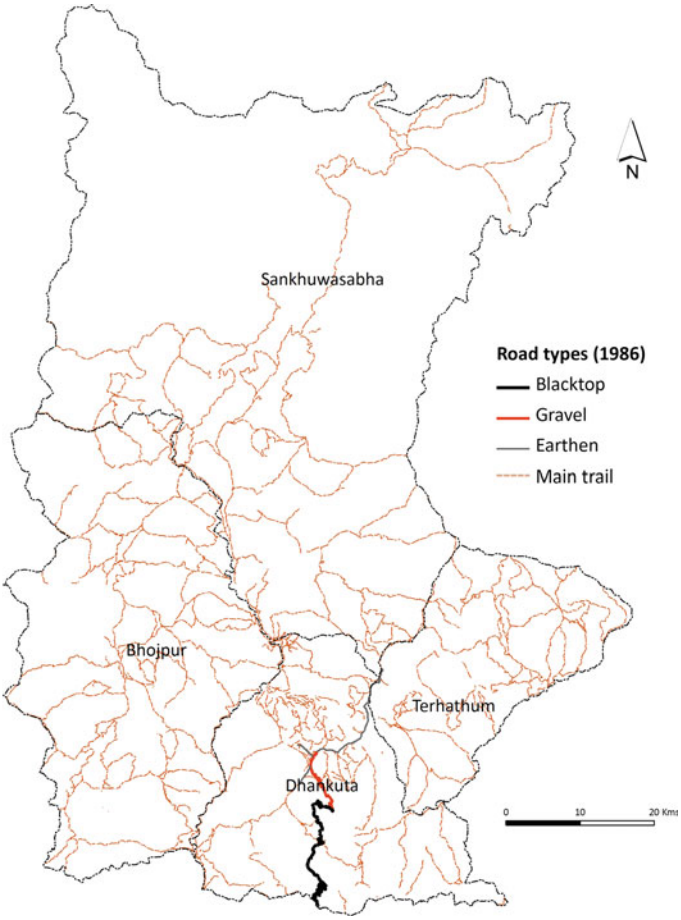

Fig. 4.7 Types of road and major trails, 1986

connects the Koshi Hills with the Tarai region and other major places across the country, as well as the bordering cities of India. There has been drastic change in the road and trail networks in the Koshi Hills over the past 24 years (Figs. 4.7 and 4.8). The average road density was 14.2/100 km^2 in 2010, increasing from 9.1/100 km^2 in 2007. Bhojpur and Sankhuwasabha have a relatively poor road density below 7.7/100 km^2. However, these two districts are also linked by an air service with Kathmandu (national capital city) and Biratnagar (regional city of the eastern Tarai region). In areas of the Koshi Hills where there are no roads, traditional highways such as trail networks and bridges are crucial. There are about 1093 km of trails and 231 trail bridges in the Koshi Hills region.

Energy consumption and sanitation and health indicators can be taken to measure the social condition of the households in the Koshi Hills. Fuel wood is the

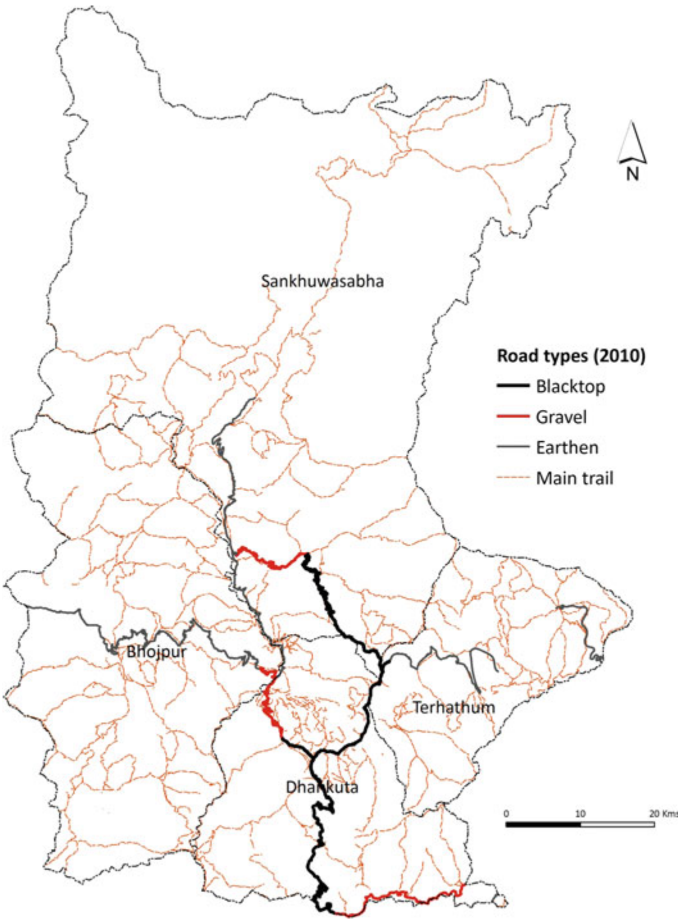

Fig. 4.8 Types of road and major trails, 2010

major source for cooking in the area, with 91% of households depending on it. Kerosene is the next important fuel, with 74% of households using it for lighting. Although availability and costs are two of the important factors associated with the use of fuel wood, the demand for it directly affects forest coverage. Further, there is a health cost associated with the use of fuel wood, with smoke released from burning solid fuels causing respiratory problems. It has been reported that this is one of the causes of respiratory illness amongst the women and children across rural areas of Nepal.

In the Koshi Hills, 67% of the households have access to tap water and 56% of households have toilet facilities. As elsewhere in other parts of the country, health facilities such as hospitals, primary health care centers, health posts, and sub-health posts provide health services to the people in the Koshi Hills (Fig. 4.9). However,

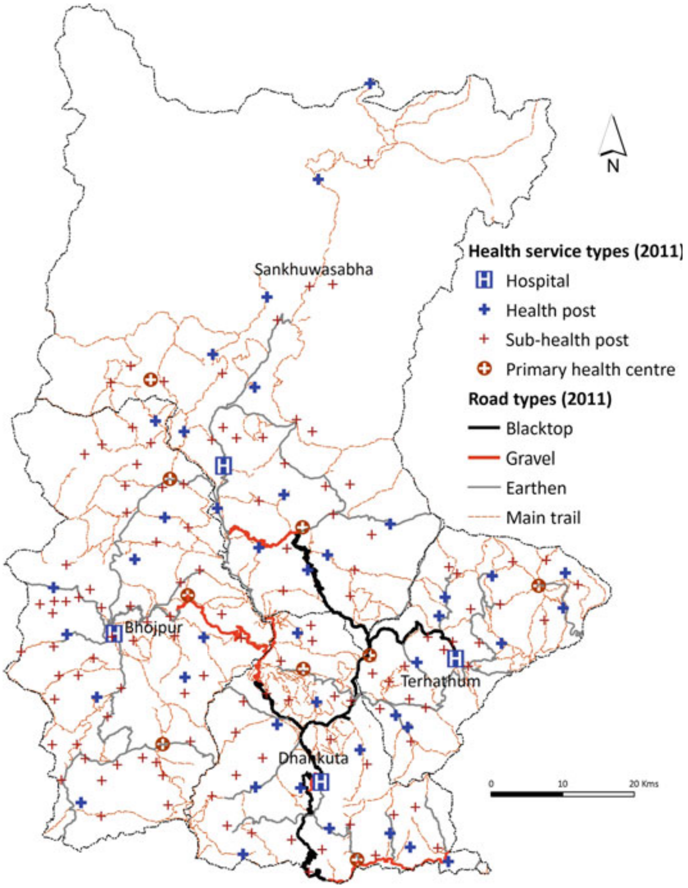

Fig. 4.9 Location of health services, 2011

health services are poor in the Koshi Hills. Residents' life expectancy, as a health indicator, was 65 in 2004, showing an improvement from 63 in 1998. These, however, were above the national average. Poor health service in the Koshi Hills is often due to an absence of health personnel, lack of medicine, etc. Topping these reasons is the distance to, and inconvenient location of, health facilities from village settlements, which are scattered across the hills and mountains.

Adult literacy, one of the human development indicators, is better in the area than in other parts of Nepal. In the Koshi Hills, the adult literacy was about 52% in 2004, having improved from 44% in 1998, compared to 49% and 37% for Nepal in both years. Among the four districts, Terhathum had the highest HDI, ranked 10th (amongst the 75 districts), while Bhojpur had the lowest, ranked 32nd. The location of schools is concentrated in areas where there is agglomeration of population

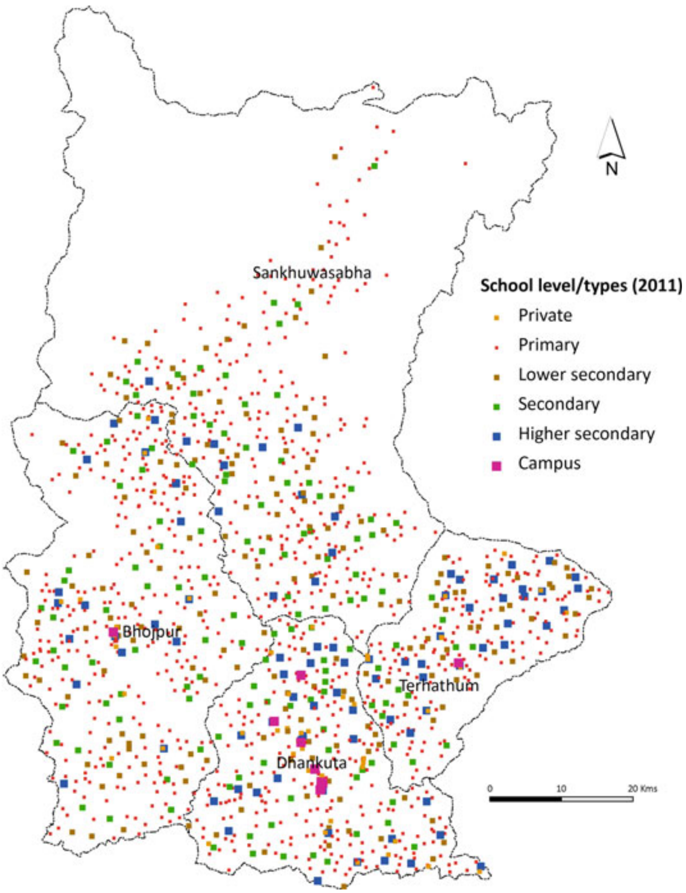

Fig. 4.10 Location of schools by academic level, 2011

clusters (Fig. 4.10). In terms of per capita, the Koshi Hills area (1152 PPP) is poorer than the average in Nepal (1310 PPP).

Local government units such as the VDC and the Municipality are responsible for local level administration, planning, and managing local development projects within their own jurisdiction boundaries. They are also responsible for coordinating all other development activities. In addition, there are a number of donor and multi-lateral agencies. Furthermore, each district has a Chamber of Commerce and Industry (CCI) that looks after business and industrial activities. Most of the non-governmental organizations (NGOs) are found working in forestry, drinking water and sanitation, womens' empowerment, savings, credit, and group mobilization. The NGOs working in the sectors have received support from different national, foreign, and international agencies. Many decades ago there existed user groups that played roles in local development in the Koshi Hills region.

4.3 Results and Analysis

4.3.1 Land Use and Change

4.3.1.1 Spatial Distribution of Land Use in 2010

Of the five major land use categories in the Koshi Hills, forest has by far the largest coverage with about 47%. Next is arable land, sharing nearly 30%. So, these two have a combined coverage which occupies the dominant position regarding land use categories, accounting for over three-quarters of the Koshi Hills total area in 2010. These two categories also dominated in the previous two mapping point years, i.e., 1996 and 1986 (Table 4.1; Fig. 4.11).

Spatially, the distribution of the two major land use categories—forest and arable land—varies among the Koshi Hills four districts. Arable land generally is confined to river basins and the lower and middle slopes of the hills, whilst forest occupies the areas around the riverbanks characterized by a hot summer climate, as well as the high and steep slopes of the mountains and hills. At the individual district level, forest is the largest natural resource in terms of areal coverage in Bhojpur and Sankhuwasabha, whereas arable land is the most important resource in terms of areal coverage in Dhankuta and Terhathum. In 2010, the former two districts had a forest coverage of 46 and 51% respectively, while in the same year the latter two districts had over 46% arable land coverage (see Table 4.3). This juxtaposing distribution pattern of forest and arable land among the districts is mainly due to terrain variation. Figure 4.3 shows that Bhojpur and Sankhuwasabha have a relatively larger proportion of mountains with high altitudes, whereas the terrain of Dhankuta and Terhathum is composed largely of low mountains.

4.3.1.2 Land Use Change from 1986 to 2010

The spatial distribution of land use and land cover categories in the Koshi Hills for three years: 1986, 1996, and 2010 is depicted in Figs. 4.12, 4.13 and 4.14 respectively. Land use ratios have changed in the Koshi Hills over the past 24 years

Table 4.1 Distribution of land use categories by year in the Koshi Hills area

Land use categories	1986		1996		2010	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Arable	199,404	30.4	219,688	33.5	196,400	29.9
Forest	259,366	39.5	245,918	37.5	307,154	46.8
Shrubland	60,541	9.2	61,946	9.4	11,544	1.8
Grassland	59,254	9.0	20,718	3.2	36,216	5.5
Others	77,551	11.8	107,846	16.4	104,802	16.0

Sources LRMP 1986, toposheet 1996, and Landsat imagery 2010

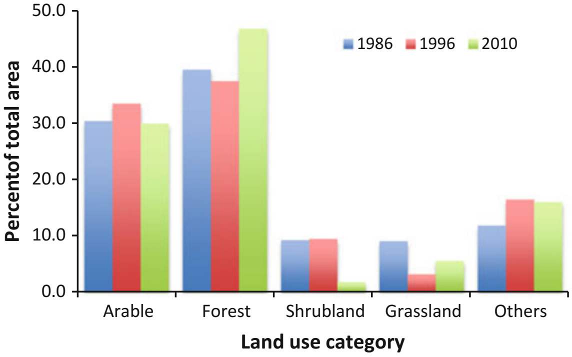

Fig. 4.11 Coverage of land use category by year in the Koshi Hills area

(Table 4.2). These changes present different features at two levels: the Koshi Hill region as a whole and the individual districts of the Koshi Hills. These are described in the following text.

First, of all land use categories, arable land and forest land show remarkable changes in the Koshi Hills. There was a 10.2% increase in arable land between 1986 and 1996, while there was a decrease of 5.2% in forest during the same time period (Table 4.2). In contrast to these changes, arable land decreased by 10.6%, while forest saw an increase of 25% in 2010, as to 1996. By 1996, forest coverage decreased to 37.5% while arable land increased slightly to 33.5%, however, forest coverage sharply increased to 46.8% in 2010 while arable land coverage reduced to 29.9% in the same year. The coverage of shrubland remained at around 9% in 1986 and showed little change in 1996 but declined sharply to 1.8% in 2010. Grassland experienced a decrease from 9% in 1986 to 5.5% in 2010. Other land uses comprising water bodies, snow land, bare land, rock and ice, built up land, and roads shared 11.8% in 1986 and rose to around 16% in the following two mapping point years.

Over the past 24 years, the area of arable land decreased by 1.5% while that of forest increased by 18.4% in the Koshi Hills. But a remarkable change has occurred in shrubland and grassland over the past 24 years. Table 4.3 depicts that the grassland declined by 65% during the decade of 1986–1996, but increased by 75% between 1996 and 2010. During these latter years, shrubland declined by 81.4%. Thus, over the past 24 years (1986–2010), shrubland and the grassland declined by 81 and 39% respectively.

Second, land use change at a district level presents different features from those at the Koshi Hills regional level. In 1986, arable land comprised 52% in Dhankuta but decreased to 48.4% in 2010. However, arable land in Terhathum decreased continuously over that 24-year period. Changes occurred in arable land cover in Bhojpur and Sankhuwasabha with similar patterns, i.e., first increasing and then decreasing. For instance, arable land in both districts occupied the largest area with 49 and 17% respectively in 1996. It was less that this in 1986 as well as in the subsequent year of 2010. The pattern of change in forest land in Bhojpur and

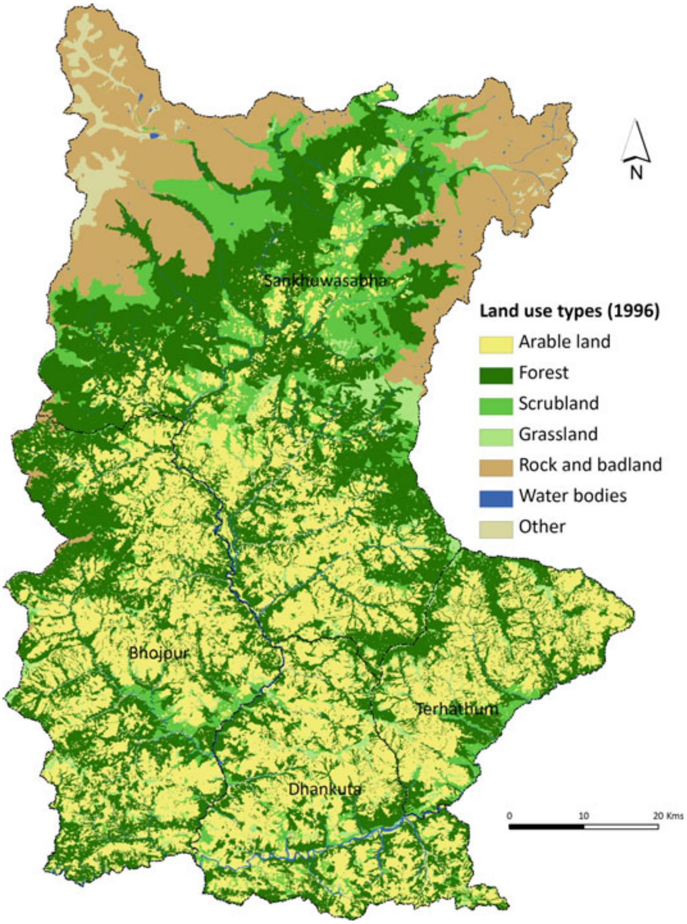

Fig. 4.12 Land use map for 1986

Sankhuwasabha appears to be the same; first decreasing and then increased (see Table 4.3). In 1996, forest occupied the lowest coverage at 42.5 and 36.8% respectively in both districts. By 2010, this coverage rose substantially to around 51% in Sankhuwasabha and 46% in Bhojpur. Terhathum has shown a continuous increase in forest coverage in all three mapping point years. On the whole, there was an increase in the forest coverage in all three districts except Bhojpur over the past 24 years.

Third, it is interesting to note that the overall patterns of change are differential among the land use categories in the Koshi Hills. Three distinct patterns of change are discernible from the information in Table 4.3. The year 1996 seemed to be crucial for coverage of arable, forest, grassland, and "other land". First, the relative share of arable land and "other land" in that year was the highest in the Koshi Hills

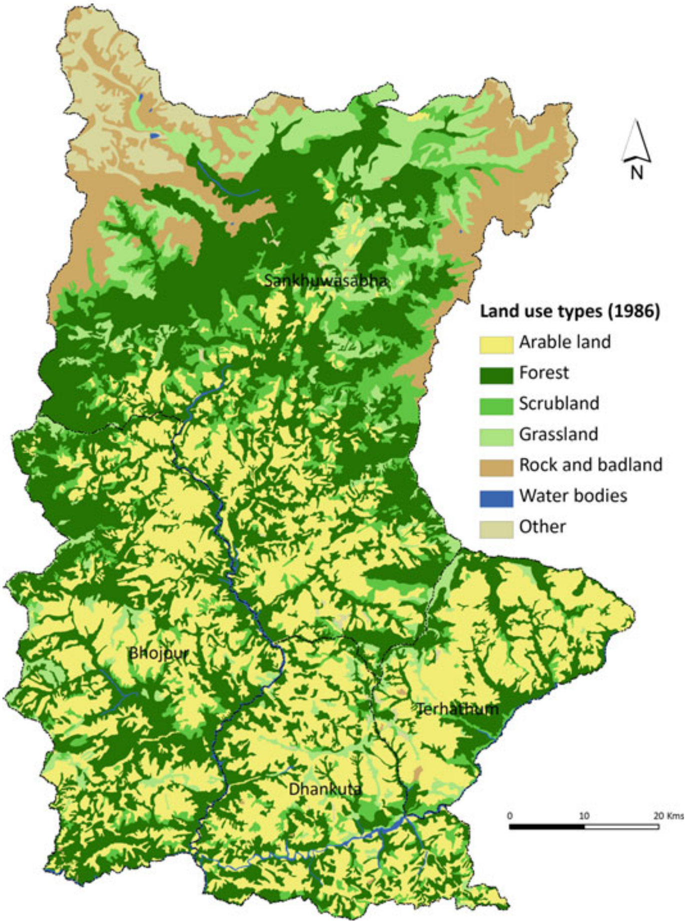

Fig. 4.13 Land use map for 1996

and then both declined before 1986 and after 2010. Second, on the other hand forest land and grassland had the lowest share in relative terms in the Koshi Hills in 1996 and then increased in both years—after and before 1996. Third, the relative share of shrubland constantly decreased in the Koshi Hills from 1986 to 2010.

Fourth, there also exists a distinctive differential manner of change, with different magnitudes, in the land use categories at individual district levels in the Koshi Hills during the past 24 years. For instance in Terhathum arable land has continually declined, while forest land has shown a reverse trend, i.e., continually increased. Conversely, there is a different pattern of change in land use categories in the districts of Bhojpur, Dhankuta, and Sankhuwasabha. In these three districts, the year 1996 seemed to be crucial. The arable land and "other land" occupied the highest relative share in 1986 having shown a declined both before and after that year, while the coverage of forest and grassland was the lowest in 1996, but

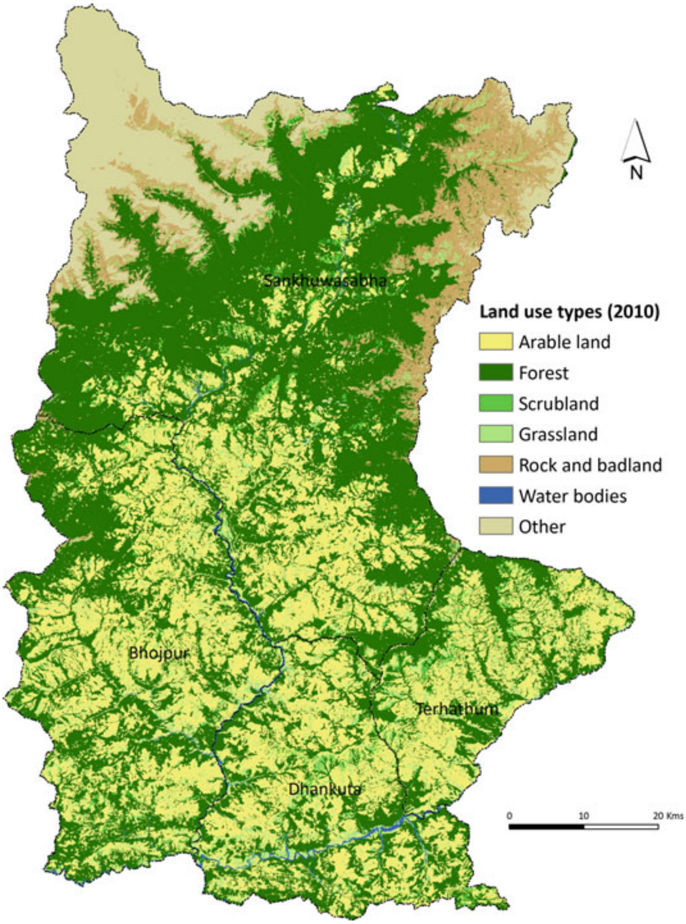

Fig. 4.14 Land use map for 2010

Table 4.2 Magnitude of change (%) in land use categories by year in the Koshi Hills

Land use categories	1986–1996		1996–2010		1986–2010	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Arable	20,284	10.2	23,288	−10.6	3004	−1.5
Forest	13,449	−5.2	61,236	24.9	47,788	18.4
Shrubland	1405	2.3	50,402	−81.4	48,997	−80.9
Grassland	38,536	−65.0	15,498	74.8	23,038	−38.9
Others	30,295	39.1	3044	2.8	27,251	35.1

Sources LRMP 1986, toposheet 1996, and Landsat imagery 2010

Table 4.3 Magnitude of change (%) in land use category in the Koshi Hills, 1986–2010

Land use type	Year	Bhojpur	Dhankuta	Sankhuwasabha	Terhathum	Relative share (%)
Arable	1986	42.7	52.0	14.5	55.7	30.4
	1996	49.0	52.6	17.0	53.0	33.5
	2010	44.5	48.4	15.6	46.3	29.9
Forest	1986	46.0	33.9	39.6	31.8	39.5
	1996	42.5	30.6	36.8	36.2	37.5
	2010	45.8	38.6	50.8	39.5	46.8
Shrubland	1986	5.3	7.0	12.4	4.9	9.2
	1996	3.9	4.9	13.9	4.9	9.4
	2010	1.6	2.2	1.5	3.0	1.8
Grassland	1986	4.8	4.4	12.7	5.7	9.0
	1996	2.3	3.0	3.2	4.7	3.2
	2010	6.7	8.7	3.3	10.1	5.5
Others	1986	1.1	2.6	20.8	1.9	11.8
	1996	2.3	2.6	29.1	1.2	16.4
	2010	1.4	2.2	28.8	1.1	16.0
Total area (ha)		152,325	89,854	346,896	67,040	656,115

Note Values were derived from land use GIS maps
Summation of the values of the five land use categories along the row of each district for a single year gives 100%, e.g., 42.7 + 46.0 + 5.3 + 4.8 + 1.1 = 100

increased in both years—1986 and 2010. In regard to shrubland, there was a declining trend in three districts, Bhojpur, Dhankuta, and Terhathum from 1986 to 2010, but in Sankhuwasabha shrubland coverage was highest in 1996 showing a decline in the other two years.

Fifth, there is some association between land use change and elevation zones in the Koshi Hills. The distribution of arable land is confined mainly to below 3000 m, whereas all other categories of land use are distributed across all elevation zones to varying magnitudes (Table 4.4). A preponderant proportion of arable land with over three-fifths appear to be concentrated in the elevation zone of 1000–2000 m and this together with the proportion of the arable land lying below the 1000-m zone represents over 92% of the total arable land. Only a small proportion of arable land is available within the 2000–3000-m zone, above this zone no arable land exists due to an unsuitable climate. Forest is found in relatively greater proportions in the 2000–3000-m zone; shrubland in the 1000–2000-m zone; grassland within the 1000–3000-m zone, and "other land" uses in the zone above 4000 m. In the latter case, snow land, bare land, and rock and ice are dominant land use units.

Changes in land use categories by elevation zones are minimal over time. This is true in the case of arable land and forest coverage. For instance arable land decreased by 4% in the 1000–2000-m zone between 1986 and 2010, while forest

Table 4.4 Share of land use categories according to elevation zones in the Koshi Hills

Elevation class (m)	Percentile share of total land by land use category by year														
	Arable			Forest			Shrubland			Grassland			Others		
	1986	1996	2010	1986	1996	2010	1986	1996	2010	1986	1996	2010	1986	1996	2010
<1000	30	30	31	28	25	23	15	19	13	4	10	34	7	6	4
1000–2000	65	63	61	28	31	30	36	27	70	20	29	41	1	1	1
2000–3000	5	7	7	32	35	33	20	19	8	31	44	11	1	1	2
3000–4000	0	0	0	11	9	13	25	27	8	18	15	6	4	15	15
>4000	0	0	0	1	0	1	4	7	1	27	3	8	87	76	77

decreased by 5% below the 1000-m zone over the same two years. There has been a substantial increase in the shrubland in the 1000–2000-m zone, with 70% in 2010, up from 36% in 1986, but a large decrease in two zones: 2000–3000 and 3000–4000 during the same years. A pronounced change has occurred in grassland in all elevation zones; its substantial share increased in 2010 compared to 1986 in two zones: <1000 and 1000–2000, while its share decreased in 2010 compared to 1986 in all remaining three zones above 3000 m. There has been a decreased share in "other land" uses in 2010 compared to 1986 in the >4000-m zone, as opposed to its share in the 3000–4000-m zone, where it increased between those two years. It appears that there exists internal trading between land use categories over time. As no adequate evidence exists, it should be therefore be a topic for future investigation.

Last, there exists internal trade-off between land use categories, analyzed through the matrix table. Table 4.5a shows that an increase in arable land at 10.2%, between 1986 and 1996, appears to be largely by encroaching upon forest land (7.8%) with small encroachments into the other three land use categories. Likewise, an increase in shrubland during the decade 1986–1996 was assumed to be due to a loss of forest land. Table 4.5a also shows that arable land and shrubland are the two major land use categories to consume most of the forest land during 1986–1996. The decreased in these two land uses—shrub land and grassland—could be linked to the increase in the forest coverage in Sankhuwasabha. This increase in "other land" might be due to a decrease in arable land, shrubland, and grassland. Table 4.5b shows that the decrease in arable land during 1996–2010 was due to a conversion of this land to grassland (7.2%) and forest and scrubland. During that decade, the increase in forest land appears to be contributed to largely by shrubland, followed by grassland and the arable land. This is because all the latter three land use categories were found to be declining significantly. Thus, during the past two and half decades (1986–2010), forest land appears to be increasing by encroaching upon shrubland, grassland, and arable land. An increase in "other land" use, mainly due to an encroachment upon forest, arable, and grassland might be due to the construction of roads, expansion of settlement clusters and institution buildings, etc. (Table 4.5c).

Arable land increased at the cost of decreased forest land during 1986–1996. This might be due to the expansion of cultivated land over the forest area by a practice of slash and burn farming within local tribal communities, an expansion of commercial farming into the land pockets lying along road sides, and/or the establishment of tea estates (Fig. 4.15). Patches of arable land have been turned into shrubland and grassland, which might be due to abandonment of cultivated land. The locations of abandoned cultivated land patches (shown by points due to un-mappable and scattered patches, Fig. 4.16), based on field observations are scattered across the Koshi Hills, most likely due to an increase in out-migration of labour force. This can be verified by the fact that there was a decrease in population of 8.4%, on average, of the total population in the Koshi Hills in 2011 (CBS 2012). Thus, during the past two and half decades, only forest land has increased at a significant rate while the other three land use categories—arable land, shrubland,

Table 4.5 Matrix of relative changes ($) of land use categories in the Koshi Hills

Land use categories	Change (%) in land use categories					Total	
	Arable	Forest	Shrubland	Grassland	Others	Area (ha)	(%)
(a) 1986–1996							
Arable	0.0	–2.7	0.5	–11.2	7.1	20,276	10.2
Forest	7.8	0.0	1.0	–11.9	8.2	–13,439	–5.2
Scrubland	1.4	–1.6	0.0	–16.4	21.0	1403	2.3
Grassland	0.7	–0.3	0.3	0.0	2.8	–38,536	–65.0
Others	0.3	–0.6	0.4	–25.4	0.0	30,295	39.1
(b) 1996–2010							
Arable	0.0	20.5	–7.6	13.4	–0.2	–23,288	–10.6
Forest	–1.6	0.0	–53.1	41.0	–1.9	61,236	24.9
Scrubland	–1.8	1.6	0.0	4.8	–0.1	–50,402	–81.4
Grassland	–7.2	1.8	–4.5	0.0	–0.7	15,498	74.8
Others	0.0	1.0	16.2	15.6	0.0	–3044	–2.8
(c) 1986–2010							
Arable	0.0	13.2	14.7	6.8	6.4	–3004	–1.5
Forest	0.9	0.0	51.2	16.7	18.3	47,788	18.4
Scrubland	0.1	1.0	0.0	1.0	1.0	–48,997	–80.9
Grassland	0.5	2.0	3.9	0.0	9.3	–23,038	–38.9
Others	0.0	2.3	11.1	14.5	0.0	27,251	35.1

and grassland—have decreased at different rates. It is evident from Table 4.5c that forest land, found to be increasing, consumed mostly shrubland, grassland, and arable land.

4.3.2 *Driving Factors of Land Use Change*

Land use change can be considered as a proxy indicator of development impact. Change in land use is a function of multiple factors or drivers and so it is difficult to explain the "change" as a consequence of a single driving force. Here, efforts are being made to explain the driving forces of land use change under major groups.

4.3.2.1 Development Planning Efforts

In Nepal, development efforts concerned with the better living conditions of people, by providing different facilities and services, have been initiated through national periodic plans. The first national five-year plan was initiated in 1956 and the current plan is the 11th plan. Economic growth has been the main target of each national plan. In addition, focuses also have been given to development approaches like

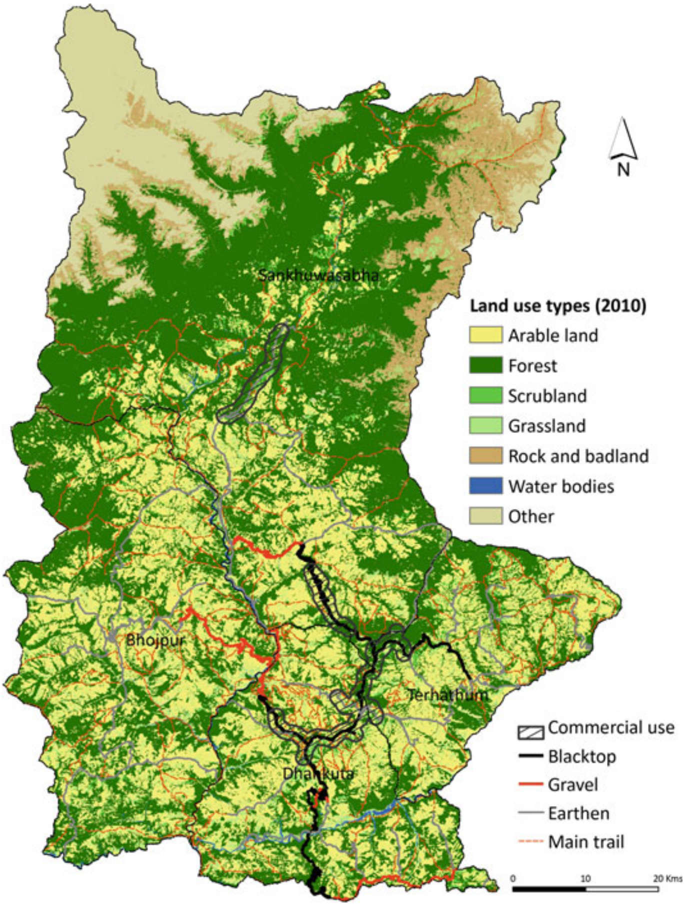

Fig. 4.15 Patches of commercial agriculture

"basic needs", "sustainability", and "poverty alleviation". The national plans have identified broad development sectors such as social services (education, health, and other), agriculture, irrigation, land reform and forestry, transport, communication and industry, commerce, and power for budget allocation and sectoral planning. In the first four plans, up to the mid-1970s, there was a focus in terms of investment given to the transport and communication sector, whereas sectors like agriculture, irrigation, land reform and forestry have received top priority from the 5th to the 7th plans. In terms of budget sharing, the "social services" sector received priority in the 8th and 9th plans. Within the social sector education received greatest priority. In the 10th plan, emphasis was given to poverty reduction and equitable growth. The 11th three-year interim plan (2007–2010) has also continued to focus on poverty reduction. Having said that, all development activities are being executed in all regions, including the Koshi Hills region, across the country under government

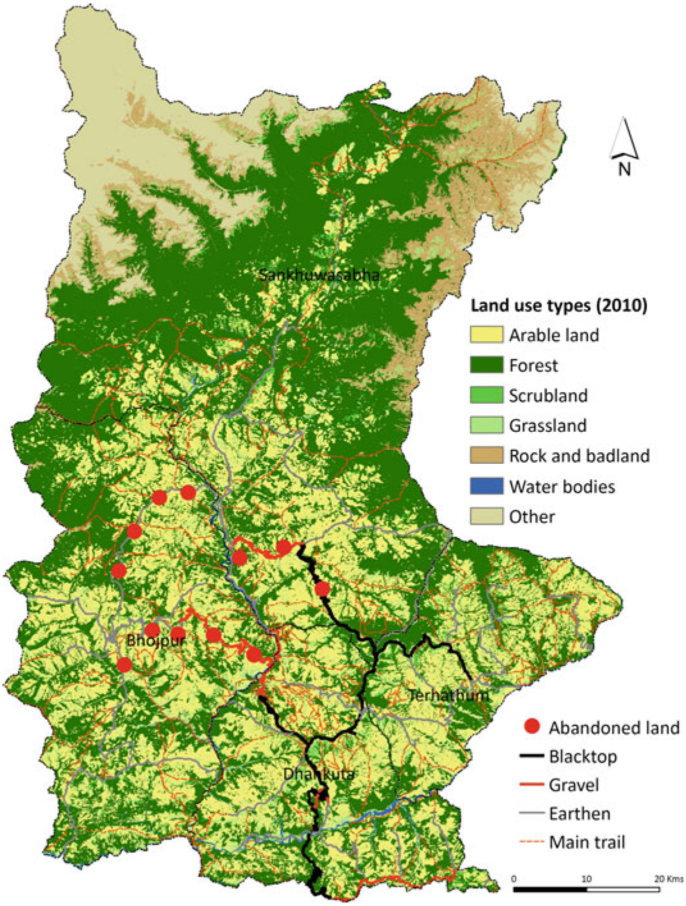

Fig. 4.16 Location of abandoned land

programs and policies. In the Koshi Hills, some of the major development programs include the Pakhribas Agricultural Research Centre, the Integrated Rural Development Program, the Dharan–Dhankuta Highway, and Landscape Conservation and Planning Environmental Resources, etc. These programs involving activities like national park and ecological conservation, agriculture, tourism, climate, rural trade, etc., deal directly and indirectly with the change in land use and its impacts in the Koshi Hills.

4.3.2.2 Agriculture Development Activities

Agricultural activity in the Koshi Hills involves complex interactions among the various agents of change in land use including availability and quality of arable land, micro-climatic conditions, human resources and social structure, and formal and informal institutions. In particular the Pakhribas Agriculture Centre, since its establishment in the 1970s, has worked on introducing improved varieties of wheat and maize crops, along with cow and goat species best suited to the specific agro-climatic conditions of the Koshi Hills. Since the early 1980s, introduction of improved agriculture development programs through CEPREAD (Centre for Environmental and Agricultural Policy Research, Extension and Development) and KOSEVEG (Koshi Seeds and Vegetables) initiated growing of off-season vegetables, seeds, large cardamom, ginger, and fruit as well as livestock rearing. These have brought about significant change in agricultural systems from subsistence to commercial farming, in areas around the road access (CEAPRED 2001). Vegetable farming in particular has further been triggered and has grown dramatically after the provision of transport linkages and market access in the late 1990s. Assessing potential risks and benefits to the farmers, through adapting various higher yielding varieties of cereal crops and turning towards cash crop cultivation, has also been a significant factor in agricultural land use.

4.3.2.3 Roads and Transport

Roads are a crucial part of the infrastructure for overall development in the Koshi Hills. Provision of roads is a catalyst, not only for influencing the process of economic and social change, but also for creating opportunities for exploitation of local resources and facilities. Furthermore, the purpose of road development in the hills of Nepal is fundamentally to integrate remote areas into developmental corridors or centers.

The increase in arable land during the 1986–1996 period could be attributed to the building of the 66-km Dharan–Dhankuta road in 1985, triggering the modern transport service in the Koshi Hills. The construction of roads continued, reaching to a total of 934 km by 2010. Use of land for agricultural purposes increased by 10% during 1986–1996, but decreased from 1996 onwards. However, traditional subsistence cereals crops have been replaced with commercial vegetable crops. In addition, commercial vegetable cultivated areas have also increased substantially along the sides of roads. For instance, the farmers in areas linked by roads have also practiced the inter-culture of “*Amreso*” (broom from grass plant) and large cardamom in shrubland and private forests. Studies of Sugden (2004) and CEAPRED (2001) indicate that the arrival of the roads, together with the intervention of agriculture innovations, has encouraged local farmers to commercialize vegetable cultivation particularly along the roadsides. Patches of commercial vegetable farming, mostly located along the roadsides, are considered to be an impact the roads have had on land use patterns. Furthermore, road impacts are found to have declined according to an increase in distance from the road. These impacts disappear beyond a certain threshold distance. Other studies show differential impacts on the intensity of agricultural production and income of farmers due to different types of road facilities, such as fair-weather roads or seasonal roads and all-weather roads. For instance households living along all-weather roads gained more benefits from improved agriculture than those living along fair-weather roads. Furthermore, while the commercial importance and role of the roadside market towns such as Hile, Sidhuwa, Basantapur, Leguwa, etc., have been enlarged, the role and importance of some of the traditional towns has declined sharply due to new roads bypassing them as well as the emergence of intervening centers, or links with larger towns, such as Taksar in the case of Bhojpur and Chainpur in Sankhuwasabha. More importantly, local handicraft and traditional artesian products have disappeared due to the penetration of cheaper manufactured goods in local markets. There was an extremely small volume of traded goods going out of the Koshi Hills compared with those entering the region and the vehicles run over the RAP roads only during the fair weather season. There has been a change or shift in the existing transport system. *Dhākar* or *Bhariya* (porter) that had served portering of goods between market towns and villages for a long time has either disappeared or been replaced by motor transport. Mules and donkeys, used as a local and traditional means of transport have been replaced and moved to areas where there are currently no motor vehicle roads. On social front, different kinds of people, from the surrounding areas, have moved to the roadside areas to build new settlements or establishing new business enterprises.

4.3.2.4 Community Forestry Program

The conservation of forests and the expansion of forests by the initiation of community forestry, leasehold forestry, and private forestry programs, as well as the conversion of some of the shrublands into the mature forest trees, are assumed to be the reasons for an increase in forest land during 1996–2010. Studies indicate that community forestry, leasehold forestry, and private forestry programs have been expanded over bare lands, for example, the conversion of shrubland to mature tree canopies, the planting of tree species such as *Utis*, *Chiraito*, *Lokta*, *Salla*, and bamboo, and the growing of *Amreso* and large cardamom within the forest land itself. By 2011 over 115,000 ha of forest had been handed over to a total of 1449 Community Forests User Groups (CFUGs) in the Koshi Hills. They comprised memberships of almost 142,000 households. A 1998 follow-up study on the physical resources in 288 sample sites of the Koshi Hills indicated that forest degradation had been reversed and that forests were widely regenerating. Compared to national forest plots, there was less grazing in the community forest plots, and there was an increase in number of species found. An impact study in 2008 found that the community forests were supplying more than twice the amount of timber, poles, and grasses needed by households compared to the 2003 baseline. The study further identified that community forest, and the Livelihoods Forestry Project (LFP), income-generating activities accounted for 25% of the changes in household income compared with the 2003 baseline. Furthermore, a 2006 mid-term review of the LFP found that 71% of the beneficiaries of income generation activities in the districts of the Koshi Hills were women with 53% of the total beneficiaries being from disadvantaged ethnic groups.

4.3.2.5 Climate Change

The Himalayan region of Nepal is one of the most sensitive hotspots to global climate change impacts. Evidence is that there is an increasing trend in temperature in the Koshi basin with more than 0.3 °C per decade at elevations over 4000 m. Over 30 years (1970–2000), the glacier area has lost 0.2% per year in the upper Tamor River basin (DFID 2013). Such widespread glacial retreat can have two direct consequences: changes in the hydrological regime and glacial lake outburst floods (GLOFs). The upper Koshi drainage basin alone has had 13 out of the 14 GLOFs recorded in the Nepal Himalaya. Several GLOF events have been recorded in the Koshi basin—the first event occurred in the Dudh Koshi basin in 1977, then in the Bhotekoshi and the Sunkoshi basins in 1981, and the most significant in 1985 which caused damage equivalent to US$ 3 million. These events caused damage to hydropower plants, roads and bridges, main trails, cultivatable land and forest, and houses in both the headwater and down water areas. The Koshi Hills districts, according to the climate change vulnerability index, lie in moderate to low ranges.

4.3.2.6 The Makalu–Barun National Park

The Makalu–Barun National Park (MBNP) and its buffer zone comprises an area of 2330 km^2, being set up in 1992 and managed by the participatory local communities. Currently, there are 88 forest user groups and 12 communities with 6000 households benefitting from the buffer zone. Since 1996, development and conservation of the MBNP has focused on park development, community support, tourism facilities, and the buffer zone. Tourism is another development impact in the MBNP. According to NTB records, 1000–1500 tourists visited the park and generated an estimated of US$ 275,000 annually (DFID 2013). At the same time, however, the increased number of visitors over the decades has also resulted in increased environmental degradation (tree harvesting, burning, grazing) along the main trails in the MBNP. More importantly, the Arun III hydroelectric project, which was designed in 1994, and other associated infrastructure such as roads within the MBNP, did not take place due to criticism of its economic viability and environmental sustainability. The project, however, began in 2008 under the BOOT system (Built, Own, Operate, Transfer system) and has caused both change in land use and community livelihoods around the project area.

4.3.3 Land Use Change Impacts

While land use change is a proxy indicator of development activities, land use change may impact on different aspects directly and indirectly. Like driving forces of land use change, the impacts due to land use change are difficult to explain, as impacts are the result of a combination of a variety of factors.

4.3.3.1 Impacts on Agriculture Practice and the Increasing Outflow of Local Products

One of the impacts seen due to intensification of the agriculture system is the vegetable farming that has taken place particularly in areas along the motor car roads. Intensification has also been observed due to the inter-culture practices of growing two or more crops, for instance, maize with beans and/or potato, and double cropping of staple crops such as rice and wheat, or maize in areas where such farming systems are feasible and applicable due to irrigation water, road and market access, and other associated facilities. This is verified by the fact that imports of dung (chicken and goat), loaded in trucks from the Tarai, have been observed in the Koshi Hills and in turn there has been an export of high-value crops to Tarai towns. Vegetables, large cardamom, ginger, tea, and fruit constitute the main cash-crops and high-value crops within the study area. Studies show that traditional subsistence cereals crops have been replaced not only with commercial vegetables, but that their cultivated areas have also increased substantially (Pant 2002; Sugden 2004; Shrestha 2006). Furthermore, reliance on subsistence farming is declining as opportunities are increasing in off-farm income (Virgo and Subba 1994). Vegetables, which were produced for subsistence consumption in the 1970s, have increased to over 70,000 million tonnes in 2004 due to commercial cultivation. For instance, the large cardamom area in the Koshi Hills grew from 1564 ha in 1991 to 3224 ha in 2008, with the ginger-growing area rising threefold, and fruit area increasing by 28% during 1971–2007. Studies have indicated that the rise in production of vegetables and spices has been due to the development of markets (near district headquarters), a linking with demand centers in the Tarai lowlands (and further access to the markets border towns of India), and increased access to technical inputs and credit. Another impact is on renting of cultivated land for sharecropping. This has risen from 9% in 1981 to 23% in 2001. Investment in the acquisition of land in the Koshi Hills has also risen due to increasing remittance from ex-Gurkhas (known as *Lahure* working in foreign armies) as well as from the local workers working abroad (new *Lahure* working in middle eastern countries, Malaysia, Korea, etc.). There is growing pressure on arable land in the main towns, as well as in and around areas accessed by roads due to internal shifts in population.

Another impact is an increase in livestock rearing due to the introduction of improved breeds or varieties of pigs, cows, and buffalos in the Koshi Hills by the Pakhribas. The number of livestock holdings increased by 22% between 1981 and 2001. Though livestock rearing has traditionally been an essential component of farming systems in the Koshi Hills, in terms of providing manure, drought power, as well as acting as a coping mechanism in times of food insecurity, the adaption of new breeds of livestock over the past few years, to improve productivity of milk and meat, has been high amongst local farmers and has been a source of income (selling milk and milk products and live animals). The raising of modern livestock, including milk processing through to chilling facilities, vehicles with refrigerators for transporting milk, and milk collection and chilling centers for small dairy farmers, is on the rise.

Furthermore, the outflow of local products being traded through the town and district centers of the Koshi Hills include vegetables such as cabbage, cauliflower, tomato, radish, etc., and other high-value products like *Akabare*, cardamom, ginger, fruits (orange, lemons), potato plants, and tea (Table 4.6). Vegetables occupy 56% of the total volume of outflow, followed by potato plants and oranges. However, the exported products, particularly vegetables, differ in volume and type among the Koshi Hills districts. Overall, Dhankuta being the largest district, represents about 41% of the total traded volume of the Koshi Hills, while Sankhuwasabha represents the smallest with 10%. The remaining two districts share about one-quarter each.

Major local products, mainly high-value crops, entering into trade over the last few years include cardamom, ginger, vegetables, potato, fruits, tea, dairy products, herbs, etc. In terms of volume of trade and value of money, ginger is by far the largest local commodity. Next exported items include cabbage, orange and so on. *Chiraito* comprises around 75% of the total cash value and 60% of the total volume of trade from the Koshi hills. An estimated 140 tons of *Chiraito* passed along the Hile–Basantapur road during the 1992–1993 trading season, while that of cardamom and herbs along the same route was 424 tons/year in 1991–1992. Terhathum alone exported 290 metric tons of cardamom to India, Pakistan, and the Gulf in 2011. Potato was also an important export agricultural product, accounting for 18.4%, followed by vegetables (14%), ginger and cardamom (11.3%), and fruits (3.3%). Fluid milk is the next important export product of Terhathum.

Two types of flows of local products are discernible. First, flows of local products have taken place through already existing networks of market centers, including the hāt bazaars across each district, and then with the major trading centers of other districts where there are sufficient road links. These outflows of products have taken place through hierarchical levels of market places, for instance, trade flows of local goods from small centers to the higher collection centers and then to other places/cities outside of the Koshi Hills within Nepal as well as to India.

The following observations can be derived from patterns of outflow of local products. First, roads have played a crucial role in dictating the direction of flow of

Table 4.6 Outflows volume (mtons) of local products from the Koshi Hills districts

Export goods	Bhojpur	Dhankuta	Solukhumbu	Terhathum	Total	%
Akabare chilly	70	122	–	–	192	0.1
Cardamom	222	177	959	3000	4358	2.9
Ginger	4010	2261	572	2000	8843	5.8
Lemons	665	–	–	–	665	0.4
Orange	4701	2688	1672	2000	11,061	7.3
Potato	21,335	2860	6051	12,050	42,296	27.8
Tea	–	–	6	–	6	0.0
Vegetables	6460	53,485	5505	19,290	84,740	55.7
Total	37,463	61,593	14,765	38,340	152,161	100

Source District Consultation Workshops and Record files of the Koshi Hill districts, June 2012 goods within the Koshi Hills, as well as to other places outside the Koshi Hills. Three districts, not Bhojpur, have roads linking them, where flows of goods take place throughout the year. There is a seasonal flow of goods between Bhojpur and the other three districts due to a fair-weather road link. Major flows take place between Bhojpur and other districts in the Koshi Hills during the fair-weather season, which signifies that Bhojpur has not yet developed centers able to create direct trade links with other centers. The other three districts have gained benefit from these outflows of traded goods through the all-weather road links. Second, only Bhojpur and Sankhuwasabha have gained benefit from outflows of traded goods with Kathmandu due to their direct air transportation links. Furthermore, the existing patterns of flow of goods provide the following development implications. The flows of traded goods that take place between the local markets or hāt bazaars (lower level) and market towns or intermediary centers of higher level located outside the districts tend to lead to specialized production systems. Intensification of vegetable production and other high-value crops is a good example. On the other hand, the flows of local products that take place between the same lower order places within the districts indicate that the production systems are subsistence-oriented and that no specialization can be expected. Third, on the other hand, despite improvements in the agricultural systems which have emerged since the 1990s, the agriculture sector is mostly subsistence, confined to limited geographic areas along the road corridors and near the main bazaars, as well as amongst larger farmers. The traditional cropping patterns based on cereals such as maize, paddy, and millet for personal consumption prevail across the Koshi Hills region, with 77% of the population being characterized as smaller farmers (<0.5 ha) who were unable or unwilling to take the risk of adopting cash crop production, due to limited land, and a lack of access to inputs (irrigation water, credit, fertilizers, extension services) and markets. Migration of the working population from rural areas has risen particularly since 2001, causing a scarcity of labor even to cultivate land, and as a result, patches of abandoned cultivated land are seen across the Koshi Hills. In 2011, the highest number of out-migrants was recorded in Bhojpur (15,151) followed by Dhankuta (14,455), Sankhuwasabha (12,056), and Terhathum (9656).

4.3.3.2 Impact on Settlement Patterns

Land use types, which depend on the physical environment (temperature, precipitation, moisture, vegetation, terrain, wind, etc.), vary according to elevation in the Koshi Hills, as with other mountain regions of Nepal. Change in land use occurs due to elevation zones over time and human intervention is crucial to this change. These processes affect the location of settlements that directly concern surrounding land use. Change in land use together with change in population (increased during 1991–2001 and decreased during 2001–2011) in the Koshi Hills is assumed to cause change in the spatial distribution of settlements according to elevation over time.

Considering the GIS overlay function performed between the layers of location of population clusters in the form of dots[1] and the elevation zones in the Koshi Hills, the result suggests an elevation zone of 1000–2000 m is the most favorable. This zone contains over 70% of the total population[2] (Table 4.7). Next is the elevation zone below 1000 m, with about 23% of the total population. Only in Sankhuwasabha, are some settlements found in the zones above 3000 m, while in the other three districts all settlements are within the elevation zones below 3000 m.

Comparing the distribution of population clusters between 1991 and 2001 with elevation zones, there was no significant variation (Table 4.7). Two explanations for this are: there was only a small population increase at 8.8% (51,868 people) between 1991 and 2001 across the 6557 km^2 of the Koshi region; and there was an internal shift of settlements/population within the same zone.

The distribution of population appears to be closely associated with the distribution of arable land in the Koshi Hills. Over 90% of the population clusters are concentrated in two elevation zones: 1000–2000 m and <1000 m where over 90% of the total arable land is found. On average about 6% of the population clusters were found to be in the 2000–3000-m elevation zone, due to a dominance of grassland, where major occupations of the people, animal husbandry, and tourism are concentrated. Administrative headquarters, major market towns, roads, basic facilities such as schools and health centers, religious monuments, and other amenities generally occur in major population clusters. It appears that people tend to have moved to places for permanent settlement where there are roads and other facilities, but those still living in remote areas are devoid of basic facilities. This process of development and migration of people has created disparity in the level of development, as well as differentials in the impacts of developmental interventions.

Scattered settlements over the Koshi Hills are problematic regarding the provision of basic facilities, as this involves lots of cost regarding their deployment, something which is beyond the capacity of local communities. There is indeed an urgent need to reduce such a disparity. Local experts suggest that development of agglomerated settlements, as a policy, is an essential measure for cost effective deployment of infrastructure and facilities. This would have a reasonably fair impact on places and people throughout the Koshi Hills.

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[1] Population dots were put on each of the district maps, based on the 2001 census, which were derived dividing the total population of the VDC/municipality by 50 persons per dot. Dots were carefully put on the map avoiding drainage areas, gorges, steep slopes, rock, snow land, and pasture land. No population data was available at the VDC/municipality level in the 2011 preliminary population census result.

[2] The populations in 1991 and 2001 respectively of four districts and the Koshi Hills as a whole were: Bhojpur (198,784 and 202,576), Dhankuta (146,386 and 165,069), Sankhuwasabha (141,903 and 159,008), Terhathum (102,870 and 113,061), and the Koshi Hills (589,943 and 639,714).

Table 4.7 Distribution of settlements (%) by elevation zone and year

Elevation classes	Bhojpur		Dhankuta		Sankhuwasabha		Terhathum		Total	
	1991	2001	1991	2001	1991	2001	1991	2001	1991	2001
<1000	20.6	21.2	32.6	32.3	31.1	31.0	8.4	8.2	24.0	24.2
1000–2000	73.7	73.1	65.3	65.2	59.6	59.7	83.6	83.7	69.9	69.6
2000–3000	5.7	5.6	2.2	2.5	9.1	9.0	7.9	8.1	6.0	6.1
3000–4000	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
>4000	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0

4.4 Discussions

The Koshi basin is the largest of the Koshi region. It is a significant river basin for a wide variety of reasons, namely, the environment and its economic, political, and international relations. The two principal natural resources of the Koshi Hills, in terms of coverage, are forest and arable land. Others include shrubland, grassland, and so on. Forest covers the largest, around 40% of the total Koshi Hills area, followed by arable land at 33%. Their significance includes generation of products for use by rural communities, valuable bio-diversity, and regulation of hydrological and atmospheric conditions. They are also an important part of the cultural heritage and a valuable asset for the tourist industry.

The forest occupies a dominant position in the land use categories and is very noticeable in the Koshi Hills, where high hills and mountains are preponderant. Since the late 1980s a growing recognition of the role of "sustainable environmental management" has led to a focus on forest conservation and management. This has happened through local communities known as "user groups", which represent an integral element for improving livelihoods in terms of social and economic well-being. Since then the community forestry program has been carried out under the policies and acts of the government. Evidence that community forestry has been able to provide improved access for the poor to its resources. The revenue generated by the forest products in the Koshi Hills has been largely from private forests, followed by community forests and non-timber forest product (NTFPs) including herbs. This means that private forests are a likely source of good income for the households who own them. Apart from forest products such as timber, fuel wood and animal fodder, the NTFPs are also an important source of revenue for communities in rural areas. Government policy in Nepal has recognized the importance of NTFP enterprises as a potential means to reduce poverty and as an important source of government revenue. There are forest product based enterprises involved in making essential oils, handmade paper, fruit squash, briquettes, ginger, spice, vegetables, and *Chiraito*.

On the other hand, it is surprising that arable land is the second most important land use category in terms of area, sharing 30% over the study period. Prime agricultural lands are confined to the major river valleys such as the Arun, the Sunkoshi, and the Tamor that lie below 3000 masl where the arable land is mostly used for subsistence production via terraced fields. However, the LRMP (1986) has found that about 30% of the total cultivated land, together with the dispersed rural settlements located in areas with over 15-degree slope in the hills and mountains, was technically vulnerable to disasters such as landslides and soil erosion (LRMP, 1986). Such sloppy land is better suited to home gardening, fruit farming, and pasture for animal rearing, according to the APROSC (1996).

Over the past 24 years, significant changes have occurred in overall land use, indicating its dynamic character. During 1986–2000, forest land grew a small amount, arable land grew at over 2%, and shrubland by over 6%. An increase in forest coverage during 1996–2000 can be attributed to the initiation of forest conservation programs such as community forestry and leasehold forestry in the late 1970s and 1980s, while a decrease in forest coverage during 1986–1996 coincided with an increase in arable land; the latter can be attributed to the building of Dharan–Dhankuta road in the early 1980s and the introduction of intensive agriculture systems (off-season vegetables) that demanded much arable land. Furthermore, use of land for agricultural purposes appears to have decreased slightly during 1996–2010, however, during the 1986–1996 decade, there was an increase in cultivated land, which coincided with a decrease in forest coverage. On the other hand, there was a decline in the population, averaging at 38.3% in the Koshi Hills during 1991–2011 due mainly to out-migration (absent population). Furthermore, a considerable internal trading appears to have occurred between land use categories, such as "forest" and "shrub" or "grassland," demonstrating a fluidity of land use. Shrubland and grassland are being converted to more productive categories of forest land, reflecting the care of communities in managing and conserving their own forest resources. Private forest areas and shrubland are also being used for growing *Utis* cum *Amreso* (broom grass) and large cardamom. The change in the two land use categories, arable and forest, in the Koshi Hills can be compared with that of neighboring districts including two Tarai districts, Morang and Sunsari, and two Hill districts, Ilam and Khotang. In the Koshi Hills, forest coverage declined from 39.5% in 1986 to 37.5% in 1996, but arable land increased from 30.4 to 33.5% during the same two years. Available sources indicate that arable land coverage in the Tarai districts was 65% in 1986 (LRMP, 1986). This continued to increase to 74% in 2000 (JAFTA 2001). However, the forest coverage of these Tarai districts was only 24% in 1986 and it further declined to 17% in 2000. Over 14 years (1986–2000), there was virtually no change in arable land coverage in the neighboring two hill districts, but forest coverage declined from 53% in 1986 to 40% in 2000.

In the study, the base map had a scale of 1:25,000, the information on land use and land cover used a scale of 1:50,000, and Landsat imagery used a resolution of 30 m. This was adjusted to the base map scale where a mapping unit represented 2.5 ha. However, careful choice of appropriate GIS functions, together with field verification of land use and land cover categories in training sites particularly along the road access to towns, where a change in land use is assumed to be occurring, were used so that loss or uncertainty of land use and land cover information from 1:50,000 to 1:25,000 was minimized at the highest possible level.

There seems to be climate change impacts on land use in the Koshi Hills. Studies on agriculture in the six case study villages of the Dudhkoshi basin depict that the effects of a much weaker monsoon were evident, particularly in relation to crop production in 2009 (DFID 2013). As a result, many rice terraces were left unplanted due to a lack of sufficient water, and many rice crops that were planted dried out and were left unusable due to the delay in consistent rainfall. Furthermore, the study carried out in 2011 found that the monsoon rainfall, with its erratic behavior, was often delayed over the last 10 years causing an increase in the cases of dry spells during the monsoon period. There has been a clear change in rainfall patterns, for instance, winter rain has been highly variable with almost none falling in the past

2 years. Cash crops such as cardamom, ginger, and broom grass, which proliferated in Terhathum, demonstrated reduced harvests and thus income due to a decrease in water availability. In addition, studies also predict there is likely to be an increasingly positive correlation between urban migration and the impacts of climate change, with more and more "climate refugees" moving to urban areas. Furthermore, farming land abandonments across different parts of the Koshi Hills have been observed due to decreases in manure supplies from livestock, as well as decreases in agricultural labor forces. This is a recent phenomenon whereby youth migrants have a tendency to leave their local areas for employment abroad.

Change has also occurred in trading patterns through traditional trade centers such as Chainpur, Dhankuta, and Olangchung of the Koshi Hills. These towns have evolved through time from their traditional roles of being long distance trading posts or centers of entrepôt trade for facilitating complementary goods between Tibet and India, to facilitating market integration of local produce. Some of the major development events which occurred in the Koshi Hills in the early 1970s and 1980s that brought about changes in the existing marketing pattern and extended market integration with the Tarai and other parts of the Koshi Hills included: Dhankuta becoming a regional headquarters of the eastern region, a shift of district headquarters from Chainpur to Khandbari in Sankhuwasabha, the development of Hile town by families from Olangchung who established trade outlets there, the construction of the Dharan–Dhankuta highway, and the agriculture improvement programme. Those families at Hile continued to live entirely on trade in cloth and other consumer goods, but over the last few years, their trading pattern has changed to include *Chiraito* and cardamom as the most important trading commodities.

Improvement in some of the social indicators such as education and health can be attributed to land use change and development impacts. In 2001, literacy rates for males and females in the Koshi Hill were 65 and 42% respectively, which represented an increase from 1971 as well as being better than those of other regions in the country. The increase in adult literacy and in the levels of education among both males and females has had a likely impact on the economic profile of the population, which has been changing with an increase in non-farming (services, clerical jobs, and sales) and off-farming employment opportunities. The Koshi Hills saw a decrease in fertility rate and an increased knowledge about health care, which can be correlated with rising educational status. The proportion of malnourished children below 3 years of age declined from around 30% in 1994 to below 7% for the three districts except Dhankuta. The Safe Motherhood Innovation Project (SMIP) found that there was an increase in awareness and utilization of maternal health services from 22% in 2004 to 66% in 2007. GIS analysis shows that preponderant proportions of the population were found to have lived within the 3 km of a health facility in the years of 1996 and 2010. This was due to people moving closer to such a facility or improved numbers of such health facilities, or both. This is very significant, since available roads connect only a few places across the region. In the case of road accessibility, the largest proportion of the population lives more than 5 km from a road (a "5-km buffer zone"), indicating that enormous travel times are required to reach them. However, there has been a decline in the proportion of the population living in this buffer zone in 2010 compared to 1986.

4.5 Conclusions

Change in land use is dynamic. Significant changes have occurred in overall land use. There has been an increase particularly in the forest land and arable land, while there has been a decrease in shrubland and grassland. There also exists considerable internal trading between land use categories, especially forest and shrubland or grassland, demonstrating a fluidity of land use across the Koshi Hills. These changes have several implications to land use policy measures and planning.

The distribution of the population appears to be closely associated with arable land in the Koshi Hills. Over 90% of population clusters are concentrated in two elevation zones: 1000–2,000 m and over 1000 m, where over 90% of the total arable land is found. Two reasons to explain this are: (i) there was only a small population increase, at 8.8%, between 1991 and 2001 across the entire Koshi region; and (ii) there was an internal shift of population within the same zone, as well as in areas having facilities of roads and other basic services such as schools, health, and markets. Yet, no improvement has taken place most significantly in the traditional pattern of scattered settlements over the hills. These settlements are lagging in basic facilities and development indicators.

Government initiatives through adopting policies and programs appear to have a crucial impact on land use change. In the Koshi Hils there were two specific activities to maintain and conserve forest coverage. First, the MBNP and its buffer zone set up in 1992. Second, the Community Forestry Programme, initiated in the Koshi Hills in the late 1980s and contributed to an increase in forest coverage after 1996. Community forestry activities have possibly contributed to a significant improvement in the availability of fodder, fuel wood, and fruit tree resources, as well as having a beneficial effect on the balance of land use as part of a broader process of agrarian change. Shrubland and grassland are being converted to more productive categories of forest land, reflecting the care of communities in managing and conserving their own forest resources. An increase in arable land during 1986–1996 could be attributed to the building of the Dharan–Dhankuta road in 1985 and the introduction of improved agricultural development programs through CEPREAD and KOSEVEG that initiated the growing of off-season vegetables, seeds, large cardamom, ginger, fruits, and livestock rearing in the early 1980s. A number of enterprises based on NTFPs produce essential oils, handmade paper, fruit squash, briquettes, herbs and Chiraito, and *Allo* based handicraft products (Kunwar et al. 2009).

The spatial digital database being created provides a benchmark of land use and change in the Koshi Hills for the three map point years: 1986, 1996, and 2010. It has been possible to exhibit and analyze spatial relationships between land use change and development interventions such as roads, community forestry, agricultural interventions, etc., on a GIS framework. GIS mapping together with careful and rigorous field verification methods, including informal discussions with people at training sites, are considered to be extremely helpful tools allowing people to look into further spatial analyses such as factors affecting remarkable changes in land use, social and economic impacts on land use, facility accessibility, and flows of goods and people between places over time. The spatial database on land use requires updating in the future to see the impacts of human intervention on changing land uses vis-à-vis cultural landscape change.

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Chapter 5
Historical Land Covers Change in the Chure-Tarai Landscape in the Last Six Decades: Drivers and Environmental Consequences

Motilal Ghimire

Abstract This chapter explores the historical processes of land cover change based on the review of past documents as well measuring the change between 1954 and 2015 in the Chure–Tarai area using published maps from 1954, 1979, 1994 and satellite based land cover maps of 2015. Deforestation and reclamation of cultivable waste land in the arable lowlands, for the purpose of resettlement through processes of land grants, installing feudal institutions to collect revenues and cover territorial administration and various policy incentives to attract hill people and Indian immigrants to expand settlements and agricultural expanse, all represent the historical processes of land cover change until 1950. The end of the Rana regime, through establishment of democracy, brought reforms in land tenure and abolished anti-peasantry feelings, which consequently attracted hill people to settle in the lowlands of Tarai, Bhawar, and Duns. Following from the eradication of malaria in the 1950s and 1960s, planned resettlement programs and the implementation of development projects attracted people from food-deficit conditions in the hills to the lowlands, causing a large-scale change in the land cover as well as the cultural landscape. Time series land cover maps revealed the predominance of forest in all physiographic units except Tarai in 1954. Forest cover began to decline in the later decades in all physiographic units at the gain of cultivated land. Forest coverage in the hill slopes, inner river valleys, and Duns and Bhawar represented 92, 72, 48, and 79% of the total area in 1954, which reduced to 89, 43, 36, and 64% in 1979. Forest cover in Tarai reduced from 30 to 15% by 1979 over the same period. It further reduced to 85, 24, 29, and 58% respectively in 1994. Only 10% of the area in Tarai was under forest. Compared to 1994, forest coverage decreased to 82, 20, 28, and 54% in the hill slopes, inner river valleys, and Duns and Bhawar respectively, in 2015. It has virtually remained the same in Tarai over the last two decades. Hence the rate of forest decline over the last six decades was high in arable areas of river valleys and Bhawar. The highest rate of deforestation was observed in the west, compared to the east and central part of the Chure–Tarai region. The

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proportion of shrub/grass areas increased notably in the Chure hill slopes, inner river valleys, and Duns. This implies a degradation of forest, which is a threat to the ecology and stability of such fragile slopes and terrain. Although conversion from forest to cultivated land is a general trend in recent decades, reclamation of forest, shrub, or grass from abandoned or damaged cultivated areas represents quite a significant characteristic of the internal dynamics of land cover change. This is attributable to abandonment of cultivated terraces on marginal hill slopes and damage caused by floods, channel shifts, and bank erosion on low land. Apart from the historical drivers, contemporary drivers of land cover change are demographics, development and increasing physical access and mobility, and urbanization. Illegal settlements on public forest land or encroachment on the land mainly by the landless, poverty stricken, and disaster hit people, as well as political instabilities, a continued dependency on forest resources, over grazing, forest fires, landslides, erosion, and floods are also recognized drivers of change. Forest and land resource degradation, loss or threat to biodiversity, increased landslide and flood disaster, the disruption of river and wetland ecology, and the depletion of ground water resources represent noticeable evidence of the negative consequences of an environment associated with the processes of land cover change.

Keywords Land cover change · Chure–Tarai · Drivers · Environment

5.1 Background

Land cover changes are widespread, accelerating, and the main driving forces of global environment change. They are core to the sustainable development debate. The causes and consequences of such change are manifold, reciprocal, and complex. Consequences of land cover change are seen on land and water resources, ecosystem processes and functions, and climate (Lambin et al. 2003); biodiversity, soil degradation (Trimble and Crosson 2000) and the ability of natural systems to support life. These all, thereby impact human livelihood systems and sustainable development (Vink and Davidson 1983; Vitousek et al. 1997). Accurate past land cover change estimations and investigations can be key to understanding the historical processes involved in the human management of ecosystem resources driven by an array of factors such as strategic decisions policy, revenue, livelihood, climate, and natural disasters (Regmi 1976; Houghton and Hacker 2003; Liu and Tian 2010; IPCC 2000). The diverse goals for land use and land cover include settlement, cultivation, forestry, grazing, urban use, industry, public use, and utilities (Turner and Meyer 1994). These goals are driven by forces of poverty and population, and economic opportunities and constraint created by access, technology, markets, urbanization institutions, and policies. Often these goals conflict with one another under the strain of complicated drivers (Briassoulis 2000).

Hence land cover change offers gray areas of research on various ecological and socio-economic systems. A critical issue for land cover change is how to resolve conflicting goals and uses of land whilst maintaining the ecological services of land for sustainable development.

One such area of research is the Chure Hills (also called as the Siwaliks Hills or Sub-Himalayas) and the adjacent Indo-Gangetic plain (collectively named the Chure–Tarai Region, which covers the Siwalik Hills, Dun, Bhawar, and Tarai) which has witnessed, in the last five decades, a multitude of events and developments like, political change, migration, deforestation, growth of infrastructure and settlements, demographic change, urbanization, and so on (Kansakar 1974; Gurung 1988; Sharma 1989, 2003).

One of the obvious manifestations of these events is land cover change. The impact of changes in pattern and cover of land resources in the Chure Hills and adjoining Tarai has serious implications for hazards and land degradation as well as resource availability, which has a synergetic relationship with the livelihoods of people living in the region. In recent years, many serious environmental problems, such as increased incidences of disaster and forest and land degradation in the Chure–Tarai region, have been reported in documents and national chronicles.

The Chure–Tarai region is extremely fragile and a sensitive ecological environment to human disturbance. More than 55% of the population lives in this region (CBS 2013). Bhawar and Tara, the northern extension of the Indo-Gantetic plain up to the foot hills represents the most important part of this region. These belts are the bread basket of Nepal, accounting for 55% of food production. They have recently been the foci of growth, trade, commerce and industry, and urbanization.

Land cover changes on such fragile ecosystems and unstable river systems of the Chure–Tarai further complicate goals of ecological balance and sustainable development. In recent years, many serious environmental problems, like increased incidences of disaster and forest and land degradations in the Churia–Tarai region, have been reported in documents and national chronicles (DWIDP 2009, 2015). Currently such problems have drawn nationwide attention, which has ushered in the formation of an independent national level board, President Chure-Tarai Madhesh Conservation and Development Board (PCTMCDB 2016).

In addition to the urgency required to address the issue of environmental degradation and sustainable development it is still unclear to what extend land cover changes have occurred in the entire region over the last 60 years, and how these changes are driven by socio-economic processes and natural phenomenon? Keeping abreast of these questions this chapter attempts to fulfil the following objectives:

- To explore the historical process of land cover change.
- To estimate land cover change based on the spatial database of the last six decades.
- To analyze the drivers and environmental consequences of land cover change.

5.2 Methodolgy

5.2.1 Land Cover Data and Sources

This study covers the land cover history of six decades i.e., 1955–2015. Land cover data representing various historical time points were used in land cover pattern and change analysis, these data have their sources in published topographic maps as well as those updated using recent, high-resolution images. The scale of these maps, published for specific purposes, varies from the 1:250,000 to 1:25,000. Hence a discrepancy in definition of land cover type is likely and the question of accuracy and comparability of land covers types between one map source and another map is very valid. In light of this fact, this chapter examines only the basic and general land cover types in order to reduce the ambiguity of definitions and to cover the earliest data, only available on smaller map scales. The study basically highlights the history of expansion of cultivated land and settlement and the loss of forest land. It examines historical and contemporary driving forces. Hence the interpretation and explanation of land cover from these sources will cautiously be undertaken.

5.2.1.1 Compiled Topographic Maps from the 1950s or Earlier

These maps (1:250,000) were prepared by the Army Maps Service, Corps of Engineers, US Army, Washington DC (http://pahar.in/nepal-satellite-images-with-maps/). These maps were based on the compilation of medium-scale maps, prepared by the Survey of India, having fair reliability. The reliability of vegetation is undetermined. Although available only on a very small scale, the land cover theme of these historical sources can be a benchmark of land cover information available in maps. Due to the small scale, many smaller river features are represented by line mode, something that other maps depict in area mode.

5.2.1.2 Land Utilization Maps of 1978/1979

These maps (1:50,000) were part of the product of the Land Resource Mapping Project (1986), and were prepared basically to provide information for forestry and agricultural land use for the purpose of land resource management and conservation in Nepal. The maps were based on aerial photographs taken in 1978/1979.

5.2.1.3 Topographic Maps of the 1990s

These topographic maps (1:25,000) were prepared by the Survey Department, Government of Nepal, and were based on aerial photographs with a scale: 1:50,000 in 1990–1996. These topographic maps comprise comprehensive classes of land use and a land cover theme covering physical and cultural features.

The land cover maps of the late 1970s and early to mid-1990s, as stated above, were also verified and corrected wherever a classification error was confirmed by comparing and examining the corresponding land cover themes on Landsat images of 1972–1977 and 1990–1992. Because land cover information contained in both datasets (1978 and 1992) is based on aerial photographs at the same scale (1:50,000), errors arising from differences in map scale are expected to be minimal.

5.2.1.4 Land Cover Data from 2015

This GIS data layer covers the entire Chure–Tarai area and was prepared by the Chure–Tarai conservation and management Master Plan Preparation Team (2016), with the author being the GIS and land use expert of the team. This land use data was produced from visual interpretation of the high-resolution imagery made available by Google Earth images, which was supplemented by digital image classification (supervised method) of Landsat-8 imagery. Cultivated land including settlements, forests, and riverbeds, were visually interpreted. An attempt was made to remove the ambiguity between forest land and shrubland. The spectral pattern of shrubs, as described in early 1990s topographic maps and observed in contemporary Landsat images, was taken as a reference for identifying shrubland from forest land. Similarly, varying forest cover characteristics depending on species type, noticed during field visits undertaken at specific places, were also considered. Barren land, shrubland, grassland, and built-up areas (in Tarai and Duns) and others features were calculated using the supervised classification method. Field visits, including ground truthing by the Master Plan Preparation team, was undertaken at more than 200 locations spread over the study area to survey land use, biophysical and cultural characteristics, and drivers of landscape within the study area.

5.2.2 Definitions and Classification

Cultivated land is defined broadly as land used for cultivation near settlements and built-up areas as described on maps and interpreted from the images. Forest includes typical forest, bush, and grass vegetation, which exert an influence on the climate or water regime. Generally, forest land has a tree crown aerial density of 10% or more, and is stocked with trees capable of producing timber or other wood products. Forest offers an ecological habitat for various wild flora and fauna. Shrubland refers to areas from which trees have less than 10% crown closure but have not been developed for other uses. It also includes degraded forests as well as forests which do not have well-defined stems. Grassland/grazing are areas which are vegetated meadows or grass comprising basically non-woody species. In some places they can be barren areas. Such grassland/grazing land commonly occurs on uncultivated flood plain areas, old riverbeds, or highly degraded forest areas, where the trees are scattered and virtually have no undergrowth. Such areas are commonly used for grazing of livestock. Riverbed refers to an active river channel, where annual or bi-annual flooding is common. Other land refers to the remaining categories, which could be ponds, orchards, airstrips, and so on.

5.3 Geographic Description of the Study Area

5.3.1 Physiography

The study area lies in the southern part of Nepal, which extends about 849 km in length and 24–72 km in breadth and has an area of 39,252 km^2 (Fig. 5.1). It shares its boundary with India in the east, west, and south. The northern boundary of the study area is shared by the Middle Mountain Region. Five physiographic regions manifesting distinctive topographic and geomorphic characteristics are identified (Ghimire et al. 2008a). These are the Chure hills, inner river valleys, Duns, Bhawar, and Tarai.

The Chure hills are a series of linear ridges $\sim$15 km in width and up to $\sim$1300 m in total relief. They occupy 34.5% of the total area. These ridges are the southernmost topographic expressions of active deformation within the Himalayan

Fig. 5.1 The Chure–Tarai region

orogen (Lavé and Avoaac 2001; DMG 2007). Geologically, the Chure hills are bounded between the Main Frontal Thrust at the south to the Main Boundary Thrust at the north. The hills are underlain by the rocks of the Lower Siwaliks (LS), Middle Siwaliks (MS), Upper Siwaliks (US), and Quaternary to recent deposits (Q) (DMG 2007). Moderate relief and steep and weathered slopes are striking features of the LS, which contain a larger proportion of beds of mud or silt stone compared to sandstone. Sharp topography with high relief, steep slopes, and escarpments are formed on the MS, consisting of alternating beds of thick massive sandstone and relatively thin layers of mudstone. The US consists of poorly consolidated boulders, cobbles, and conglomerate and are highly erodible. Topography built on the US is subdued and highly dissected by streams and gullies. At several locations, they appear as uplifted and tilted quaternary terraces. Broad valleys with wider streambeds are developed on the US, which are known inner river valleys, occupying about 2.24% of the total area. Notable are the valleys in the Maikhola, Kamala, Ratu, Raigaon, Chinchu, and Rangoon Khola (Ghimire et al. 2008a, b).

Duns are the intermontane longitudinal valleys of tectonic origin covered by quaternary deposits of fluvial origin. Udaipur, Hetauda, Chitwan, Dang-Deukhuri, and Surkhet are the Duns of Nepal. Duns have generally flat or rolling topography and comprise river and fan terraces. Duns comprise about 8.4% of the total area. Bhawar is known as a piedmont zone between the Chure hills and Tarai, which consist of both active and inactive fans at the topographic break with gradients between 1 and 5°. Bhawar comprises about 14.9% of the total area. Tarai is the northern end of the Indo-Gangetic plain, which forms the southernmost part of Nepal. It is a depositional landform composed of recent Quaternary alluvium, boulders, gravel, silt, and clay, 400–600 m thick (DMG 2007). The region is normally flat and has a minor relief caused by river channel shifting. It covers an area of 40.05%. Duns, Bhawar, and Tarai represent the bread basket of Nepal.

5.3.2 Climate

The climate of the study area features subtropical to warm temperate types, depending upon the altitude of the location. The subtropical monsoon climate is experienced in the Tarai plains and Duns and warm temperate climate in the Chure hills at 1000 masl. Average maximum temperatures range 28–30 °C with extremes of 41–45 °C; minimum temperatures range 15.5–20 °C with extremes of –0.7–6 °C. The seasonal temperature range becomes wider from the east to west under the influence of the continental land mass. May to July are the hottest months and November to January the coldest.

Due to frontal location of the Chure hills, their orographic effect produces the rain-bearing summer monsoon, which results in heavy rainfall during the monsoon regime (June–September) compared to other parts of Nepal. Of the total rainfall,

Table 5.1 Maximum, minimum, and extreme temperatures as well as rainfall, 1983–2013

Stations	Location	Maximum temperature		Minimum temperature		Rainfall		
		Mean	Extreme	Mean	Extreme	Annual (mm)	Monsoon June to September (%)	Extreme (mm in 24 h)
Tikapur	Far-west Nepal (Bhawar)	30.5	45	17.4	0	1662	85.6	296
Birendra Nagar	Mid-west Nepal (Dun)	28.3	42.8	15.5	−0.7	1621	82.5	281
Dang	Mid-west Nepal (Dun)	28.3	41	15.8	0	1853	84.2	308
Butwal	West (Bhawar Foothill)	30.4	45	20.4	2	2292	86.4	354
Rampur	Central Nepal (Dun)	30.6	43.2	17.7	0.2	2023	80.8	296
Karmaiya	Central Nepal (Tarai)	30.9	42.5	20.6	2	1754	84.2	407
Lahan	East Nepal	30.2	41.5	20.1	2.2	1266	79.8	228
Dharan	East Nepal (foothill)	29.7	38.8	19.2	3.5	2242	78.5	352
Chandragadi	East Nepal (Chandragadi)	31.8	39	19.2	6	2616	83.9	437

Source DHM (2014)

about 83% occurs during the monsoon (Table 5.1). Westerly disturbances bring scant rain in the winter season and thunderstorms are frequent in the pre-monsoon (March–May).

5.3.3 Demography

The total number of households in the study area is 2,796,334 with a population of 14,514,646 according to 2011 census (CBS 2013). The average household size is 5.12 people ranging from 4.3 (Duns) to 5.5 (Tarai). The proportion of the population is the highest in Tarai, followed by Bhawar and Chure hills, with the the lowest in Duns. Compared to Tarai, Bhawar and Duns, has a population density which is significantly lower in the Chure hills. On the hill slopes, the population density for the whole area was 90. Due to a high production potential, migration, good infrastructure facilities and urbanization, the density of the population in low-lying areas, represented by the Duns, Bhawar, and Tarai, is very high.

5.4 History of Settlement and Land Cover Change in Pre-modern Nepal

Very little is known about the political or economic history of Tarai before the unification of Nepal in 1769, a process initiated by the King Prithibi Narayan Shah. Before unification, almost all the current Tarai region was under the jurisdiction of various Hill states and principalities. Tarai contributed a sizable revenue (Regmi 1971; Ojha 1983). Unification of Nepal demanded a growing need for military expenditure for territorial expansion campaigns. Control of the Tarai to accrue revenue from resources such as land and forest (elephants, herbs, and timber) to support growing military expenditure, as well as for luxury goods required for the palace and nobles, was one of the prime motives of early Gorkha rulers (Regmi 1971). After that the Nepalese Government attempted to attract migrants from India and the Hills into Tarai by various programs and incentives devised to settle and cultivate by reclaiming forest and waste land so that land revenue could be increased. These initiatives were largely unsuccessful at encouraging migration into Tarai due to a very inhospitable malaria hazard. It remained sparsely populated by indigenous people called Tharus in the piedmont area (Bhawar), Maithili, and other Indian ethnic origins near the Indo-Nepal border which had acquired some resistance against the infectious malaria raging the region. Deforestation or conservation was also linked to the strategic requirements of the unification period. Forests were destroyed in some strategic locations to create settlements so that the new settlers could serve to restrict the entry of enemies (i.e., from British India). These settlements were generally the central places where settlements were necessary to be developed for the expansion of cultivation and trade (Adhikari and Dhungana 2010).

In 1846 the Rana ruler took over power from Shah ruler. The Rana regime continued to encourage settlement and expand cultivated land on forested Tarai. They introduced the *Jamindari* system, where lands as *Mauja* or villages were granted to civil and military officials, nobility, and local chieftains. These landlords were obliged to recruit tenants for the cultivatable land and collect revenue for the state (Regmi 1971). Such a policy entailed a transformation of forest cover into cultivation land or settlements. During the Rana period, from the middle of the nineteenth century, ending in 1951 (Rose and Scholz 1980), there had been several attempts to attract farmers from hill regions to settle in the Tarai. Government encouraged deforestation by providing three to four years of tax exemption on newly reclaimed land (Adhikari and Dhungana 2010). Only a small group from the southern part of the hill region dared to settle in the region mainly to escape repression, enforced slavery, military service, and excessive taxation imposed on them by rulers (Ghimire 1992; Agergaard 1998). The majority of hill farmers chose to move across the border as they were attracted by better opportunities in India and elsewhere. Hence an active policy of encouraging Indian immigrants was followed. Local administrators were encouraged to attract Indian settlers and revenue collectors were often obligated to settle a specified number of immigrants every year (Regmi 1971). Some Indian immigrants were also appointed as *Jamindars* (landlords), although preference was given to hill migrants. Government introduced irrigation facilities at their own expense in eastern Nepal to raise land productivity and attract settlers.

Prior to 1860, purchase of land by Indian nationals in Nepal was restricted. After restoration of the far-western Tarai from British India, the Nepalese Government formulated a legal code, which made a provision for the allotment of land to Indian nationals through sale and purchase so as to appropriate income from the restored territory for Rana families and favorites (Kansakar 1984). This resulted in the large-scale migration of the Indian people from the adjoining border areas of India.

A policy of maximizing revenue by exporting forest products was pursued more vigorously in the 1850s, seeing a great demand for sal timber in India due to its urbanization and industrialization.

The government experimented with several schemes of harvesting and export, and established saw mills, built railway lines, and dredged rivers to facilitate timber export (Gaige 1975). The trade of timber and other forest produce benefited only the ruling class in Nepal as well as business people from India.

Between the late nineteenth to early twentieth century, the government experimented with a program where private entrepreneurs were given, on contract, vast areas of land for reclamation and settlement. The contractor would pay a fee for the land, and then levy taxes of his own on the cultivators and settlers. This method was followed especially in the eastern Tarai (Regmi 1971). Direct and concerted efforts in land settlement stopped after the Anglo-Nepal war 1914–1916 until 1920.

However, the settlers were encouraged through indirect measures such as remission of tax, amnesty to criminals, runaway slaves, and debtors, and exemption of compulsory tax (Ojha 1983).

In the 1920s, following advice given by the British Indian forester Collier (1928), large tracts of forest in the districts of Morang, Mahottary, Sarlahi, Chitawan, Surkhet, and Kailali-Kanchanpur were reclaimed for agriculture in order to attract the surplus labor power in the hills. The program contained many features common to modern land resettlement schemes in Nepal. According to the plan, forest clearing and subsequent settlement were to be done under supervision of a government agency. However, the reclamation program again failed to attract hill people to settle in the hot, humid, and malarial environment of the Tarai. Instead, the program benefitted Indian immigrants. It was reported that in order to extract sal timber, an Indian contractor extended the railway line to Godawari at the foothills of far-western Nepal. Forest was cleared so rapidly by the contractor that it alarmed the Nepalese Government so much they cancelled the contract (Kansakar 2001).

Nepal underwent a dramatic change with the advent of democracy in 1951. Land reform and other related measures were undertaken during the 1950s. Laws were enacted to protect tenancy rights. Compulsory labor obligations and other levies imposed by landlords and the state were abolished. *Jagir* tenure and the *Jamindari* system was replaced by collection through district revenue officers. All *Birta* tenure was abolished and was converted to state land, i.e., *Raiker*. These measures contributed to improve the peasants' position and attracted hill people. Meanwhile several projects for economic development including five-year development plans were introduced in the 1950s and 1960s, which paralleled with malaria eradication (1960s) and the planned resettlement program. Government recognized the great potential of agriculture development in the Tarai as a means of increasing revenue, food production, and supplies and for providing land to the landless people including disaster victims.

By 1961 around 5000 families were allocated 27,000 ha of land of which 10,350 ha actually was bought under cultivation (Ministry of Economic Planning 1962). By 1975 around 6000 families on 11,250 ha had settled, far less than the target of 18,000 families resettled on 52,980 ha of land. The scope of resettlement expanded to a fifth Five Year Plan (1975–1980). Priority was given to landless people and disaster victims. During this period, about 1945 families were provided 3350 ha of land against the target of 22,500 families on 50,000 ha (Ojha 1983). Another source states that during 1964–1974 land cleared for legal settlement was 77,700 ha, but an additional 237,600 ha of forest as reported by NPC (1974) was lost by encroachment (Gurung 1988).

Apart from a resettlement program, spontaneous (illegal) settlement of the Tarai forests was prominent. Many people who were not accommodated in the resettlement program settled spontaneously on neighborhood forest areas. During the 1960s and 1970s spontaneous settlement was estimated to be 66,860 ha mostly in the piedmont (Bhawar) and Dun region as against the legal settlements of 20,300 ha (Ministry of Forest 1976). In some cases spontaneous settlements were found in environmentally unstable areas, for instance, river banks and foothills which are prone to floods and erosion. Spontaneous settlements resulted in a loss of valuable forest resources and a threat to biodiversity and wild life. The official effort to evacuate illegal occupants in these areas was marked by riots and bloodshed. The government attempted to check the illegal settlements further by providing land certificates after an inventory and cadastral survey of the illegal settlements, but very little success was achieved. Inadequacy of planned programs for resettlement, ad hoc land allotment policies, laxity in enforcing control measures, repeated legalization of illegal encroachments, political instability stemmed from the overthrow of the democratic system, lack of coordination between government agencies, and construction of east–west highways were reported to be the drivers encouraging spontaneous (illegal) settlements.

Malaria eradication (1958–1970) was a great success, which in conjunction with a planned resettlement program supported by development of infrastructures resulted in a large-scale migration of hill people to Tarai. The visible consequences of migration and settlement have been deforestation and change in land use and population Subedi (1991). Estimates of deforestation in the Tarai vary widely. For the period 1964–1972, the figures for deforestation range from 120,000 ha (Ministry of Forest 1976) to 340,000 ha (World Bank 1978) quoted in Gurung (1988). The first inventory of forest resources made in 1963/1964, based on aerial photographs from the late 1950s and early 1960s for the Tarai and adjacent region, indicated that 51% of the area was under forest. In terms of geographical division, forest occupied 40.5% in the east (Jhapa to Parsa) 48.8% central (Chitwan to Kapilvastu), and 72% in the west (Dang to Kanchanpur) (Gurung 1988) during the same decade, whereas the agricultural land comprised 51, 43, and 12% respectively. The Land Resource Mapping project (1986) produced an estimate based on aerial photographs (1978/1979) which revealed the decline of forest areas to 43.7% for whole of the Tarai by 1978/1979 as compared to the statistics of 1963/1964. Forest cover declined to 28.1, 44.7, and 67.5% in the east, central, and west Nepal respectively in 1988.

5.5 Land Cover Change: Evidence from Historical Maps and Images

5.5.1 Land Cover in 1954

As already discussed, maps prepared by the Army Maps Service, Corps of Engineers, US Army, provided the information on the agricultural and forest land in the Chure Region in the 1950s or earlier. Table 5.2 shows the land cover statistics, by physiographic region. Almost all parts of the Chure hill slopes were covered by forest, i.e., 93% of the total area. A few small patches of cultivated land in the Chure hill slopes represent the locations of the seasonal livestock sheds known as *Goths,* where cattle are kept for seasonal grazing (Ghimire 2001). The cultivated

Table 5.2 Land cover in 1954

Physiography	Cultural		Forest		Riverbed		Total
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)
Hill slopes	91,849	6.8	1,252,411	92.6	8208	0.6	1,352,468
Inner valley	12,000	13.6	64,018	72.7	12,075	13.7	88,093
Dun	109,652	36.5	199,608	57.8	18,734	5.7	327,994
Bhawar	100,599	17.2	466,274	79.8	17,633	3	584,506
Tarai, Madhesh	1,045,330	66.5	476,081	30.3	50,908	3.2	1,572,319
Grand total	1,359,430	34.9	2,458,392	62.4	107,558	2.7	3,925,380

Source Topographic maps 1:100,000 scale, Survey of India, 1965 land in the eastern Chure hill slopes covers a considerably larger proportion of area, i.e., 10% compared to its central (7.7%) and western (4.2%) counterparts. The inner river valleys constitute 86.4% of the total area under forest, riverbed (Table 5.2), and cultivated land. The inner river valleys of the east occupy about 23% of the total land area under cultivation. Marin, Kamala, and Triyuga river valleys, historically occupied by indigenous groups such as Danuwars and Tharus had considerable land under cultivation. However, the Ratu and Kankai Mai river valleys were totally forested in the east. The cultivated patches in the river valleys of central and western Chure occupied about 6.8 and 3.6% of the total area. Very small patches of cultivated land were seen in the Bagmati and Lalbakaiya river valleys in central Chure. Most of the present-day densely settled Rangoon, Puntura, Babai, Karnali, and Bheri river valleys in the western Chure are under dense forest.

Duns, occupying 36.5% of the total area under cultivation seems to be an historically settled area. The eastern Dun (Udaipur Valley) comprises 23.7% of the total land under cultivation. The population census of Nepal (1952–1954) recorded that eastern Dun, which includes hilly parts of Sindhuli and the Udaipur District, comprised 188,204 people, living in 1197 settlements (Sankyha Bibhag 1958). Of the total, 55% is constituted by Nepali speaking people, followed by Tamang (14.5%), Magar (11.7%), Rai-Kirat (6.4%), Tharu (5.6%), Danuwar (1.94%), and Maitheli (1.28%) (Sankyha Bibhag 1958). Nepali speaking groups and Hill ethnic groups (Magars, Tamangs, Rai-Kirat, and others) dominate hilly parts. In the flat Dun valleys the proportion of indigenous tribes such as Tharu and Danuwars could be much higher. Central Dun, which comprises of the Rapti and Narayani river valley comprising Chisapani Gadhi, Chitwan, and Nawalpur constitute 19.8% of the land under cultivation, with the remainder, 80.2%, being under forest and riverbed. The contemporary population of central Dun 1952–1952 was 239,677 living in 1502 settlements. Of these, Nepali speaking people constituted 37.9%, Tamang 33.14%, Tharu 11.3%, Chepang 5.79%, and Magars 2.01% of the total population. The population of indigenous Tharus in the valleys of Dun is expected to be much higher. This is because much of the hill originating Nepali speaking and ethnic groups lived in nearby hills. Cultivated land in the western Dun is high, i.e., 72.5% of the total land area, which comprises the Dang, Deukhuri, and Surkhet valley. The population census 1952–1954 excludes Surkhet from the western Dun. The population enumerated for the Dang and Deukhuri valley accounts for 81,395 people living in 415 settlements. Tharu ethnic groups constituted 57% of the total population, followed by Nepali speaking groups (36.5%).

Bhawar, which is piedmont, formed from the coalesce of alluvial fans, constituted more than 82.8% of land under forest giving way to only 17.2% for cultivated land. The cultivated land accounted for 29.4, 10, and 9.4% in eastern, central, and western Bhawar, respectively. The isolated pockets of settlement were mainly of the Tharu community. From Chandi Nadi in Dhanusha to Thori in Parsa, with the exception of only a few pockets of small settlements, all areas were under dense forest also known as *Charkose Jhari*, which extended 13–23 km, with an average of 17 km from the foothills. Contrastingly, the Bhawar area of Siraha and Saptari was almost totally cultivated, dominated by the Tharus and Mathili speaking

Madhesi people. Similarly, the Bhawar part of Koshi to the Mechi River was mostly forest. Patches of cultivated land with settlements such as Dharan, Panbari, Madhumalla, Damak, Dakini, Khudunabari, Madanpur, Budhabare, and Boragaon existed. Except for some market centers like Dharan, most of these areas were traditionally occupied by indigenous people such as the Rajbansi, Dhimal, Satar, Meches, and others.

The contiguity of forest area in central Bhawar was broken by cultivated land extending towards Tarai. The Tinau River fan, Ramapur, Bankatti, the Kanchan Khola flood plains, the east of Beta, and the Banganga River were cultivated areas where the Tharu population was dominant. In the far west, between Rapti and the Karnali River, all land was under forest cover except for some small parts of Bhawar located in the south. Prominent settlements were Kanchanpur, Sainawar, Aori, Shivapur, Naubasta, and Laxmanpur. Between Karnali and Mahakali, virtually continuous forest cover existed. Most of the towns, market centers, and villages, which emerged along the Mahendra highway were under forest land.

Tarai, with ideal characteristics found on the Indo-Gangetic plain, that is with fertile soils, had 30.3% of its land under forest cover and 66.5% under cultivation. The proportion of cultivation was 70.3% in the east, and 88.2 and 38.2% in the central and western areas, respectively. Forest area in the Tarai lying east of the Koshi River existed as thin corridors in many places to the Indian–Nepal border. The rest of the area was under cultivation. Part of the Tarai extending from Saptari to Parsa was mostly cultivated area. The cultivation extended from the Indian–Nepal border to *Charkose Jhari,* which extended to the foothills. Central Tarai had around 88.2% of land under cultivation. A few stretches of forest protruding from Bhawar forest areas existed. Settlements compared to others parts of Tarai appeared denser. The southern parts appeared densely populated, which matched adjacent parts of India. Forest constituted the dominant cover type (51.8%) in the western Tarai, which extended from Bhawar to the Indian–Nepal border to join across the border various forest reserves in India, Uttar Pradesh. This trans-boundary extension of forest formed an important corridor for the passage of wildlife. However, the forest was interspersed with cultivated patches in various places. The important extended cultivated area was situated in the Patharia River catchment, which consisted Durgoli, Pipraha, and Bhajni as its main villages. Similarly, the flood plains of the Mohana River along the Indian–Nepal border were also cultivated.

The population of eastern Tarai and Bhawar was 1,806,049 living in 3398 settlements with a density of 568 people/km^2. The Maithili people and those with eastern Tarai dialects constituted 50.7 and 35.5% of the total population in 1952–1954. (Sankhya Bibhag 1985). Nepali speaking people comprised only 4.4% and the indigenous people of Tarai—Tharu, Rajbanshi, Dhimal, Danuwar, Jhangar comprised 5% of the total population.

Central Tarai and Bhawar comprised a population of 348,179 with a density of 428 people/km^2 living within 1302 settlements. People speaking western Tarai dialects constituted 74.4% of the total population, followed by Tharu (19.7%). Nepali speaking Hill people constituted only 2.0% of the total population (NPC, 1952–1954). The population of western Tarai and Bhawar was strikingly low, i.e., 255,189 with a density of 133 people/km^2 living in 982 settlements. Tharus constituted the overwhelming share of the population, i.e., 63.7%, and people with far-western Tarai dialects along with those which were Nepali speaking constituted 27.7 and 3.3%, respectively. Settlements in Tarai and Bhawar were overwhelmingly villages or small market centers. Biratnagar, Janakpur, Malangwa, Birgunj, and Nepalgunj which were close to Indian railways/stations were the only declared urban municipalities (≥ 5000 population) in Tarai with none in the inner Tarai of Nepal (Figs. 5.2, 5.3, 5.4, 5.5 and 5.6; Table 5.3).

5.5.2 Land Cover Change: 1954–1979

A drastic change in land cover was observed between 1954 and 1979 (Fig. 5.7; Tables 5.4 and 5.5). Over the period of 25 years the expansion of cultural land and

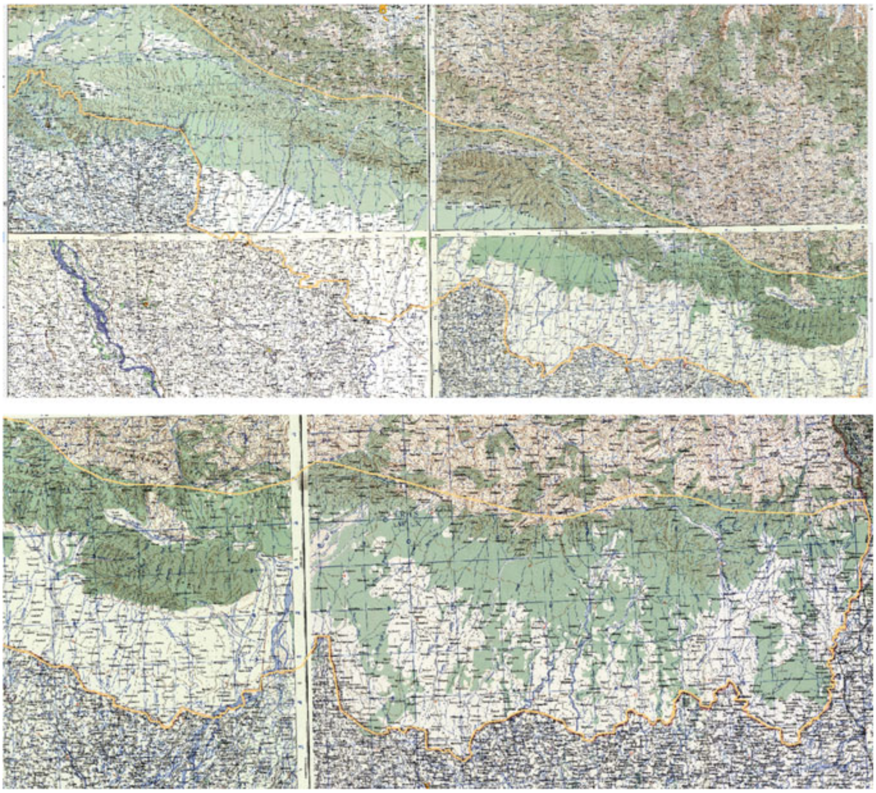

Fig. 5.2 Eastern Topographic maps of 1954, Eastern part

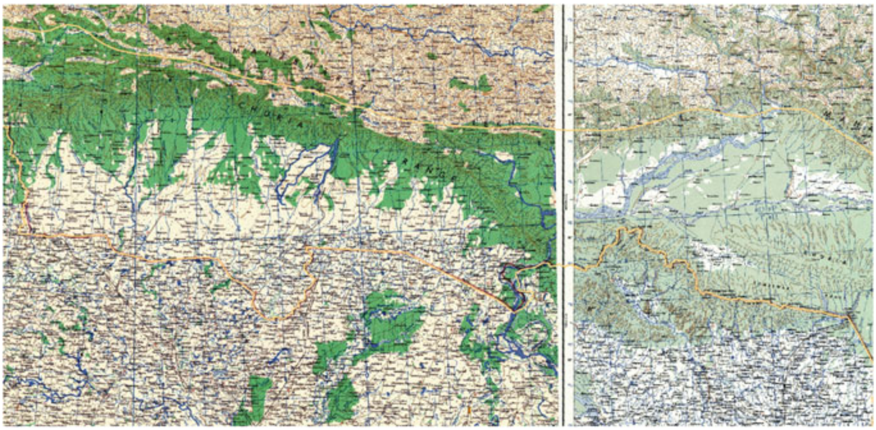

Fig. 5.3 Topographic maps 1954, Central part

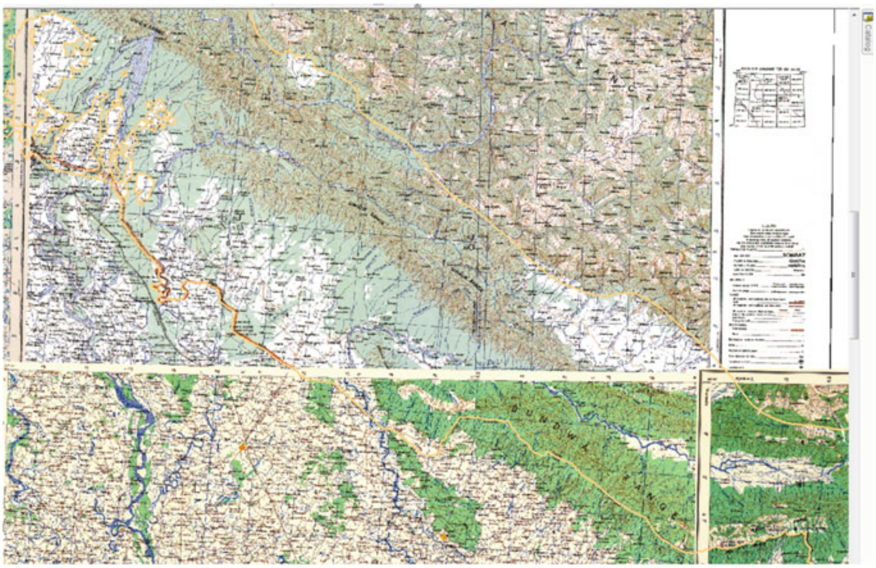

Fig. 5.4 Topographic maps 1954, Western part

loss of forest cover, in terms of area was highest in Tarai, followed by Bhawar, Dun, inner river valleys, and hill slopes, respectively. However, the proportionate changes in cultural land and forest cover were highest in inner valleys, followed by Bhawar, Dun, and hill slopes. Cultivated land had increased by only 8% on the Chure hill slopes. Between regions across the east–west transect, west registered the highest increment in cultivated land on hill slopes and inner valleys; in the east it

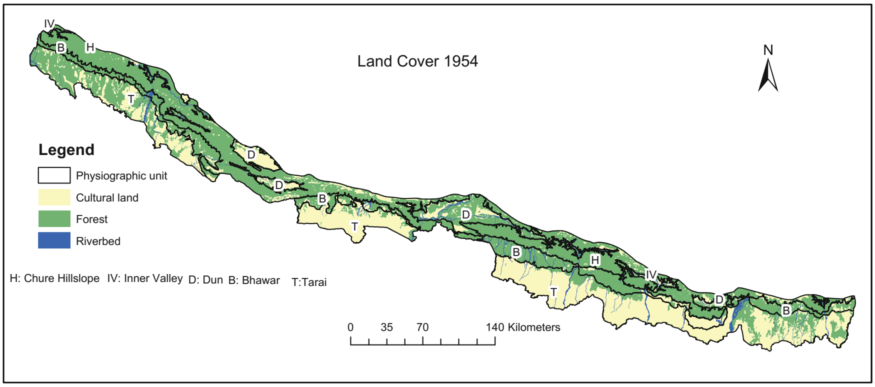

Fig. 5.5 Land cover in 1954

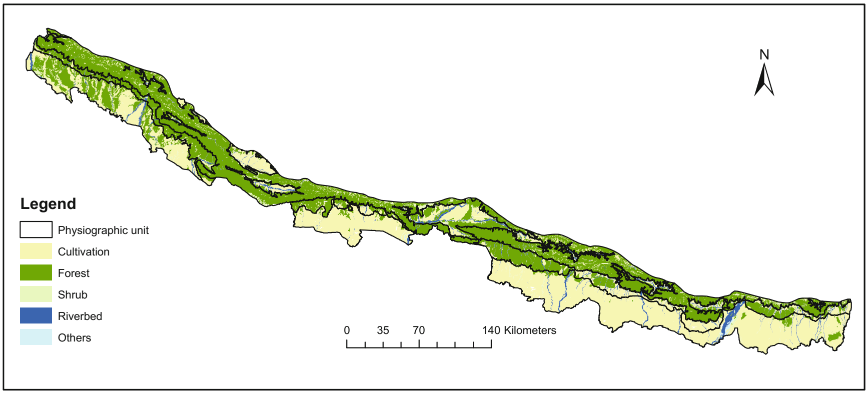

Fig. 5.6 Land cover in 1979

was in Tarai and Bhawar, and in the central areas it was in Dun (Table 5.5). Owing to steep and rugged terrain as well as poor soils, hill slopes were not a preferable destination for immigrants compared to the highly productive land of the plains and river valleys. The eradication of malaria, coupled with a growing and developing infrastructure, physical mobility, and the availability of services in both Bhawar and Tarai acted as an additional impetus for in-migration. In addition to that, households victimized by acute poverty and natural disasters in the surrounding hill districts were attracted to the inner valleys such as Kankai Mai, Ratu, and Kamala in the east, and Bheri, Karnali, Rangoon, and the Puntura river valleys in the west. These settlements were unregistered, with people squatting on both forest and public land.

The plain lowlands, with their concentration of infrastructure and production factors, emerged as a dominant region both demographically and economically (Gurung 1988). The population in the Tarai districts including Duns and part of the hill slopes, according to the 1981 census, was 6,556,828, which was 43.6% of the

Table 5.3 Proportion of cultural land per geographic region in 1954

Region	Hill slopes		Inner valley		Dun		Bhawar		Tarai, Madhesh		Total	
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage
East	36,568	10.0	10,084	23.0	6028	23.7	65,381	29.4	493,944	70.3	612,004	45.1
Central	30,185	7.7	706	6.8	39661	19.8	20,061	10.0	386,297	88.2	476,910	38.4
West	25,096	4.2	1210	3.6	63964	72.5	15,157	9.4	165,089	38.2	280,515	21.2
Total	91,849	6.8	12,000	13.6	109,652	36.5	100,599	17.2	1,045,329	66.5	1,369,429	34.9

Note percentage = percentage of cultivated land to total land area in every physiographic unit of each zone

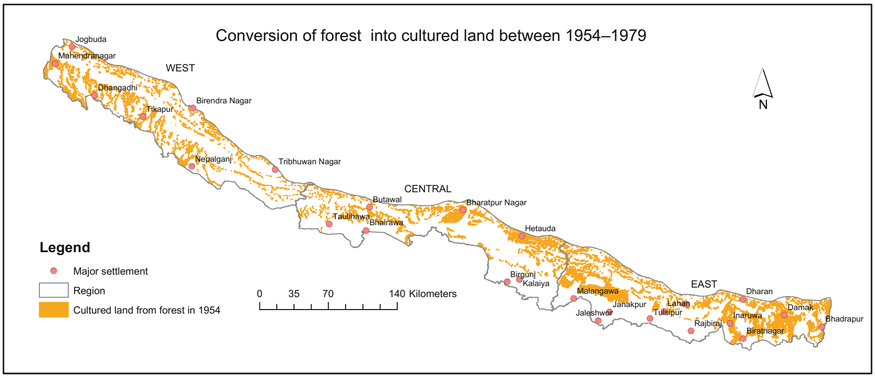

Fig. 5.7 Conversion of forest land into cultivated land, 1954–1979

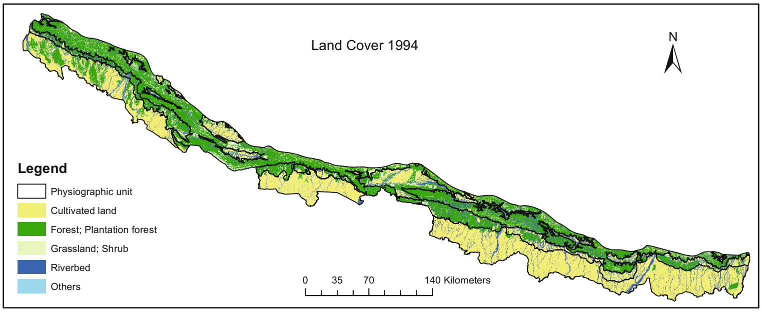

Fig. 5.8 Land cover, 1994

total population compared with 35.2% in 1952/1954 (CBS 1981). The population would have been higher if the Chure hill slopes of non-Tarai districts such as Ilam, Udaipur, Sindhuli, Makwanpur, Arghakhanchi, Salyan, Surkhet, and Dadeldhura had been considered.

5.5.3 Land Cover Change: 1979–1994

The period between 1979 and 1994 (Fig. 5.8, Table 5.6) also showed a similar trend in land cover change in all physiographic units. The overall share of cultivated

Table 5.4 Land cover in 1979

Physiographic division	Cultivated land		Forest		Shrub/grass		Riverbed		Total
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)
Chure hillslopes	99,149	7.3	1,202,625	88.9	32,960	2.4	17,735	1.3	1,352,469
Inner river valley	31,043	35.2	38,261	43.4	898	1.0	17,891	20.3	88,093
Dun	158,112	48.2	118,349	36.1	17,375	5.3	34,159	10.4	327,995
Bhawar	167,274	28.6	376,319	64.4	8,313	1.4	32,600	5.6	584,506
Tarai, Madhesh	1,214,928	77.3	240,850	15.3	44,010	2.8	72,529	4.6	1,572,317
Total	1,670,506	42.6	1,976,404	50.3	103,556	2.6	174,914	4.5	3,925,380

Source Land utilization maps 1: 50,000 scale, based on aerial photographs 1: 50,000 scale. LRMP

Table 5.5 Change in cultivated land between 1954 and 1979

Region	Chure hillslopes		Inner river valley		Dun		Bhawar		Tarai		Total	
East	1496	*4*	5480	*54*	4189	*69*	54,313	*83*	122,339	*25*	187,818	*31*
Central	2619	*9*	3308	*469*	40,998	*103*	10,286	*51*	−138	*0*	57,074	*12*
West	3185	*13*	10,255	*848*	3272	*5*	2076	*14*	53,895	*33*	62,684	*22*
Total	7300	*8*	19,043	*159*	48,459	*32*	66,675	*66*	176,097	*17*	307,576	*22*

Note Change in cultivated land is given in hectares and *italics* represent percentages

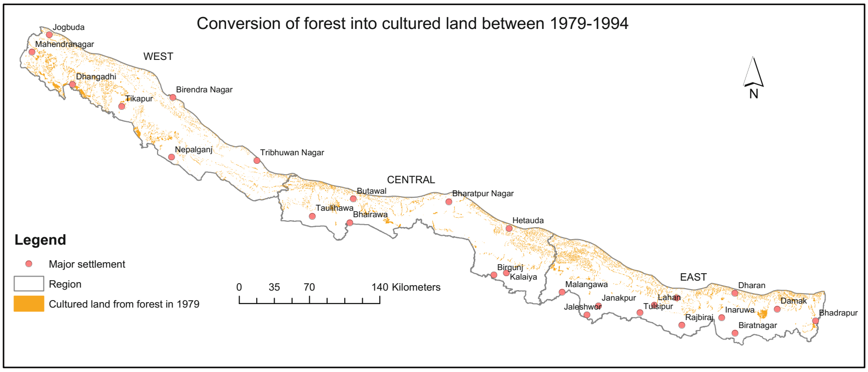

Fig. 5.9 Change in cultivated land, 1979–1994

land increased from 42.6% in 1979 to 44.9% in 1994, i.e., by 2.3%; forest land decreased to 4.9%; shrubland/degrading forest increased to 1.5%; and riverbeds increased to 1.1% over the same period of years. The share of cultivated land showed a significant increase of 6.8% on inner valleys over the 15-year period, followed by Tarai (3.8%), Bhawar (3.5%), and lastly by hill slopes (Tables 5.7 and 5.8). In terms of area there was a net increase of 17,394 ha in Tarai, which was a trade-off between increases of 37,204 ha of cultivated land in west Tarai and the loss of the 16,552 ha and 3258 ha of cultivated land in central and eastern Tarai. This increase resulted in mass deforestation in Tarai, along with substantial illegal encroachment. The loss of cultivated land in central and eastern Tarai can be attributed to the damage caused by floods and river shifts, which either turned areas into grass land, reclaimed forest land, or plantation land. In east and west Bhawar there was an increase of about 6170–7130 ha of cultivated land, which was mainly attributed to forest encroachment. Central Bhawar showed a small decrease in cultivated land. Inner valleys witnessed a consistent rise in cultivated land with a total increase of 5721 ha.

The net increase in cultivated areas in hillslopes was 2215 ha, but eastern hill slopes registered an alarming increase of 6148 ha, which was mainly due to illegal

Table 5.6 Land cover, 1994

Physiographic divisions	Cultivated land		Forest		Shrub/grass		Riverbed		Total
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)
Chure hillslopes	101,442	7.5	1,154,593	85.4	67,316	5.0	29,118	2.2	1,352,469
Inner river valley	36,997	42.0	21,037	23.9	3420	3.9	26,639	30.2	88,093
Dun	169,498	51.7	97,800	29.8	22,863	7.0	37,832	11.5	327,994
Bhawar	180,837	30.9	342,626	58.6	19,886	3.4	41,157	7.0	584,506
Tarai, Madhesh	1,274,971	81.1	166,623	10.6	46,211	2.9	84,511	5.4	1,572,317
Total	1,763,594	44.9	1,782,815	45.4	159,701	4.1	219,270	5.6	3,925,380

Source Topographic maps 1:25,000 scale (aerial photographs 1990–1994), Survey Department, Government of Nepal

Table 5.7 Change in cultivated land, 1979–1994

Row labels	Chure hillslopes	Inner valley	Dun	Bhawar	Tarai, Madhesh	Total
East	6148	4033	2692	7130	−3,258	16,745
Central	−1393	868	5955	−1122	−16,552	−12,243
West	−2540	820	2552	6170	37,204	44,205
Total	2215	5721	11,200	12,178	17,394	48,708

encroachment into forest land on gentler slopes or on narrow valleys and terraces. Central and western hill slopes registered a decrease of 1393 and 2540 ha of cultivated land. Remarkably, in the same period these regions showed an increase in shrubland coverage, which was partly due to a prevalence of abandoned cultivated terraces caused by soil degradation and low agricultural productivity, labor shortage, and comparative benefits from non-agricultural jobs in towns and market centers as well as lucrative remittance from foreign jobs. Abandonment of cultivated terraces gave rise to the growth of greenery either as shrub and/or bush land or as regenerated forest in private land (Fig. 5.9).

5.5.4 Land Cover Change: 1994–2015

No significant change in cultured land was observed during 1994–2015 in all physiographic units (Fig. 5.10). The change of overall share of cultivated land to other land was only 2% in Bhawar, while in other areas the change was 1% or less. Noticeable proportionate change in forest and shrubland/grassland was observed over the last 21 years. The loss of forest cover was quite significant in all but the Tarai, i.e., in the range of 2–4% of the total change in coverage. Similarly, the change in shrubland/grassland cover was 2–9%, the lowest was in the Tarai and highest in the inner valleys. During this period, conversion of forest to cultivated land, on the Chure hillslopes in the central and eastern region, was above 11,000 ha, whilst in the west it was around 8500 ha (Fig. 5.11). In Bhawar this conversion was greater than 6500 ha in the central and eastern regions, while in the west it was around 3400 ha. West Tarai showed evidence of conversion of forest land to culitvated land. In central and eastern Tarai it was in the range 6000–12000 ha. Comparatively, the same land cover conversion was lower in the inner river valleys and Dun. Conversion of cultivated areas to forest or shrubland was prominent in the east, particularly in Tarai, the Chure hill slopes, and Bhawar. The transformation of cultivated land into forestland/shrubland indicates abandonment of terraces accounting for 6700 ha (west) to 15,000 ha (east) (Fig. 5.12). Hence terrace abandonment and extension of cultivated land in the Chure hill slopes, which are two opposing processes, are operating simultaneously. This indicates that injudicious land resource management and threats to biodiversity and ecosystem

Table 5.8 Land cover, 2015

Physiographic divisions	Cultured		Forest		Shrub/grass		Riverbed		Total
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)
Chure hillslopes	102,812	7.6	1,103,379	81.6	118,434	8.8	27,844	2.1	1,352,469
Inner river valley	37,944	43.1	17,958	20.4	11,118	12.6	21,072	23.9	88,093
Dun	170,142	51.9	91,425	27.9	34,360	10.5	32,067	9.8	327,994
Bhawar	190,696	32.6	318,115	54.4	35,864	6.1	39,831	6.8	584,506
Tarai	1,270,850	80.8	151,292	9.6	71,845	4.6	78,330	5.0	1,572,317
Total	1,772,610	45.2	1,681,991	42.8	271,614	6.9	199,165	5.1	3,925,380

Source Google Earth image, 2015; Landsat 8 and topographic map, 1994, updated

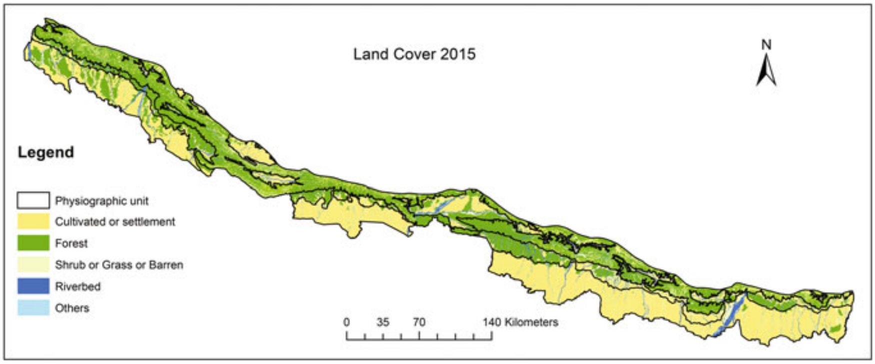

Fig. 5.10 Land cover in 2015

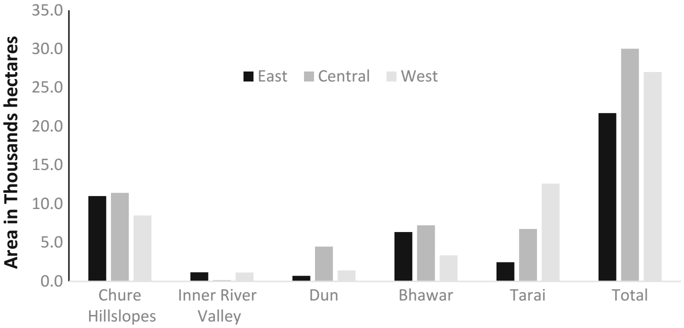

Fig. 5.11 Conversion of forest land to cultivated land (1994–2015)

goods and services are occurring on the hill slopes. Likewise, conversion of cultivated land to forestland and shrubland to grassland has been noticed in the eastern and western Tarai, eastern Bhawar, and the central Dun. Much of this conversion is attributed to reclaimed land from bank erosion, river shifts, floods, and siltation. A general awareness seems to have increased regarding planting trees and retaining grasses or shrubs to protect the land from unstable river flows. However, large areas of land, from old riverbeds, river shift areas, or siltation areas are reclaimed for agriculture (Fig. 5.13). In Tarai the conversion of old riverbeds to cultivated land has been over 25,000 ha during the last two decades; while in the inner valleys, Duns and the Bhawar the conversion of old river valleys represents 4000–6000 ha (Fig. 5.13). Conversion to shrubland/grassland from old riverbeds is one of the characteristics of the internal dynamics of land cover change.

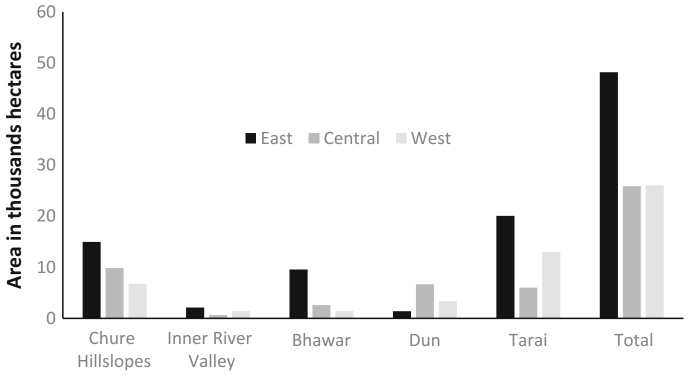

Fig. 5.12 Conversion of cultivated land to forestland/shrubland (1994–2015)

5.6 Drivers of Land Use, Land Cover Change, and Their Environmental Consequences

The pathways of land use and land cover change reveal a complex interplay of natural and human factors. The change in land use and land cover is basically forest land to agricultural land or shrubland/degraded forest. However, this is not happening in only one direction, but is reversible and is dictated by various political and socio-economic as well as natural drivers. The role of these drivers and the environmental consequences of land cover change are discussed in the following text.

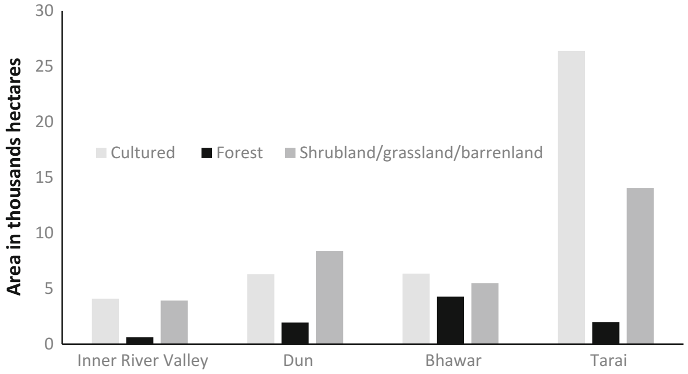

Fig. 5.13 Conversion of riverbeds to cultivated land, forestland/shrubland, and grassland (1994–2015)

5.6.1 Revenue Generation and Territorial Administration

As discussed earlier, deforestation and reclamation of cultivable waste land in Tarai and Bhawar for the purpose of resettlement, expansion of agricultural land through the processes of land grants, installing feudal institutions to collect revenues and hold territorial administration, and policy incentives to attract migration and resettlement, were the historical drivers of the land cover change. Until the 1930s the main concern of the rulers was to secure the loyalty of the local elite and others having a role in the army and administration. To earn loyalty, land grants (*birta)* was offered extensively to them, resulting in the fact that common ownership (i.e., state ownership) was transferred to private ownership. Almost three-quarters of the forest land in the Tarai was under this type of grant. These lands were later converted to agricultural lands (Acharya et al. 2008). Exploitation of forest resources such as Sal timber mainly to be used for railway sleepers, building materials in India, and non-timber products such as medicine and herbs, as a source of income was also a subsidiary driver for land cover change in the historical context until the modern era.

5.6.2 Malaria Eradication, Land Reform and Resettlement, and Development Plans After the 1950s

The advent of democracy in 1951 in Nepal brought about land reform and other related measures undertaken during 1950s. Tenancy rights were protected and an anti-peasantry land tenure system, Jagir Birta tenure, and the Zimindari system were abolished with revenues being collected by district revenue officers. These measures attracted the hill people but did not substantially benefit peasants and landless people (Regmi 1976). Meanwhile several projects for economic development, including five-year development plans were introduced in the 1950s and 1960s, which paralleled with malaria eradication (1960s) and planned resettlement programs. Government recognized the great potential of agriculture development in the Tarai as a means of increasing revenue, food production, and supplies as well as for providing land to landless people, including the disaster victims.

5.6.3 Illegal Settlement and Encroachment

Many hill migrants, which were not accommodated in the resettlement program settled spontaneously by encroaching on forest areas mostly in the Bhawar and Dun. Some cases of spontaneous settlements were found on environmentally unstable areas, for instance, river banks and foothills which were prone to floods and erosion. The spontaneous settlement resulted in a loss of valuable forest resources and a threat to biodiversity and wildlife. The government attempted to check this illegal settlement further by providing land certificates after a full inventory and cadastral survey of the illegal settlements was made. However, very little success was achieved. An inadequacy of planned programs for resettlement, ad hoc land allotment policies, laxity of enforcing control measures, repeated legalization of illegal encroachments, political instability stemmed from the overthrow of democratic systems, lack of coordination between government agencies, and construction of an east–west highway were reported to be the drivers which encouraged these spontaneous (illegal) settlements.

The trend of illegal settlement and deforestation has not been arrested as yet. The tendency of encroachment into public land and forest land by landless people is rampant in the Tarai and Bhawar. Landlessness induced forest encroachment has posed a serious challenge to the management of Nepal's Tarai forest land. A recent study by the Department of Forest shows 94,872 ha of Tarai forest land was encroached during 1992–2014, this area and is increasing yearly. Similarly, forest loss during 1991–2011 accounted for 32,000 ha in the Tarai region, a rate of 0.42% (FRA/DFRS 2014). In some districts such encroachment tendencies has further increased. For example about 20,000 ha were encroached in the Kailali District in 2014. Local authorities say that people with power are encroaching on public land in the name of the freed Kamaiyas and landless people thereby taking advantage of the drive being launched by various organizations to distribute public land to freed Kamaiyas. Politicians are found to have used both their power and influence to distribute public land to their aides and relatives in the name of landless people.

It is estimated that 25% of the population of Tarai is landless, or has less than 0.4 ha, in 2011 (CBS 2011). In a recent call for registration by the Landless Commission in 2014, 1.2 million households were registered as landless, of which, over 80% were living in or near forest land and making their living either through agriculture or forest based activities. Denying access to forest in many cases has further triggered a burgeoning conflict between the landless groups, forest authorities, and local residents—again often resulting in forest degradation.

5.6.4 Demographic Shift and Urbanization in Tarai

A major shift in population from marginal hills to the Tarai including Bhawar and Dun, has become a major feature in the population distribution trend. After malarial eradication, forest clearance, land reform, concentration of development activities with the extension of the road network (including the east–west highway and feeder ways; joining hills and the Tarai district headquarters), and development of irrigation facilities, Tarai has become a destination for migration, a frontier of settlement, and a loci of urbanization and industrialization. The share of Tarai's population has increased from 38% in 1981 and 48.4% in 2001 to 50.4% in 2011. Of 58 urban centres all over Nepal in 2011, 29 were located in the Tarai, which covered 44.3% of the total urban population with an annual growth rate of 3.2%. Of

14 urban centres with populations over 100,000, 10 were located in the Tarai and Dun (CBS 2013). In May 2014, the Nepalese government announced 72 new municipalities, marking a significant urban shift in Nepalese society, of these 57 are located in the Tarai and Dun. The opportunities for employment and the rich agricultural resources, coupled with industrialization, commercial growth, and urban development have provided economic attraction to the people of the hills and mountains. Currently, the total population of the Chure–Tarai region is 14,748,672, i.e., 55% of the total population of Nepal, compared to 51% in 1991. Growth of urban centers and infrastructures has given impetus to deforestation and degradation as a consequence of a lack of good governance and political instability, discussed in the following text.

5.6.5 Migration and Encroachment in the Chure Hills and Inner River Valleys

The history of the large-scale migration in the hills is uncertain. An influx of hill migrants to Tarai, after the eradication of malaria, could be one of the main causes in the Chure hills. However, the migration and settlement history of the people from the middle mountains in parts of the western Chure hills is probably older than in Tarai. In the Banganga watershed, Arghakhanchi districts, many people who were either poverty stricken, or disaster victims, including some outlawed people from the Magarat region (part of middle mountain) settled some 100–200 years ago in the Chure hills and went on to convert forest land on slopes and valleys to cultured terraces and sheds. The origin of many settlements in the Chure hills can be traced back to their status as sheds or “Kharkas” in the recent past (greater than 20 years ago). These Kharkas were the sites of marginal cultivated land in terms of productivity, located away from the main farm unit. They also acted as grazing places and seasonal sheds for cattle and buffalo. In course of time these Kharkas became sites of permanent residence for the households (Ghimire 2001).

In the inner river valleys of the Chure hills, deforestation and conversion of cultivated land was attributed to migrants who were the victims of acute poverty and natural disasters in the nearby hills districts. Settlements of the hill people in the inner river valleys such as the Ratu Khola valley, the Kamala River, the Bagmati valley, and the Lalbakaiya River owe their origin to immigrants who were displaced by natural disasters and poverty or who sought refuge from social punishment. However, in wider inner valleys some settlements of the indigenous community, such as Danuwars and Tharus, existed long before the arrival of the hill people.

In the far-east the settlements on the Chure hill slopes seem to have originated in 1850 and increased in number after the eradication of Malaria (Niraula 2004). The settlers mostly from Bhojpur, Terathum, and Okhaldhunga reclaimed the cultivated land by burning and encroaching into forest areas.

5.6.6 Political Instabilities

Political transformation, transition, and instability since the 1950s, to present, remain one of the major drivers of deforestation. The lack of governance and very weak forest administration during political regime change accelerated deforestation in the Tarai. The Panchayat system, which was introduced in 1960 caused deforestation in the Tarai. Various political and non-political people were able to obtain uncultivated forest or waste land on personal decrees from the king at no personal cost. These people were considered key to the political system by the king (Chaudhary et al. 2015). The opportunistic forest encroachment and exploitation of timber and non-timber products was further intensified in the Tarai after the introduction of the multi-party system in 1990 as well as during the Maoist insurgency and second national political movement (1996–2006). Similarly, after regime change in 2006, a large tract of forest land, including plantation areas, was illegally cleared on an institutional level. Involvement of political and local institutions with the state authority has fostered deforestation and an expansion of cultivated land for the rehabilitation of the so-called landless, disaster victims, or internally displaced people across several districts such as Ramauli area Sarlahi.

5.6.7 Dependency on Forest Resources

The high dependency on fuel wood for energy consumption in both domestic and commercial use in rural areas, semi-urban areas, and market centers located in Chure–Tarai region, Bhawar, Tarai, and Duns has continued to be a driving force causing forest degradation and impoverization. Similarly, unemployed landless people, or people with little land, also have increased deforestation in the areas where there is a market. Many people living in squatter settlements or nearly riverbanks and roads repeatedly go into the forest, collect firewood both green as well as dry, and bring hundreds of loads into towns. This activity has become their only available means of a livelihood. Pulling carts and tractors are also used to extract firewood and timber. Although the dependency for fuel wood is decreasing, i.e., 78% in 1998 to 64% in 2013 due to a growing use of alternative sources of energy, the supply of firewood is never expected to meet its demand based on the current population growth (WECs 2012). In addition to fuel wood, people depend on forest land for grass and fodder for domesticated animals. Moreover, forest is the only source for timber used in the construction of houses. Similarly, forest land is essential for non-timber forest products and herbal resources.

5.6.8 Grazing and Forest Fires

Forest covered areas of the Chure–Tarai have been used for open grazing for a long time. An increase in livestock numbers has fostered excessive and uncontrolled grazing as well as exploitation of forest resources for fodder and litter. The forests of the Chure hill slopes are the favorite destination grazing sites for cattle and goats belonging to the people of middle hills and the Tarai. Cattle living more than 10 km away are brought to the hill slopes for grazing when their usual grazing sites, such as flood plains and old riverbeds, do not have enough grass during dry season. Similarly, people of the middle hills, inner valleys, Chure, and Tarai have established seasonal sheds for grazing their cattle and sheep in many parts of the Chure hill slopes. This allows access to sources of better forage and fodder. Such sheds have encouraged forest encroachment for settlements and agriculture around homesteads.

Forest fire is one of the major drivers of deforestation, causing destruction of hectares of forest every year. It has modified the vegetation composition, which led to vegetation succession (Chaudhary et al. 2015). Recurrent forest fires have severely damaged biodiversity and wildlife, prohibited regeneration and growth of seedlings, destroyed non-timber forest products, and encouraged invasive species into the sub-tropical forests. With expansion and increment in settlements, increased incidence of grazing, and growing forest encroachment and illegal timber smuggling, forest fires have increased tremendously in recent decades.

5.6.9 Natural Drivers

Changing river morphology, landslides, and erosion have been natural drivers of change in the Churia–Tarai region. Overgrazing and deforestation have increased hill slope erosion and the formation of severe gullies. Landslides, which contribute to huge amounts of sediment load in rivers, can cause floods, sedimentation, river course shifts, and bank erosion in the Bhawar and Tarai regions and severe land degradation in hillslopes. River instabilities have attributed change in the micro-topography and land cover in the Duns, Bhawar, and Tarai. While interpreting river morphology from maps and images several incidences of land damage and course abandonment can be detected. Loss of cultivated land, grass/grazing land, and forest land has occurred due to river encroachment in places. However, in other places, land abandoned by channels or old riverbeds has been cultivated or reused as grazing areas or tree plantations in hazardous areas. The cyclic pattern of encroachment and abandonment has driven changes in the land cover of the Churia–Tarai region.

5.6.10 *Land Fragmentation*

Land fragmentation due to family separation is prevalent and is one of the limiting factors for modern technological and scientific innovation in agriculture. The average parcel size is less than 0.3 hectares and per family parcel holding is 6.0 in Tarai (CBS 2013). Pressure on cultivated land is increasing rapidly as a result of population growth on one hand and damage by flooding on the other. As a result, fragmentation of land has been on increasing trend, which will further accelerate the pace of land degradation and constrain agricultural development, and will cause net negative effect of pressure on forest resources and coverage. Cycle of damage and reclamation of land from flood at the interval of 6–7 years (Ghimire et al. 2008a, b) in Tarai has further exacerbated the land fragmentation and complicated the land use.

5.7 Environmental Consequences

Forest clearance, settlement, and agricultural expansion on fertile lowlands of the Chure–Tarai, along with revenue generation, national integration, population redistribution from low to high, agriculture and development potential, proximity and access to Indian rail and road networks, as well as several other factors, all contribute to the legacy of land cover change in the Tarai. The expansion of agriculture has contributed to produce 56% of the national grain supply with a 125% surplus production (MoAC 2006) in Tarai. This represents a positive impact of land cover change. Contributions to national income through trade, transport, business, and industrial development are also beneficial impacts to the economy and employment in Nepal. However, an underpinning question is how sustainable has management, of land resources and development efforts, been in such a fragile and sensitive ecosystem, in the context of land cover change over the last six decades.

Land cover change processes have left the forest cover of Chure–Tarai at about 68% of its original area over the last six decades. Excluding the Chure hillslopes, only 50% of forest land cover is left. Reckless extraction of timber and other forest resources, without forest management until recently, has caused the degradation of available forest with the extinction of important trees and other plant species since the beginning of the Rana regime. The loss of forest cover has limited the space for biodiversity in the Chure–Tarai ecosystem.

The Chure hills and Tarai landscape consist of 23 ecosystems, which are of international significance, both in view of the numerous globally threatened species of fauna and flora they harbor, as well as because of the diversity of ecosystems contained within the area. Altogether, 380 floral species belonging to tree, shrub, herb, and epiphytic plants are found in the Tarai and Chure hills (BPP 1995). Similarly, about 91 species of mammals, 648 species of birds, 68 species of reptiles, 22 species of amphibians, 154 species of fish, and 325 species of butterflies are found in the region. The richness of flora and fauna has been under potential threat due to growing population pressure on forest land and other land resources. These ecosystems have been highly disturbed by forest encroachment, open grazing, forest fires, and excessive dependency on, and misuse of, forest resources. In recent decades construction of tracks and roads on fragile land, without considering environmental damage, has further added to the disturbance of ecosystems. Introduction of invasive plants has further threatened the natural ecosystems of the lowlands including wetlands (Siwakoti 2006).

Realizing the great significance of the biodiversity of the sub-tropical hills and lowlands, the government of Nepal established five protected areas in the Terai and Siwalik Hills. These are: the Koshi Tappu Wildlife Reserve, the Parsa Wildlife Reserve, Royal Chitwan National Park, Royal Bardia National Park, and the Royal Suklaphanta Wildlife Reserve. Unfortunately, biological resources outside these protected areas are under great pressure from exploitation and the conversion of forest land to farmland through frequent illegal encroachment and exploitation of the forest. Although several community based participation schemes like private, community, collaborative, lease hold, and religious forest management are in place, they have not been commendably effective at protecting and managing forest resources (Adhikari and Dhungana 2010).

The destruction of forest and the extension of agriculture through legal and illegal channels in Bhawar and the Chure hills has worsened the hazards: landslides on hill slopes contributing to heavy sediment loads in streams and rivers, gully and bank erosion, siltation, channel shifts, and flooding in the lowlands (Burton et al. 1989; Carson 1985; Singh 2009; Ghimire et al. 2006). Although much cultivated land lies on gentle to sloping lands, i.e., less than a 30% slopes, more than 7% of the cultivated land lies on the steep slopes (<30%), something which is not ecologically viable (Ghimire 2012). The forest cover of the Chure hills and Bhawar zone act as a buffer zone to check flood from the fast flowing hill rivers entering the Tarai (LRMP 1986; Ghimire et al. 2008a, b).

The Chure hills are made of soft material, sand, sediment, and boulders, uplifted relatively recently in geological time as part of the formation of the Himalayan mountains. Because of their composition, the hills are much more sensitive to loss of vegetation cover and other human activities. Studies show that about 34% of the Chure hill slopes are highly susceptible to erosion and landslide and only 25% of the hillslopes are relatively stable. Similarly, about 12% of the area in Bhawar and Tarai is prone to flooding, river erosion, and shifts and sedimentation (RCTMCDB 2015). The expansion of agricultural land and settlements has increased risk to lives and property from floods and erosion. Over the last 20 years house units in the hill slope increased in numbers from 80,000 to 134,700, this is a 67% rise (Ghimire et al. 2008a, b. Of these, 21% are located on highly susceptible slopes. On the flood prone areas of the low, flat land of Bhawar and Tarai about 12,244 houses are located on the high flood zone. Disasters caused by flooding and landslides in Nepal are highest in the Chure–Tarai area (Khanal et al. 2007; DWIDP 2009) and disaster incidence is likely to increase if encroachment into forest land is continued. A vast amount of money from the development budget is spend every year to protect or recover land and property.

One of the detrimental effects of injudicious land cover change has been the threat to the availability fresh water. The coarser, porous, and permeable alluvial deposits of the piedmont makes Bhawar a main aquifer system and recharge zone for the Tarai (LRMP 1986). In Bhawar rainfall during the monsoon percolates down and emerges as springs and marshes along the northern edges of the Tarai, which are the main sources of water for irrigation. The loss of forest and the sprawl of urban areas in the Bhawar zone has decreased the recharge of ground water and increased runoff of rainwater. Hence the deforestation unaccompanied growth of settlements and urbanization has led to a drying up of streams, rivulets, and springs.

Tarai is an important area of wetland habitat where 80 natural lakes, 12 marshes, and more than 55 riverine flood plains, seasonally flooded grassland, and rice fields exist. These wetland ecosystem are rich in floral diversity, which supports about 720 vascular plants (Siwakoti 2006). In addition, wetlands maintain water quality, ground water discharge and recharge, flood control, and various ecological services. These wetlands and their biotic resources are being by threatened or degraded/declined by injudicious land cover and land use manipulation as evidenced by the indiscreet or haphazard development of settlements and infrastructures and the disposal of urban and industrial waste. Many such wetlands are filled or drained for settlements and agriculture (Jha 2009).

Massive exploitation of bed materials from rivers flowing through the Chure–Tarai region beyond their regenerating capacities is a recognized ecological issue that has emerged with land cover and cultural landscape changes in the region. The natural resources like sand, gravel, and boulders are in high demand for roads, highways, and infrastructures in Nepal and India. The Chure–Tarai rivers are rich in such resources and are good sources of income and revenue generation. However, unscientific and wanton mining of bed materials is reported to have destroyed many ecosystems in the rivers. One study indicated that the extraction activities has lower the groundwater table and caused the depletion of productivity. Ultimately, it causes an increase in pollution and causes a nuisance to the aesthetic beauty of the land (Dahal et al. 2012). Extraction of riverbed materials directly affects hydraulic structures like bridges, dams, and weirs. Other impacts include the destruction of the aquatic habitat, disappearance of native fish species, and invasion of exotic species (Jha 2009; Siwakoti 2006; Dahal et al. 2012).

5.8 Conclusions

Land cover change in the Chure–Tarai region has been a historical phenomenon driven by geopolitics, policies, economics, and social factors. Land grants to the regime’s coterie, installing feudal institutions to collect revenues to cover military expenditure, territorial administration, various policy incentives to attract hill people and Indian immigrants to expand settlements and agriculture in the forest and waste land of Tarai were all important historical processes affecting land cover change until 1950. The end of the Rana regime and the dawn of democracy in Nepal brought reforms in land tenure and abolishment of anti-peasantry policies, which attracted hill people to settle in the Duns, Bhawar, and Tarai by reclaiming cultivated land through forest clearance. Followed by the eradication of malaria in the 1950s and 1960s, planned resettlement programs, and implementation of development projects, attracted people from the hills to the plain lowlands, causing a large-scale change to land cover and to the cultural landscape. A predominance of forest in all physiographic units except Tarai in 1954 was observed. Forest coverage declined in the later decades in lieu of expansion of cultivated land. Forest coverage in the hill slopes, inner river valleys, Duns and Bhawar was in the order of 92, 72, 48, and 79% of the total area in 1954, which had reduced to 89, 43, 36, and 64% in 1979. In Tarai it reduced from 30 to 15% of the total area. Furthermore, by 1994 forest coverage reduced to 85, 24, 29, and 58% of total land area, respectively. Only 10% of the area was under forest in Tarai. Compared to 1994, forest land decreased to 82, 20, 28, and 54% in the hill slopes, inner river valleys, Duns, and Bhawar, respectively, in the last two decades (2015). Forest cover in Tarai virtually remained same. Hence the rate of forest decline over the last six decades was high in the arable areas of the inner valleys, Bhawar, and Duns. On a region basis, highest rate of deforestation was observed in the west. The proportion of shrub/grass area increased in all areas notablyt in the Chure hill slopes, inner river valleys and Duns. This implies a degradation of forest in the hill slopes, which is a threat to the ecology and stability of such fragile slopes. Although conversion from forest to cultivated land is a general trend in recent decades, cultivated land transformed into forest land, shrubland, or grassland has been quite a significant characteristic of the internal dynamics of land cover change, which is attributable to abandonment of cultivated terraces on marginal hill slopes and damage caused by floods, channel shifts, and bank erosion on low land including the Tarai. Contemporary drivers of land cover change are high rates of migration from the hills to the Tarai, economic and infrastructure development increasing physical access and mobility, and urbanization. Illegal settlement on public land and forest encroachment mainly by landless, poverty stricken, and disaster hit people, political instabilities and ineffective forest administration, a continued dependency on forest resources, over grazing, forest fires, landslides, erosion, and floods although all negative forces are also crucial drivers of change. Forest and land resource degradation, loss or threat to biodiversity, increased water induced disasters, disruption of the river and wetland ecology, and depletion of groundwater resources are the negative consequences faced by an environment associated with processes of land cover change. Implementation of well-planned, comprehensive conservation strategies, including land use, settlement, agricultural planning and development, forest and biodiversity conservation and restoration, hazard and disaster management, sustainable use of land resources, and cautious development activities are all required to address the issues of land cover change in the Chure–Tarai region of Nepal.

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Chapter 6
Patch Analysis of Cultivated Land Abandonment in the Hills of Western Nepal

Chhabi Lal Chidi

Abstract Growing natural vegetation on abandoned cultivated land is increasing in many parts of the world. Release of population pressure on marginal hill areas due to heavy outmigration in recent decades has resulted in growing land abandonment at marginal hill areas. Patch-level analysis is a useful method to identify the land abandonment situation. Patch-level data of abandoned and not abandoned cultivated land were derived from Landsat image. Descriptive statistics, abandonment ratio and nonparametric statistical tools have been used. Andhikhola watershed of the middle hill of Nepal is the study area. Land abandonment is higher at higher altitude and north-facing slope. Smaller patches have been more abandoned than larger patches. Even larger patches have been abandoned at higher-altitude regions. Although distance to highway and urban centre have a great influence on land abandonment, there are many other factors among which edge contrast, slope gradient and slope aspect are very important.

Keywords Abandonment ratio · Chi-square · Edge contrast · Land abandonment · Patch size

6.1 Introduction

Growing natural vegetation as a result of decline in traditional agricultural practices can be observed worldwide (Gellrich et al. 2007). Expansion of cultivated land even in mountain slope has occurred due to rapid population growth resulting in growing environmental degradation and poverty in the Nepal Himalaya (Ekholm 1975). In the last two decades, heavy outmigration of population from rural hill and mountain areas has resulted in growing land abandonment because of the relating labour deficit. However, land abandonment is not only because of the depopulation but also because of the fact that the agriculture system of these areas has reduced the

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scope for enhancement of productivity of traditional agriculture also because of fragile mountain environment, poor economies of scale owing to the highly fragmented and diversified biophysical condition, and resistance to adopting modern, market-oriented farming practice by mountain people (Walther 1986; Vogel 1988; MacDonald et al. 2000). As a result, cultivated land is shrinking. Invasion of cultivated land by natural vegetation is increasing day by day (Chidi 2015).

It has a tremendously adverse impact on food security and local livelihood, in areas which have been already suffering from mass poverty and food deficit (Khanal and Watanabe 2006).

Remote sensing (RS) and geographical information system (GIS) technology have made it easier for real-time data derivation of changing pattern of landscape and land use. Landscape metrics are used in research of landscape structure. They analyse the spatial heterogeneity of patches which are useful to quantify the landscape characteristics (Csorba and Szabo 2010). Patch-level analysis is useful for such a highly diversified and fragmented cultivated land such as hill areas of Nepal. Detail information of individual patch such as location, proximity and other related characteristics can be derived using GIS technology. Ratio of abandoned to not abandoned cultivated land is a suitable measure to identify the land abandonment pattern. Distribution pattern of patch-level ratio with their location characteristics is very helpful to identify their determining factors. The knowledge of the changing pattern and spatial pattern of driving factors can be obtained based on the statistical tools. Nonparametric statistical technique is a very useful tool for analysing most land use data because of the data characteristics problems of being normality to use parametric statistical methods. Currently, very few studies have indicated the agriculture land abandonment in Nepal and not a single study focuses on land abandonment situation. Therefore, this study aims to analyse the recent land abandonment situation using descriptive statistics and nonparametric statistical tools in the hill areas in Nepal.

6.2 Method and Materials

6.2.1 The Study Area

Andhikhola watershed of Syangja District, Western Hill of Nepal, is selected as the study area (Fig. 6.1). The geographical extension of the study area is 27°56′20″ to 28°13′46″ north latitude and 83°35′07″ to 83°57′00″ east longitude. This watershed area covers 480.9 km^2 which has altitudinal range between 520 and 2468 m within nearly 35 km aerial distance. Steep hill slopes with streams and streamlets between the hill flank to the upper parts of the watershed area and lower-altitude area containing mostly deposited flat fertile land along the main stream and tributaries. Due to the monsoon region, winter is cold and dry and summer is wet and warm. Climatic data of 2012 show that annual rainfall is 3200 mm. Eighty per cent of total annual rainfall is contributed by summer monsoon and the remaining 20% by winter. Temperature ranges from 5 to 32 °C. The intensive subsistence farming of the area is similar to other such hill areas of Nepal. Some commercial farming and business activities are also another occupation along the highway and other accessible areas. This area is crossed by highway from south-west to north-east which connects this area with other parts of Nepal. There are some other roads which connect other parts of the study area. A few urban and suburban centres along the highway and accessible areas have been developed. Most of them are located in lower parts of the watershed. During the last two decades, there was a heavy out migration of people from rural hill to urban area, tarai area and foreign

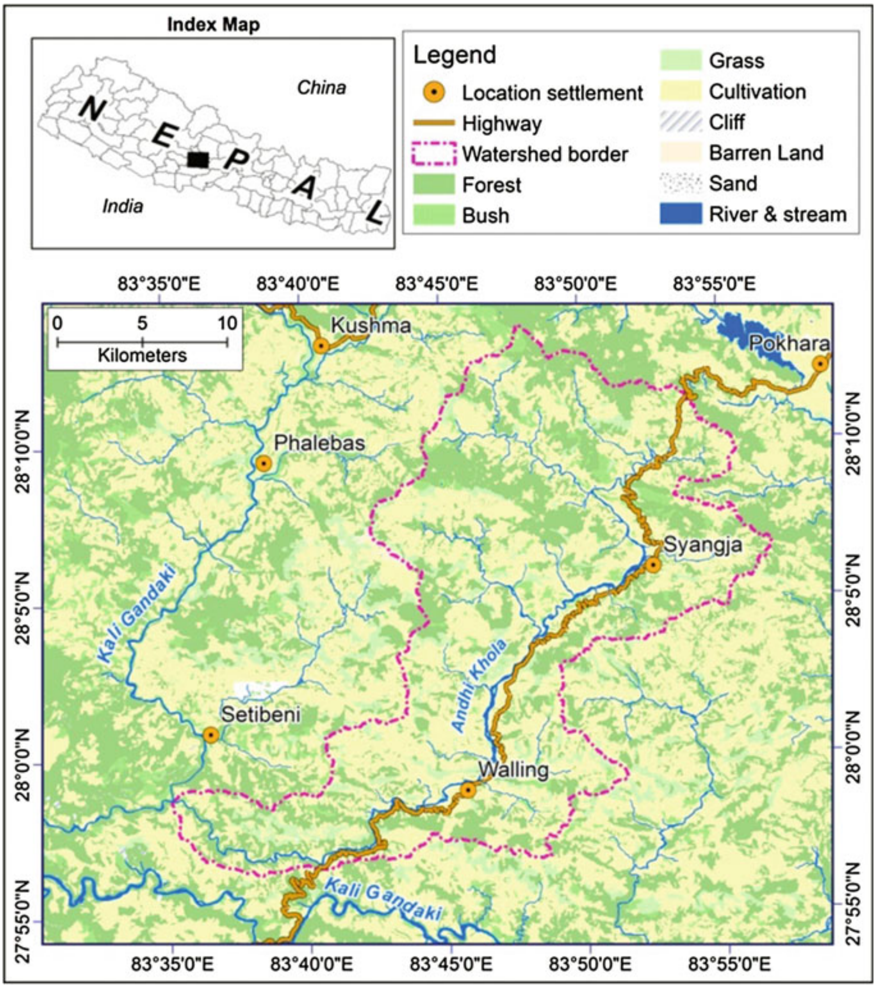

Fig. 6.1 Location of the study area

countries. There is a continuous decrease in sex ratio in the district indicating the increasing male migration from the study area. Annual population change rate during 2001–2011 is −0.93%, yet national rate is 1.35%. It indicates high rate of outmigration of population in this area during this period. People of mountain and hill region of Nepal have limited access to land, knowledge and information about technology and to credit. The land resources they possess are often of poorest quality and prone to degradation. All these factors lead to unsustainable management of land resources and encroachment into marginal land, which in turn leads to a vicious cycle of further poverty and land degradation. Uplands of Nepal are passing through a dynamic stage of demographic scenario, whereby cropland scarcity and less job opportunities in the uplands have resulted in heavy land abandonment in such a short period of time from the past occupancy of marginal land under high population pressure.

6.2.2 Data Generation

Population and sex ratio change in terms of percentage of each ward was calculated from two censuses 2001 and 2011. Land use maps of 30 m spatial resolution were derived from Landsat7 and Landsat8 images acquired in 1999 and 2014, respectively. Images were classified by supervised classification method using maximum likelihood and probability method in Erdas Imagine (Lillesand and Kiefer 1987) Land use was categorized into forest, shrub, grassland, cultivated land, sandy area and water body. Forest, shrub and grassland were combined into vegetated area. Overall accuracy of image classification is 85% in 1999 and 95% in 2014. Ten metres digital elevation model (DEM) was developed by nearest neighbour method using 20 m contour interval of topographical map in ArcGIS. Altitude, slope gradient and slope aspect maps were generated on the basis of DEM. All classified images were converted into vector file in ArcGIS. Separate vector layers were generated for land use change of total watershed area, ward-level land use change, different elevation zones, different slope gradient zones and slope aspects. Raster layers of distance to highway, urban centre and river or stream were generated with surface layer, i.e. DEM. Cultivated land in 1999 but converted to forest, shrubs and grassland in 2014 is identified as abandoned land. Cultivated land which remained so in both 1999 and 2014 is defined not abandoned cultivated land. Converted cultivated land of 1999 to other land use category such as sand, water body is not assumed as abandoned because those lands are forcibly converted land cover due to natural disaster. A map of abandoned and not abandoned patches was prepared. Separate areas of each of the abandoned and not abandoned patches were calculated to identify their size. Adjoining land use category of each of the abandoned and not abandoned patches was identified calculating perimeter length of adjoining land use in 1999. From the field survey, it was reported that cultivated patch surrounded by vegetated area (forest, shrubs and grassland) area is more possible to be abandoned than surrounded by cultivated land because of the problems of protecting crops from wildlife. Edge contrast is the ratio of perimeter adjoined to vegetated area in 1999. Centre points of each pixel of Landsat image were created and it is intersected with abandoned and not abandoned patch to acquire patch ID. Average altitude, slope gradient, slope aspect, distance to highway, distance to urban centre, population change and sex ratio change in each patch were calculated. Population change and sex ratio was derived from ward-level vector file. Finally, variables of edge contrast, patch size, altitude, slope gradient, slope aspect, distance to highway, distance to urban centre, distance to river, population change and sex ratio were developed. Field-level information was gathered when visiting the study area. Informal discussion with local people and concerned district-level line agencies was done. Reality check approach (RCA) was adopted to collect information from fifteen different settlements of the study area. These settlements were selected at different locations on the basis of altitude, accessibility, topography and socio-economic situation.

6.2.3 Data Process and Analysis

Logistic regression model was applied to identify the probability value of abandoned and not abandoned patches of cultivated land. But the result of logistic regression did not give significant determination of explanatory variable on land abandonment situation. So this study used descriptive statistics, abandonment ratio and nonparametric statistical tools such as Chi-square, phi and Cramer's V. Separate mean, standard deviation, maximum and minimum values of each variable of abandoned and not abandoned patches were calculated. Test of difference of means of variables in abandoned and not abandoned was calculated to identify whether the mean is significantly different or not. Mean indicates the differences of the supporting features of land abandonment and not abandonment patches. Standard deviation indicates the deviation of variables from the mean. Maximum and minimum value indicates the ranges or extension of values of each variable which is very useful to identify numerical characteristics of variables.

Abandonment ratio is the proportion of abandoned land in comparison to not abandoned land of a particular region to similar proportion of the whole study area. So, this ratio helps to identify the distribution pattern of intensity of land abandonment situation in the study area. Ratios of abandoned and not abandoned patches and area of separate altitude zone, patch size, edge contrast were calculated. Local land abandonment ratio is calculated by dividing number of abandoned patches by not abandoned patches. Total abandonment ratio is calculated by dividing abandoned number of patches by not abandoned number of patches of the whole study area. Similarly, abandoned area is divided by not abandoned area. Finally abandonment ratio is calculated by local land abandonment ratio by total abandonment ratio. It can be calculated using this formula:

$$R_0 = \frac{\mathrm{L_{ab}}/\mathrm{L_{not}}}{\mathrm{T_{ab}}/\mathrm{T_{not}}} \tag{6.1}$$

where $\mathrm{L_{ab}}$ is the number of patches or total area of abandoned cultivated land in a particular region. $\mathrm{L_{not}}$ is the number of patches or total area of not abandoned cultivated land in a particular region. $\mathrm{T_{ab}}$ is the number of patches or total area of abandoned cultivated land of the whole area. $\mathrm{T_{not}}$ is the number of patches or total area of not abandoned cultivated land of the whole area.

If abandonment ratio is one ($R_0 = 1$), it indicates no difference than average abandonment situation. If the value is two, there is double abandonment intensity. Similarly, less than one indicate not abandonment exceeds the abandonment, which means there is lower abandonment.

The Chi-square test is a powerful statistical tool widely applicable for geographical data analysis because these data are mostly nominal and are based on some sort of frequency grouping. This test may be the most important tool among all distribution free tests and enables us to compare the frequency distributions rather than mean values (Pal 1982). Therefore, all variables were converted into categorical form grouping the certain range of the values. Then, nonparametric Pearson's Chi-square test was used to identify whether there are association of these categorical variables with land abandonment situation or not. Cramer's V and phi values were also calculated to identify the strength of association of variables with land abandonment. The Chi-square is calculated using the formula:

$$\chi^2 = \frac{(O - E)^2}{E} \tag{6.2}$$

where χ is the Greek letter chi and χ^2 is read as Chi-square, O is the total number of frequencies in a class and E is the corresponding expected frequencies.

Since Chi-square does not provide the magnitude of association between two attributes. Therefore, obtained Chi-square value is converted into phi coefficient (Ø) which provides the magnitude of association (Kothari and Garg 2014). Phi coefficient (Ø) is nonparametric measure of coefficient of correlation. It is calculated using the formula:

$$\varnothing = \sqrt{\frac{\chi^2}{N}} \tag{6.3}$$

where N is the number of patches.

Phi can be interpreted as symmetric percent difference, measuring the percent of concentration of cases on the diagonal. It is identical to the correlation coefficient varying from −1 to +1. It is mostly used for two row and two column nominal tables and Cramer's V is applied with no restriction of the number of categories or column and rows. This research has observations of more than two categories of column and two categories of row. Therefore, Cramer's V has also been used in this research. It is calculated using the following formula:

$$V = \sqrt{\frac{\chi^2}{N(k-1)}} \tag{6.4}$$

where k is the number of rows or columns in the table. Cramer's V defines a perfect relationship as one which is predictive or ordered monotonic, and defines a null relationship as statistical independence. However, the more unequal the marginal, the more V will be less than one wherever one is the perfect relation.

6.3 Result and Discussion

6.3.1 General Overview

Total cultivated land in the study area has decreased from 18,987.20 to 15,325.34 ha, i.e. −19.29% change during the period between 1999 and 2014. Accordingly, vegetated area (forest, shrubs and grassland) has increased by 13.15%. During this period most of the abandoned cultivated land was converted into vegetated area. There is an inverse trend of increasing land abandonment with decreasing trend of population change with increasing altitude (Chidi 2015). The land abandonment is increasing with increasing altitude in the study area. There is not significant decreasing trend of land abandonment with increasing slope gradient, but decreasing cultivated land is related to different slope aspects. Southern part has a less proportion of land abandonment in comparison with not abandoned cultivated land. Lower plain area along the river terraces has lower proportion of land abandonment. It is because of the suitable fertile land for cultivation and additionally this area has better irrigation facility. Highway provides a major access in the study area which passes through lowland area. Major urban area is located along the highway. Highway is a major influencing factor for human concentration because of land suitability and accessibility; and development of market centre along the highway. This situation has resulted in population movement from higher altitude to lower area. Lowland area with higher carrying capacity has played lower role as a push factor for migration rather than highland area. Agricultural productivity especially in the hills and mountains is declining due to erosion of fertile surface soils every year. It is because of the decreasing soil quality resulted by improper management system of cultivated land (Joshy et al. 1997). There is decreasing productivity of maize from 3.85 metric ton/hectare in 2007 to 3.27 in 2011 (DADO 2011). Maize is the major food crop of cultivated hill slope in this district. The higher proportion of land abandonment at steeper slope, higher altitude and remote area prove the same situation in the study area (Fig. 6.2).

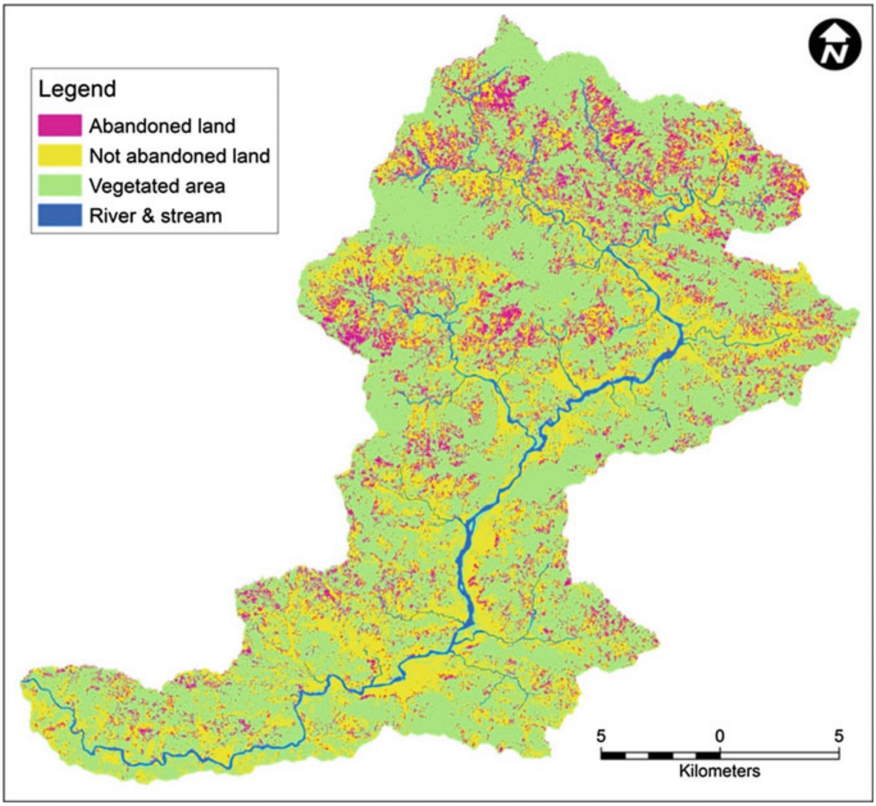

Fig. 6.2 Distribution pattern of abandoned and not abandoned cultivated land

6.3.2 *Variable Characteristics*

Descriptive statistics was prepared from 40,898 observed patches; among them, 28,366 are abandoned and 12,532 are not abandoned. Average values of edge contrast, patch size, altitude, slope, distance to river and sex ratio change in abandoned and not abandoned land are not significantly different (0.01 level of significance). Similarly, mean of population change is also not significantly different (0.05 significance level). Mean value of distance to highway and urban centre are different in abandoned and not abandoned land (see Table 6.1) which indicates that abandoned patches are farther from highway and urban centre than not abandoned patches. Mean and standard deviation of edge contrast in both abandoned and not abandoned cultivated patches seems similar. Smallest patch size of abandoned cultivated land is slightly larger than not abandoned patch, but the largest size of abandoned and not abandoned patch size is highly different. Standard deviation is also highly different (0.82 of abandoned and 12.47 of not abandoned).

Table 6.1 Variable character of abandoned and not abandoned patches

Variables	Mean		Standard deviation		Maximum		Minimum	
	Aban	Not	Aban	Not	Aban	Not	Aban	Not
Edge contrast % (**)	59.28	56.06	30.14	29.62	100	100	0.00	0.00
Patch size in hectare (**)	0.25	0.91	0.82	12.47	71.44	1087	0.04	0.05
Altitude in metre (**)	1174	1163	280.38	269.32	2471	2180	242	520
Slope degree (**)	25.89	24.74	11.74	12.01	67.68	73.88	0.00	0.00
Distance to highway km	4.20	4.15	2.88	2.91	12.50	12.31	0.00	0.00
Distance to Urban km	5.78	5.71	3.14	3.11	14.82	14.25	0.03	0.13
Distance to river km (**)	1.87	1.82	1.21	1.22	5.71	5.74	0.00	0.00
Population change % (*)	−10.24	−9.88	15.14	15.70	59.25	59.25	−60.38	−60.38
Sex ratio change % (**)	−2.14	−2.01	4.21	4.14	9.30	9.30	−9.00	−9.00

Note **Null hypothesis of mean difference is accepted (0.01 significance level)
*Null hypothesis of mean difference is accepted (0.05 significance level)

Altitudinal range of abandoned patch is higher because of maximum and minimum range of abandoned land is higher than not abandoned cultivated land.

Maximum slope of not abandoned is quite higher than abandoned land. It is also the case for standard deviation. So, not abandoned cultivated patches are distributed from the lowest to the highest slope gradient. Levene's test for equality of variance (F-test) indicates that slope gradient, highway distance, urban distance have different in variance in abandoned and not abandoned patches. Variance of edge contrast, patch size, altitude, population change and sex ratio are not significantly (0.01 significance level) different which indicates the local variability is different between abandoned and not abandoned patches.

6.3.3 *Abandonment Ratio*

The land abandonment ratio 0.63 means that proportion of abandoned area in 2014 is 63% if not abandoned area is assumed 100%. It indicates that abandoned area is nearly two-third parts in comparison with not abandoned cultivated land in the study area. The proportion of land abandonment is increasing with decreasing patch size and increasing altitude. Smaller patch have higher proportion of abandonment than larger patch in each altitudinal zone. The proportion of total area of abandoned smallest patches is four times greater than total area of not abandoned patches. At higher-altitude region, there is higher abandonment even larger patch greater than ten hectare (see Table 6.2).

Altitudinal variation has greater impact on land abandonment as indicated in Table 6.2. The land abandonment ratio of the area is the highest at the highest

Table 6.2 Abandonment ratio of area for altitude and patch size

Altitude (m)	Total patch area in hectare						
	0.01–0.25	0.25–0.5	0.5–1	1–5	5–10	Over 10	Total
Over 1700	4.71	2.23	2.70	1.94	0.23	2.58	2.31
1401–1700	4.02	3.66	2.96	2.18	1.33	0.84	2.02
1101–1400	3.79	3.33	2.97	1.95	0.99	0.38	2.09
801–1100	4.22	2.95	1.70	0.82	0.05	0.00	0.64
Below 801	4.28	2.62	2.21	0.32	0.08	0.00	0.19
Total	4.06	3.14	2.32	1.41	0.51	0.10	0.63

altitude above 1700 m. In this region, the area of abandoned land is 2.31 times more than not abandoned area. It continues up to 1100 m with slight decrease. Below 1100 m abandoned area is lower and no existence of larger abandoned patches. It is because of the higher intensity of depopulation with increasing altitude. It indicates the direct effect of depopulation on land abandonment situation at different altitudinal zones.

Average abandonment ratio of patch frequency (number) is 2.26 which means abandoned number of patches is 2.26 times more than not abandoned patches in the study area (see Table 6.3). Table 6.3 indicates that the number of small abandoned patches has exceeded the number of not abandoned smaller patches (see Table 6.3). The highest ratio (1.35) is at higher-latitude region above 1700 m. It indicates that abandoned patches are 35% more than not abandoned patches of the average abandonment ratio of patches in the study area. The ratio of the number of patch size is decreasing with increasing size. It also proves that number of abandoned patches is decreasing with increasing size and altitude. However, the ratio is not decreasing with decreasing altitude. The ratio from 0.5 to 10 ha patch size is higher between 1100 and 1400 altitudinal ranges. It means that this region has higher abandonment of these patch size than higher and lower altitude region. This altitudinal ranges is mostly middle sloppy land, so it has higher abandoned patches of middle sizes.

Table 6.3 Abandoned ratio of number of patches by altitude and size

Altitude in m	Patch size in hectare						
	0.01–0.25	0.25–0.5	0.5–1	1–5	5–10	Over 10	Total
Over 1700	1.35	0.64	0.79	0.58	0.07	0.44	1.12
1401–1700	1.13	1.03	0.82	0.72	0.39	0.23	1.05
1101–1400	1.07	0.93	0.85	0.61	0.28	0.13	0.99
801–1100	1.20	0.83	0.49	0.28	0.01	0.00	0.99
Below 800	1.20	0.73	0.36	0.09	0.03	0.00	0.93
Grand	1.15	0.88	0.66	0.45	0.15	0.07	2.26

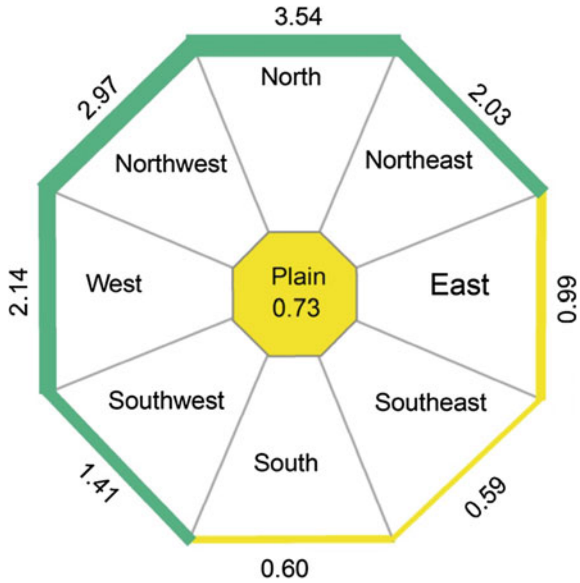

Fig. 6.3 Abandonment ratio of slope aspect. Width of *octagon line* indicates the land abandonment ratio which is also given in numerical value. *Green colour* indicates abandonment has exceeded average land abandonment, and *yellow colour* indicates *lower* proportion of land abandonment than average land abandonment in the study area

The aspect of a slope shows very significant influences on its local climate because of its influence on temperature due to the angle of the sun. In the northern hemisphere, the north side of slopes is often shaded, while the southern side receives more solar radiation for a given surface area insolation, because the slope is tilted towards the sun and is not shaded directly by the earth itself. Hill region of Nepal consists of different slope aspects which are directly related to sun angle and sunny days. Most crop plant needs sufficient sun energy for proper growth, flowering and fruiting crops. So, it is considered that southern face is more suitable for most crops than northern slope face. Figure 6.3 shows the ratio of the area of cultivated land abandonment in different slope aspects. The highest ratio of land abandonment is in the northern slope. This slope aspect has 3.54 times more abandonment area than average land abandonment ratio in the whole watershed area. The second highest ratio is in the north-west. Most shadowy slope aspects such as north-east, north, north-west, west and south-west have exceeded by land abandonment to not abandoned land. Similarly, sunny slopes such as east, south-east and south have less abandoned situation. South-facing slope has the least proportion of land abandonment. Plain area has less abandonment but more than south-east and south. It is because of the fact that plain area does not include only the lower river basin but also includes hill top and hill terraces where the land abandonment situation is higher. The highest shadowy slopes such as north and north-west slope faces have the highest proportion of land abandonment, while the highest sunny slope such as south and south-east have the least proportion of land abandonment.

6.3.4 Association of Land Abandonment

Chi-square test of abandoned and not abandoned patches with categorized ten variables indicates the association of variables with abandoned and not abandoned patch. All variables are associated with land abandonment situation. This result indicates that these ten variables have significant effect on land abandonment. Phi and Cramer's V results indicates that there is a weak strength of dependency of land abandonment on these variables except patch size, but it is equally important to say that the confidence level of association is more than 95%. Mean difference of edge contrast does not indicate the significant difference between abandoned and not abandoned cultivated land. However, Chi-square indicates the association with abandoned and not abandoned cultivated land.

Phi and Cramer's V further proves the weak association. Similar types of association are in patch size, altitude, slope, distance to river, population change and sex ratio. They have different strength of association (phi and Cramer's V is the highest 0.074 of edge contrast to lowest 0.017 of altitude). Patch size has the greatest strength of association among ten variables which has phi and Cramer's V is 0.148. The greater difference on standard deviation and the largest patch size (see Table 6.1) has some evidence of this. Table 6.4 further indicates that there is a significant difference of mean from distance to highway and urban centre which is further proved by Chi-square test. It proves that the significant association of these two variables with land abandonment situation. However, these two variables have also weak strength determining land abandonment situation. Higher strength of influence of slope aspect on land abandonment situation has been indicated (see Fig. 6.3) which is further proved by Chi-square test. The weak strength of association (phi and Cramer's V is 0.065) is shown in Table 6.4. The higher association was in the statistical processing of area of land and its strength has been decreased

Table 6.4 Association of land abandonment with different variables

Variables	Pearson Chi-square		Phi		Cramer's V	
	Value	P value	Value	P value	Value	P value
Edge contrast	224.8	0.000	0.074	0.000	0.074	0.000
Patch size	900.1	0.000	0.148	0.000	0.148	0.000
Altitude	11.43	0.022	0.017	0.022	0.017	0.022
Slope	136.1	0.000	0.058	0.000	0.058	0.000
Slope aspect	170.4	0.000	0.065	0.000	0.065	0.000
Highway distance	129.3	0.024	0.018	0.024	0.018	0.024
Urban distance	20.12	0.003	0.022	0.003	0.022	0.003
River distance	17.54	0.002	0.021	0.001	0.021	0.001
Population change	19.31	0.002	0.022	0.002	0.022	0.002
Sex ratio change	19.08	0.002	0.022	0.002	0.022	0.002

by the calculation using only patch number. Therefore, it can be concluded that patch size of the abandoned cultivated land is much smaller than that of the not abandoned cultivated land.

6.4 Conclusion

Depopulation in the study area has great influence on land use change resulting in increasing land abandonment situation in the study area. Land abandonment is seen everywhere in the study area. However, greater intensity is at higher altitude and northern part of the study area. Lowland river basin area has the least land abandonment. It is because of land suitability for cultivation, better irrigation facility, and accessibility. Highway passes through lowland parallel to the Andhikhola River and most of the major market centres are distributed along the highway. Therefore, land abandonment increases with the increase of altitude and remoteness. This study is based on patch-level analysis of abandoned and not abandoned cultivated land deriving from Landsat image. Ten location characteristics of individual patches were derived using ArcGIS. Different descriptive statistics, abandonment ratio and nonparametric statistical technique were used to identify the association of land abandonment with derived location characteristics. Average characteristics of edge contrast, patch size, altitude, slope gradient, distance to river, population change and sex ratio are not significantly different among abandoned and not abandoned patches but there are significant difference in the size of abandoned and not abandoned patches. Average distance to highway and urban centres are significantly different from abandoned and not abandoned patches. Smaller patches are more abandoned than larger patches. Area of smaller patch size has been abandoned four times more than in comparison with average abandonment ratio. Abandonment ratio is increasing with increasing altitude. Abandoned ratio of number of patches is also increasing with decreasing patch size. Middle altitudinal region have more abandonment than higher and lower region. Even larger patch abandonment is more at altitude above 1700 m. Aspect has greater impact on land abandonment ratio. Higher proportion of land abandonment at shadowy slope faces and the least proportion of land abandonment are in sunny slope. Statistical test proves that there is association of land abandonment and not abandonment with above defined ten location characteristics. Patch size is significantly different among abandoned and not abandoned cultivated land. Although the strength of association seems low, it indicates the significant relation with land abandonment situation. In such a complex topographical feature of the study area, it is very difficult to derive clear-cut picture at general level, so microlevel analysis of land abandonment including social variables is also required.

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Part II
Eco-environmental Change

Chapter 7
Review of Ecosystem Monitoring in Nepal and Evolving Earth Observation Technologies

Hammad Gilani, Faisal Mueen Qamer, Muhammad Sohail, Kabir Uddin, Atul Jain and Wu Ning

Abstract Nepal, a Himalayan country, is situated on the southern slopes of the central Himalayas and represents about one-third of its whole length. Nepal has a population of around 26.5 million and a large proportion of this rely upon land-based activities for their livelihoods. Its elevation ranges 60–8848 masl which constitutes 10 major ecoregions providing diverse ecosystem services crucial for its inhabitants as well as downstream populations. At the ecosystem level, changes in structure, function, patterns of disturbance, and potential impacts of climate change on species are notable concerns. Earth Observation (EO) technologies are being applied for the monitoring and assessment of Nepal on various scales. Since recently, EO supported assessments are also being linked to decision-making processes. In this chapter, we review the status of EO based assessment of key ecosystem components, including forests, rangelands, agro-ecosystems, and wetlands in Nepal. The chapter also looks at the current information gaps and potential use of upcoming satellite technology developments in the context of Nepal.

Keywords Nepal · Earth Observation (EO) · Ecosystem · Forests · Rangelands · Agro-ecosystems and Wetlands

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7.1 Introduction

Nepal, a Himalayan country, is situated on the southern slopes of the central Himalayas and represents about one-third of its whole length. The hills and high mountains (>300 masl) cover around 86% of the total land of the country and 14% of the remainder are flatlands called Terai with elevations lower than 300 masl. While the average length of the country is 885 km from east to west, the width varies from 145 to 241 km. Nepal has a population of around 26.5 million, in 2011, with a population growth rate of 1.35% per annum. A large percentage of its population depend upon land-based activities for their livelihoods (Regmi 2015). It has a total land area of 147,181 km^2, divided into five physiographic regions: High Mountain (34,475 km^2), Mountain (28,895 km^2), Hill (43,503 km^2), Siwalik (18,886 km^2), and Terai (21,422 km^2) (Shrestha et al. 1999). Administratively, Nepal has 75 districts and 4057 village development committees (VDCs). These 75 districts are divided into 14 administrative zones, which are grouped into 5 development regions: far-western, mid-western, western, central, and eastern. The five physiographic and also five development regions are cross cutting each other, named "eco-development regions". Its elevation ranges 60–8848 masl which constitutes 10 major ecoregions providing diverse ecosystem services crucial for its inhabitants as well as downstream populations (Fig. 7.1). Nepal has five climatic zones broadly corresponding to altitudes, i.e., tropical and sub-tropical zones lying below 1200 masl, the temperate zone between 1200 and 2400 masl, the cold zone between 2400 and 3600 masl, the sub-arctic zone between 3600 and 4400 masl, and the arctic zone above 4400 masl (Shrestha et al. 1999).

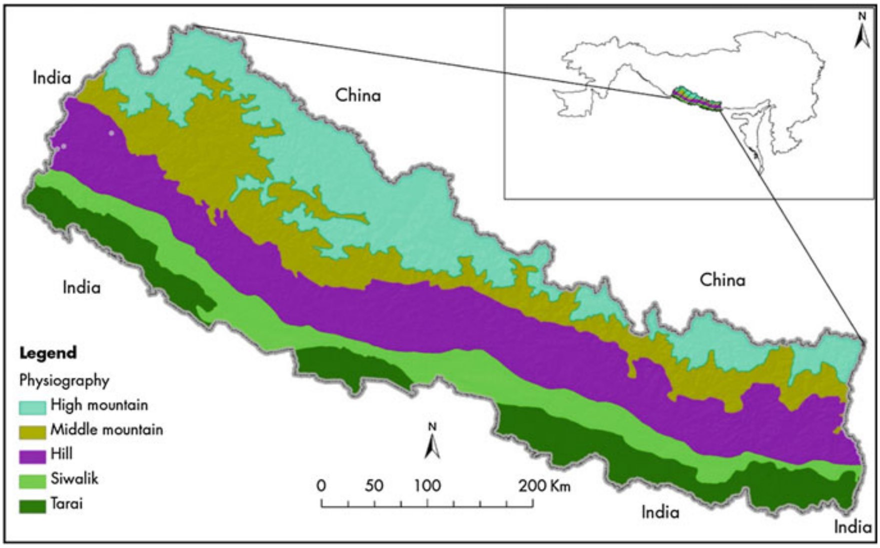

Fig. 7.1 Location map of Nepal

Socio-economic changes such as increasing population, urbanization, mechanization and intensification of agriculture, increased energy demand, migration, globalization, government plans and policies, and political conditions are influencing ecosystems and their services in Nepal. Among all socio-economic factors, population increase is the main driver which triggers other drivers of changing ecosystems. According to the census in 2011, by the Central Bureau of Statistics (CBS), the urban population of Nepal increased from nearly 3% in 1952 to 17% in 2011, with an overall population growth rate of 1.35% per annum. Overall, an increasing trend in population in Nepal is resulting in an increased demand for energy and food at all levels. For instance, demand for fuel wood at a household level is inducing huge pressure on forests especially in the Terai region. Likewise, the challenge of meeting the food demands of an increasing population is also resulting in mechanization and expansion of agriculture, consequently leading to deforestation and shrinkage of grasslands, which is one of the major drivers of land use change from forest to non-forest (all other land cover and land uses except forested land). Climatic factors are also catalyzing socio-economic drivers to affect the ecosystems of Nepal. For instance, climate induced hazards such as floods, droughts, and landslides occurring in vulnerable areas have led to an increased rate of out-migration and competition for food, accommodation, and income opportunities (Niraula et al. 2013).

In Nepal several policies have been devised and legislative measures been taken regarding the conservation, sustainable use, and sharing of benefits from the country's biological resources. The important policies and strategies include (year of policy implementation appears in the parentheses): the Forest Policy (1991 and 2000); Agriculture Perspective Plan (1995); Agriculture Policy (2004); Herbs and Non-timber Forest Products (NTFP) Development Policy (2004); Wildlife Farming, Breeding, and Research Working Policy (2003); and the Wetland Policy (2003). Likewise, other policies and strategies are: Mountain Development Policy (2002); Sustainable Development Agenda for Nepal (2003); Nepal Biodiversity Strategy (2002); Water Resources Strategy (2002); and the periodical policies incorporated in the present Tenth Plan (2002–2007).

Recent developments in Earth Observing (EO) satellite technology, information technology, computer hardware and software, and infrastructure development have helped in the development of a better quality of temporal products, e.g., land cover, land use, forest cover measurement and assessment, agriculture monitoring, long-term rangeland mapping and evaluation, water resource taxation, etc. As a result, such datasets are increasingly being used for wider applications and decision-making processes (Fritz et al. 2012).

In addition, EO data has enhanced our ability to not only monitor but also model the interactions between human activities and natural systems at various spatial levels and geographical scales. While numerous global datasets and derived products have been produced in recent years, emphasis has been put more on making these products accurate and acceptable to the wider user community (Tropek et al. 2014). Existing research suggests that local knowledge and ground-based data information are essential to improve the quality of these products, which then can be applied for better management and decision-making processes (Uddin et al. 2015).

Nepal falls under the category of a data-scarce country, especially in terms of derived EO data products. Involvement of government and non-government, as well as independent, researchers is minimal in producing EO-based ecosystem service products. In this chapter we review the current status of EO-based data products of key ecosystem components, including forests, rangelands, agricultural lands, and wetlands in Nepal. The chapter also looks into current information gaps and potential use of upcoming satellite technology developments in the context of Nepal.

7.2 Forest Cover Assessment and Monitoring

In Nepal several forest cover change assessment studies have been conducted using different datasets and methodologies at different scales and time intervals (Uddin et al. 2015; Paudel et al. 2016). According to Forest Resource Assessment (FRA) carried out by the Food and Agriculture Organization of the United Nation (FAO), forest cover reported 48,170 km^2 (32.73%) for 1990, 39,000 km^2 (26.5%) in 2000, 36,360 km^2 (24.7%) in 2005, and 36,360 km^2 (24.7%) in 2010 (FAO, 2010). The Land Resource Mapping Project (LRMP) for 1978/1979 mapped forests and scrubs separately and their forest classification consists of four density classes (0–10, 10–40, 40–70, and 70–100%). Additionally, each forest zone is defined according to the dominant forest type (coniferous, hardwood, or mixed) and the presence of various dominant species. The FRA was made through the combined use of aerial photographs (1977–1979), extensive ground truthing, land surveys, and topographic maps. The resolution of the aerial pictures was approximately 1:12,000 allowing the creation of land cover maps at both 1:25,000 and 1:50,000 scales. Recently, the Ministry of Forests and Soil Conservation, Department of Forest Research and Survey, in Nepal, assessed the "state of Nepal's forests" using RapidEye satellite imagery (2011–2014), secondary images (Google Earth, Landsat), ancillary maps (Land Resource Mapping Project (LRMP) and topographical sheets), and field inventory data (DFRS 2015). This assessment found: forest cover 59,600 km^2 (40.36%), other wooded land cover 6500 km^2 (4.38%), and other land cover 81,600 km^2 (55.26%). These two datasets are considered the most authentic and are accepted by the Nepalese government for reporting purposes. Another recent national land cover database for Nepal developed by Uddin et al. (2015) is based on Landsat TM data for 2010. According to this dataset about 39.1% of Nepal is covered by forest land.

Apart from these national level datasets, a number of sub-national/local-scale land cover, especially forest cover, studies have been undertaken in Nepal (Bhattarai et al. 2009; Gautam et al. 2002; Niraula et al. 2013; Jackson et al. 1998; Chaudhary et al. 2016; Bajracharya et al. 2010; Schweik et al. 1997; Gautam et al.

2003, 2004; Bishop 1990; Thapa 1996; Thapa and Weber 1990; Thapa and Murayama 2012; Virgo and Subba 1994; Khanal 2002). While these sub-national/local-scale studies not only developed maps but also report forest cover estimates based on socio-economic and biophysical datasets, these datasets are either out-dated or were not collected using systematic approaches. Therefore, it is difficult to estimate the accuracy of the change values, which can be used for comparison purposes (see Tables 1 and 2 in Paudel et al. 2016).

Monitoring and mapping forest degradation and carbon stocks is more challenging as it relies on ground measurements with complementary remote-sensing tools (GOFC-GOLD 2009). Thompson et al. (2013) proposed seven indicators for five remotely sensed criteria (although improving calibration requires ground work) to determine forest degradation in the context of sustainable ecosystem management. Acharya and Dangi (2009) and Acharya et al. (2011) reviewed data and methods in the context of Nepal's forest degradation. They propose the use of EO data and methods along ground information to assess forest degradation. Panta et al. (2008) used Landsat satellite data (1976–1996) to assess and map forest degradation over the Chitwan district. They conclude that forest areas of all forest types, other than riverine forest, has been reduced.

7.2.1 Community Forestry and Protected-Area Monitoring

The Forest Act, 1993, identifies two primary kinds of forest (national and private) and five secondary kinds of forest under national forests (government managed, community managed, protected forest, leasehold forest, religious forest, and private forest). About 1.45 million households or 35% of the population of Nepal is involved in a community forestry management program. To date, 17,685 community forestry user groups (CFUGs) have been formed (DoF 2012). A total of 16,526 km^2 (11.2% of total area of the country) of national forest have been handed over to people as community forests from which 2,177,858 households have benefited. In Nepal, there are 10 national parks, 3 wildlife reserves, 6 conservation areas, 1 hunting reserve, and 12 buffer zones in and around parks/reserves covering an area of 34,185 km^2 (23.3% of the total area of the country) (DoF 2012). Approximately, 30–50% of the revenue earned by national parks and wildlife reserves are ploughed back to the local surrounding communities for development work. In forests outside protected areas, community users utilize all financial benefits from the sustainable use of forests. The lesson Nepal has leaned is that the peoples' participation is crucial for forest conservation.

Jordan (2002) conducted a study through a participatory GIS approach in the Yarsha Khola watershed, Dolakha district. Likewise, Shrestha and Tuladhar (2005) have worked on intensive field surveys in 36 community forest user groups to delineate forest boundaries in the Jhikhu Khola watershed, Kavre District. The community forest boundaries were drawn on transparent overlaid on top of enlarged 1:5000-scale aerial photographs. These studies revealed that use of geospatial data and techniques with the integration of local inform can help advance community forestry towards better management.

A REDD + pilot project, is being implemented across three watersheds, Kayar Khola in the Chitwan district, Ludi Khola in the Gorkha district, and Charnawati in the Dolakha district, representing the three regions of plains, hills, and mountains. Under this community forest REDD + project, 112 community forests, 89 leasehold forests, and 4 private forests were delineated through participatory GIS approach using high-resolution satellite images from GeoEye-1. This project showed how a community forest with delineated boundaries can be used to extract biophysical (deforestation, forest degradation, enhancement, and carbon stock change) and social parameters (Gilani et al. 2015). Niraula et al. (2013) also showed real, measured impacts of community forestry programs through ground repeat photography and satellite remote-sensing images in the Dolakha district of Nepal.

The usage of EO data and technologies for monitoring and management of protected areas in Nepal are rarely functional, therefore, limited comprehensive systematic studies are carried out, which can account for forest dynamics over long time periods. Zomer et al. (2001), investigated the dynamics of forest cover change along the riparian corridors within the newly established Makalu–Barun National Park and Conservation Area (MBCA) of eastern Nepal based on a comparison of remote-sensing data over a 20-year interval. Nagendra et al. (2004), Chaudhary et al. (2016), and Chettri et al. (2013) assessed the implications of land cover change periods of the last 34 years (1976–2010), on ecosystem services and the dependency of people in the Koshi Tappu Wildlife Reserve, Nepal. The analysis revealed that the Koshi Tappu Wildlife Reserve has gone through significant changes in land cover and ecosystems over the last 34 years due to the change in river course and anthropogenic pressure leading to direct change of species' habitats.

7.2.2 Forest Biomass and Carbon Stock Estimation and Mapping

Gibbs (2007) reviewed different remote-sensing datasets by discussing the benefits, limitations, and uncertainties of different remote-sensing platforms. In most of the studies, field-measured biomass values are being used as training methods for predicting biomass values linking biophysical parameters extracted from remotely sensed data. Design (sample extrapolation) or model (empirical and mechanistic) based remote-sensing approaches are being commonly adopted for biomass assessment and mapping (Kajisa et al. 2009; Huang et al. 2013; Cho et al. 2012; Gonzalez et al. 2010).

In Nepal a number of studies have been conducted to map AGB maps at the local (Hussin et al. 2014; Mbaabu et al. 2014; Karna et al. 2015; Gilani et al. 2015) to sub-national (Joshi et al. 2014; Puliti 2012) levels. These efforts are necessary, because of the high diversity and complexities in Nepal in terms of altitude, terrain, bio-diversity, and socio-demography. These poses the need to understand their interactions in order to support land resources development and conservation on different spatial scales. More recently ICIMOD has developed an online web system to publish biomass and carbon stock maps (http://apps.geoportal.icimod.org/biomass) and other relevant layers (i.e., forest cover, 2010, elevation, maximum tree canopy height, and census population, 2011). Using this website users can also collect data for the available demand and balance of biomass values on the VDC level. These efforts will also aid the Forest Carbon Partnership Facility (FCPF) program of the World Bank (WB), which has chosen Nepal as one of four countries for a result-based payment system for the REDD + scheme (reducing of emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries).

7.2.3 Gaps—Forest Cover Assessment and Monitoring

- Systematic temporal assessment of forest cover (deforestation and forest degradation).
- A detailed digitized community forests boundaries database along with 3D mapping of community forests for management and planning purposes.
- Monitoring the performance of community forests using satellite data (high- or medium-resolution).
- Continuous monitoring of all protected areas for better management and conservation practices.
- Local (community forest, VDC) to sub-national (district) to national level forest inventory data to integrate remotely sensed data for biomass and carbon stock mapping and monitoring.
- Dissemination of national-level remotely sensed products to local to sub-national level, for ownership and validation.
- Long-term ecological monitoring using permanent sampling with consistent and harmonized satellite data and methodology.
- Linking socio-economic dynamics with the products derived from remote sensing to understand real drivers, causes, and impacts.
- Requirement for a common platform to assess all available datasets (forest cover, forest inventories, socio-economical, etc.)

7.2.4 Future Perspective—Forest Cover Assessment and Monitoring

- Active remote-sensing: to date almost 90% of studies are being conducted using optical data. In Nepal there is a lot of scope and potential to study forest ecosystems using active remote-sensing data (RADAR, LiDAR).
- Instant mapping and analysis techniques: Unmanned Aerial Vehicle (UAV), terrestrial laser scanning systems, etc., can provide instant and the most accurate results.
- State of the art technology: ubiquitous computing, geo-sensor networks, geospatial data infrastructures, digital earth, big data, cloud computing, web 2.0, the internet of things, and crowd-sourcing are emerging.
- Decision Support System (DSS): most web portals are just for visualization of spatial and somewhat temporal datasets. Work is required on a collective DSS which can provide a one-stop solution for policy and decision makers.

7.3 Rangelands Management and Monitoring Practices

Rangelands in Nepal comprise of grasslands, scrublands, and sparse forests that are distributed all over the country ranging from the sub-tropical savanna in the Terai to the alpine and sub-alpine grasslands in the high mountain region. In Nepal, rangelands are the basis for the livelihoods of the local communities and contribute significantly to the national economy and more importantly rangelands are a unique habitat for biodiversity and overall ecosystems. In high-hill and mid-hills regions, livestock farming is the main source of livelihood of the people and rangelands are the major basis for livestock production. Rangelands management is expected to contribute to livelihood improvement and food security, reduce internal migration, and minimize the effects of climate change.

According to the LRMP land use map about 1.7 million hectares or 12% of the total land in Nepal is rangeland, the majority of which lies in mountains, mid-hills, and the lower hills (Yonzon 1999). LRMP data suggests that 70% of the rangelands are situated in the western and mid-western regions. It is estimated that only 37% of the rangeland forage is actually available or accessible for livestock. However, another study by Joshi et al. (2013) reported 7.8 million hectares (53%) of rangeland in Nepal, based on GlobCover2009 (300-m), MERIS sensor on board the ENVISAT satellite mission.

Paudel and Andersen (2010) identified Ghiling in the Upper Mustang, Nepal as a degraded grazing area. They analyzed Landsat MSS, TM, ETM+, and SPOT images ranging 1976–2008 and NOAA NDVI data from 1981 to 2006. Even in this study, a weighted grazing pressure surface model was developed combining information from satellite images, topography, forage availability, and detailed field work data on points of livestock concentration, herder rankings of forage quality, and grazing patterns in each pasture unit.

7.3.1 Rangelands Management—Key Questions

- What are the strategic elements that can be prioritized for addressing the issues of rangelands degradation and desertification in Nepal?
- What are the priority research areas in developing an understanding of the relationship between wetlands and rangelands in a holistic manner?
- How to approach the long-term monitoring of rangelands and how to assess the impacts caused by climate and socio-economic changes in Nepal's rangelands?
- What are the vulnerabilities and adaptation possibilities for pastoralists in Nepal?
- How can ecosystem services arising from rangelands be evaluated in economic terms and how can a reward system for pastoralists be developed?
- How can new potentials be integrated in terms of both adaptation and mitigation in the rangelands management of Nepal?

7.3.2 Challenges in Monitoring Rangelands

In spite of their importance, the rangelands of Nepal have not been comprehensively studied and the detailed accounts of their various aspects are not available. Some of the outstanding unresolved issues related to rangelands in Nepal are: (1) overlapping definitions of rangeland, pasture, grassland, and other types of land use that produce forage; (2) difficulties in estimating the amount of range use because of their remoteness; (3) the intensive and extensive nature of herd movement patterns; (4) a lack of estimates of mountain agro-pastoralist; and (5) a lack of grazing patterns/systems for households depending on rangelands.

Rangeland areal coverage in any region is directly dependent on natural factors, such as climates, especially when the area is calculated using remotely sensed data. One of the fundamental keys is the data capturing time of remote-sensing. For example, if the data is captured after the rainy season, the vegetation flourishes well and the rangeland areas can be easily identified compared to other land covers. On the other hand, if the area lies in a low-rainfall region, then it is not only difficult to identify the vegetation classes, but also rangeland areas would be highly diminished. Hence, the temporal identification and mapping of rangeland areas is necessary to understand the dynamics of rangeland coverage. In addition, information on rangeland dynamics is necessary for the sustainable management of rangeland resources. This aids understanding the most detrimental factors like overstocking and overgrazing in rangeland management, things which are mostly responsible for the degradation of rangelands.

Spatial and spectral resolution of sensors, play a very important role for classifying land features, as it is directly proportional to the coverage area. If the coverage area is large, medium to coarser resolution satellite data can be effectively used for mapping and monitoring whereas for small areas high-resolution data is necessary to delineate rangeland areas accurately in different ecological regions of Nepal's Himalayan range. The topographic effects, such as Earth's curvature, mountain shadow, and clouds also create obstacles to monitoring rangelands through optical remotely sensed data. To determine rangeland types and associated productivity, knowledge of the geographical distribution of soil type is necessary.

7.3.3 Future Prospective—Rangeland Assessment and Monitoring

- Medium to coarse resolution satellite data: in Nepal almost 96% of rangeland exists in hills to high mountains (mostly inaccessible areas). Medium (Landsat, Sentinel, etc.) to coarse resolution (MODIS, NOAA, etc.) satellite images for long-term monitoring of vegetation and more specific rangelands.
- Integration of datasets: climatic, social, livestock, and biophysical datasets must be integrated to understand the holistic picture of rangeland dynamics and to provide evidence for range managers that the trend is either upward, downward, or stable. If the trend is downward then the range manager can reduce livestock numbers, instigate more uniform grazing practice using fencing, herding, or developing new watering points, or develop an intensive grazing management system involving appropriate combinations of rest, rotation, and deferment.
- Long-term monitoring: flux tower sites use eddy covariance methods to measure the exchanges of carbon dioxide (CO_2), water vapor, and energy between terrestrial ecosystems and the atmosphere. Geo-tagging camera trapping methods analyze the movement of grazing animals with the integration of biophysical parameters (NDVI, EVI etc.). Although these techniques are bit expensive but can be utilize for long term monitoring and reporting.
- Species level assessment: there are a number of hyperspectral satellites and sensors (Hyperion, high-resolution hyperspectral imager with 220 spectral bands; HySI, Hyper Spectral Camera with 64 fixed bands; HIS, hyperspectral instrument with 232 spectral bands, etc.) available, which can provide a detailed assessment and monitoring of rangelands.
- Modeling and up-scaling: machine learning algorithms (linear regression, logistic regression, decision tree, naive bayes, random forest, etc.) are very much established using metrics to train and validate the models to assess and monitoring for larger, and inaccessible, areas. For metrics, biophysical parameters can be extracted from satellite and ground collected data.

7.4 Agricultural Monitoring

In Nepal two-thirds of the total population depends on agriculture for their subsistence and more than one-third of the Gross Domestic Product (GDP) comes from the agricultural sector. Ensuring effective agricultural production across the country has been a serious challenge due to the high degree of spatial and temporal climate variability, irrigated and rain-fed agricultural systems, coupled with the fragile social and economic fabric holding farming communities together, as well as unique mountain practices. The government of Nepal has given high importance to ensuring food security for all its citizens. The country's Interim Constitution of 2007 has given recognition to food sovereignty as a basic human right. Recently, policy makers have shown increased interest in revitalizing the national food security monitoring system. Food security has figured prominently in planning and policy documents so that the 2007–2010 Interim Plan devoted a major chapter to aspects of food security ranging from food availability, access and utilization issues, to early warning and disaster preparedness and response. Food availability, derived from crop sown areas, diseases, and weather impacts and crop yield, are some of the key variables for assessing food security at a national level. Currently a number of government and international organizations are involved in food security monitoring activities through field-level data collection on food security status, crop conditions, weather situations, market outlooks, nutritional status, local development activities generating income, etc.

7.4.1 Conventional Monitoring System

In the current conventional agriculture monitoring system the District Agricultural Development Office (DADO) is responsible for collection of weekly crop situation data. Seasonal crop cutting exercises are conducted for the main cereal crops to verify the Ministry of Agricultural Development (MoAD) crop estimates. In the past, MoAD, the World Food Programme (WFP), and FAO have conducted joint crop and food security assessments to determine the extent of crop loss due to drought and floods and assess food security impacts. The WFP field monitors collect quarterly crop status and outlook data and prepare district crop loss maps. In the context of drought monitoring, the Department of Hydrology and Meteorology publishes monthly weather and rainfall reports. Rainfall stations are however limited and other techniques need to be explored, such as satellite imagery, to improve the rainfall information. In addition, WFP field monitors also prepare district wide rainfall maps based on the perception of people as to whether rainfall was normal, below normal, or above normal. Continuous monitoring of in-season changes in climate conditions and their impacts on allied crops is still a major challenge in the existing monitoring system. For any operational agriculture monitoring systems, early drought detection, monitoring drought development, intensity and impacts on agriculture, early assessment of crop sown areas, and monitoring of crop growth conditions is extremely important, especially in Nepal where the irrigation infrastructure is poor and agriculture practices are closely intertwined with climate variability.

7.4.2 Integration of EO Data Products

Remote-sensing data, in combination with ground data, can reveal valuable information about environmental conditions that may affect farmers' livelihoods. GIS and remote-sensing technologies can help in identifying regions experiencing unfavorable crop growing conditions and food supply shortfalls, and determine food insecure areas and populations (Minamiguchi 2004). EO data offer timely, objective, cost-effective, repetitive, and synoptic information that can be used to monitor agricultural land over large geographic areas. Research over the past several decades in the field of agricultural remote-sensing has led to the development of substantial capacity for crop monitoring and production estimation using EO. Satellite remote-sensing has become an integral component of operational agricultural monitoring systems, enabling crop analysts to track development of growing seasons, and provide actionable information to decision makers for developing effective agricultural policies and timely responses to food shortfalls.

In an effort to exploit the use of remote-sensing data products in the existing crop monitoring system the MoAD, WFP, and ICIMOD made a collaborative effort in designing, validating, and operationalizing a robust and effective agriculture-monitoring system in Nepal. This system analyses historical climate data using the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), rainfall data, and other EO-based data with current conditions. Drought conditions are assessed using the monthly and three-monthly Standardized Precipitation Index (SPI) on a near, real-time basis. Assessment of in-season crop sown areas for three major cereal crops, including wheat, maize, and rice, are made during the growing season based on MODIS satellite data. Using remote-sensing data for vegetation indices, temperature, and rainfall, the system generated anomaly maps are inferred to predict the increase or shortfall in crop production. Comparisons can be made both spatially and in graphs and figures at district and VDC levels (Qamer et al. 2014). Timely information on possible anomalies in crop production can later be used by institutions like MoAD and WFP to trigger appropriate management responses.

7.4.3 Gaps and Future Priorities—Agricultural Monitoring

- Considering the small farm sizes and mixed cropping patterns in Nepal, the development of high-quality, crop-type maps along with a local farming practices calendar is imperative to lay the foundation of an effective crop monitoring system. The launch of Sentinel-2 and Landsat-8 is expected to provide the most useful optical imagery for crop-type mapping and agricultural monitoring (Claverie 2015).

- In the current drought-monitoring system, the SPI is being used as a drought hazard indicator. While it has well-established advantages within the precipitation-only drought indices, the limitation of SPI lies in its presumption of a direct consequence of crop production losses in a given region and that it does not account for the role played by the soil in regulating moisture in the crop root zone. There is a need to establish a drought indicator which displays the performance of crops based on the availability of water during the growing season whilst also considering crop type and soil conditions (Verdin and Klaver 2002).
- At the farming level developing a locally relevant and comprehensive agriculture advisory. The advisee will also require information on aspects like existing farming practices calendars, local crops, agricultural market prices and arrivals, availability of fertilizers, electricity timings, early warning systems for disasters, plant and veterinary disease prevention, financing, and insurance services. An efficient use of available agro-metrological data, along with local biophysical conditions and farming practices, in the form of an advisory service, could minimize the adverse effects of extreme weather and take advantage of favorable weather.

7.5 Wetlands Mapping and Monitoring

The wetlands of Nepal, however, range from the torpid ponds of the sub-tropical Terai to the glacial lakes of the high Himalayas, which indicate the diversity in the species of wildlife that might be expected to be supported by them. The Nepal wetlands cover over 7,435 km^2, i.e., nearly 5% of the area of the country. The Terai consists of large numbers of wetlands (163) followed by hills and the mountains (79) extended from Mechi in the east to Mahakali in the west. At present only 9 wetlands are included in the Ramsar sites (Table 7.1). Wetlands of Nepal have 193 of the 841 recorded bird species. Of the 91 threatened species of flora and 89 threatened species of fauna; 11 flora and 59 fauna are dependent on wetlands for all, or part of the year. Wetlands are probably the last refuges of some wild relatives of cultivated plants (Rijal 2016).

Lakes/wetlands provide water for irrigation, maintain biodiversity, enhance livelihoods of the people through ecotourism, form a basis for cultural and spiritual development and so on. The lakes of Nepal are culturally important in higher altitude areas for example Jatapokhari, Pach Pokhari, Gosai Kund, Maipokhari, and so on. The mid-hill lakes are beautiful and in Terai the lakes and wetlands are productive due to agricultural activities. However, according to the census, 2001, about 21% of Nepalese ethnic groups are directly depended on water. A map-based inventory conducted in 2009 by the National Lake Conservation Development

Table 7.1 An overview of ramsar sites in Nepal

No	Ramsar sites	District	Location	Area (km^2)	Zone	Attitude (m)	Ramsar designation date
1	Koshi Tappu Wildlife Reserve	Sunsari	26°39′ N, 086°59′ E	175	Terai	90	17.12.1998
2	Jagadishpur Reservoir	Kapilvastu	27°35′ N, 083°05′ E	2.25	Terai	195	13.08.2003
3	Ghodaghodi Lake Area	Kailali	28°41′ N, 080°57′ E	25.63	Terai	205	13.08.2003
4	Beeshazari and Associated Lakes	Chitwan	27°37′ N, 084°26′ E	32	Terai	285	13.08.2003
5	Rara Lake	Mugu	29°30′ N, 082°05′ E	15.83	Himal	2990	23.09.2007
6	Phoksundo Lake	Dolpa	29°12′ N, 082°57′ E	4.94	Himal	3610	23.09.2007
7	Gosaikunda and Associated Lakes	Rasuwa	28°05′ N, 085°25′ E	10.3	Himal	4700	23.09.2007
8	Gokyo and Associated Lakes	Solukhumbu	27°52′ N, 080°42′ E	77.7	Himal	5000	23.09.2007
9	Mai Pokhari	Ilam	27° 0.42′ N, 087° 55′ E	0.9	Midhill	2100	27.11.2008

Committee (NLCDC) lists 5358 lakes in Nepal. Nepal is a signatory to a number of international conventions and treaties to protect the environment and biodiversity. Three of these are of special importance in relation to the conservation of wetlands:

1. Convention on the wetlands of international importance, especially waterfowl habitats (Ramsar Convention), signed on 17 December 1987.
2. Agreement on the network of aquaculture centers in Asia and the Pacific, signed on 8 January 1988.
3. Convention on biological diversity, signed on 12 June 1992.

Bhuju et al. (2009) compiled a map-based inventory of lakes of Nepal. A list of 5358 lakes have been prepared using topographical sheets, whereas only 278 lakes were identified on district maps. In this inventory, the classification and categories of the lakes is still missing. In Nepal, particularly wetlands are being neglected in terms of detailed mapping, monitoring, and management.

7.5.1 Gaps and Future Priorities—Wetlands Monitoring

- National level inventory and monitoring: on the national level, first need an up-to-date inventory of wetlands is essential using high-resolution (GeoEye, IKONOS, WorldView etc.) to medium-resolution (Landsat, SPOT, Sentinel) satellite data. Second, need systematic monitoring using temporal high-to-medium-resolution satellite images. Aquatic and terrestrial vegetation and mineral mapping and monitoring is also essential to understand the impact of the surrounding environment and overall climate change.
- Habitat suitability modeling: integration of biophysical and species level ground data can be used for habitat suitability modeling of various flora and fauna species (e.g., Spatially Explicit Species Index (SESI)) models can be utilized to predict biological responses of selected species to diverse scenarios of projected alterations in hydrological regimes).
- Long-term and continuous monitoring: the permanent sample plots, flux towers, and geo-tagging camera trapping can be utilized for long-term conditions monitoring of wetlands. Assessment of the quality of water and its impact on aquatic and terrestrial flora and fauna needs to be monitor and analyzed.

7.6 Conclusion

Through review we observed that except for forest land the rest of the ecosystems of Nepal are not being explored and properly monitored through EO technologies. From the monitoring point of view lots of scope and opportunities exist. First of all national as well as sub-national level frameworks need to be developed and then implemented. To overcome research collaboration, technical training and infrastructure development in the geospatial domain is very much needed (Murthy et al. 2016).

The quantitative assessments of ecosystem elements and monitoring the changes over time and space are key to a wide range of interventions on issues of national to global interest, including land degradation, climate change, food security, poverty, and environmental sustainability. Remote-sensing based assessments provide an efficient and transparent means to conduct these assessments across space and time. In Nepal, a good amount of work has been accomplished by utilizing medium-to-high-resolution optical remote-sensing data. Recently, use of active remote-sensing like RADAR and LiDAR data has gained momentum, particularly in the context of forest structure monitoring and wetlands characterization.

In Nepal, there has been some early efforts made to use UAV as a middle ground between space-based assessments and ground-based assessments. However, these UAVs lack an adequate number of sensors and sophistication to calibrate data with ground conditions. In general, much of existing remote-sensing work helps us gather observed changes—either in spatial patterns or over time at any given location on a pixel by pixel basis. However, a weakness of some of this work is that it is either very coarsely linked to ground features or not linked at all. There is a clear and present need to add more verification and meaning to spectral information in a consistent manner, that is to fill in the middle ground between ground work and remote-sensing work in the same area, and establish real links. By linking remotely sensed data with site-based data, ecological questions can be addressed across a range of spatial scales.

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Chapter 8
Spatio-temporal Patterns of the Net Primary Productivity in Southern Himalayas During 2001–2015

Xi Nan, Ainong Li, Wei Zhao, Jinhu Bian, Huaan Jin, Wei Deng and Hriday Lal Koirala

Abstract Vegetation in southern Himalayas is susceptible to both extrinsic (e.g., climate change) and intrinsic (e.g., earthquakes) factors. Analysis of spatio-temporal patterns and variability of net primary productivity (NPP) help to understand ecological functioning in this area. Based on MODIS net primary productivity data (MOD17A3H), we investigated the spatial distribution of NPP values and its spatio-temporal variation in southern Himalayas during 2001–2015 with the methods of gross statistics, correlation analysis and spatial statistics. The impacts of the Nepal Ms8.1 earthquake in April 2015 were also analyzed. The results indicate that: (1) in the past 15 years, NPP in southern Himalayas maintains a growth trend in general, with an average amount of 1.60 g $\mathrm{Cm}^{-2}\ \mathrm{a}^{-1}$, while the tendency appears negative at lower altitudes below 1000 m, and positive in the mid-altitude areas and above; (2) NPP in southern Himalayas is characterized by vertical altitudinal belts, among which, NPP reaches to a maximum at the altitude of 1200–2700 m with an average of about 800 g $\mathrm{Cm}^{-2}\ \mathrm{a}^{-1}$; (3) The average NPP values of evergreen broad-leaved forest, deciduous forest, coniferous forest, grassland, sparse vegetation in southern Himalayas were 835.0, 711.6, 623.9, 144.8, 25.5 g $\mathrm{Cm}^{-2}\ \mathrm{a}^{-1}$, respectively, and their average growth rates are 5.08, 2.17, 1.135, 0.7086, 0.22 g $\mathrm{Cm}^{-2}\ \mathrm{a}^{-1}$; (4) Along the major axis of high seismic intensive

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region, anomalous decreases of NPP could be found in a period of five years before earthquake (from 2010 to 2014). There is a positive correlation between these anomalous areas and average temperatures, but negative correlation with rainfall, which suggests that anomalous decrease of NPP may correlate with tectonic activity before the earthquake occurs.

Keywords NPP · Time-series analysis · 4.25 earthquake · Nepal · Remote sensing

8.1 Introduction

Himalayas are located in the southern margin of the Tibetan Plateau, where the warm moist flow from the Indian Ocean is blocked by the 2450 km range of mountains and developed altitudinal vegetation belts in southern Himalayas. It is a typical area for its biodiversity and referred to as an important ecological barrier in South Asia. Because of its susceptibility to the climate change and impacts on the global ecological environment, the area has drawn great concern and is regarded as a significant place carrying out vegetation observation and eco-environment analysis. In addition, Himalayas are on the orogenic zone of the Eurasian and Indian plate, hence are subjected to tectonic activities and frequent earthquakes. Strong earthquakes not only cause short-term ecological damage but also bring more complex driving factors and anomalies for regional ecological environment modeling.

Extensive researches on the eco-environment evolution in Tibetan Plateau have been conducted in recent years, and progresses were made in several ways, such as spatio-temporal pattern of regional eco-environment, responses to climatic variation, land cover pattern, carbon cycling and interrelationship among the factors mentioned above (Deji and Lu 2013; Li et al. 2013; Zhang et al. 2013; Sun et al. 2014; Qi et al. 2016). Annual net primary productivity (NPP) of terrestrial vegetation, which characterizes the net amount of carbon fixed by plant photosynthesis, is not only a crucial index in global change ecology but plays a vital role in the research of carbon cycling and ecological resources management (Field et al. 1998; Wang et al. 2013). It is already prevalent to estimate NPP values in Tibetan Plateau (Wu et al. 2003; Zhou et al. 2004; Wang et al. 2007; Zhang et al. 2013); however, in southern Himalayas, there spatio-temporal pattern of NPP and the influence factors are still dimness. Moreover, NPP disturbance in Pokhara area in Nepal is especially in need of investigation after the violent Nepal earthquake (happened on April 25, 2015).

Recently, moderate-resolution imaging spectroradiometer (MODIS) data are widely used in estimation of regional NPP. MOD17A3, produced with MODIS parameters through the BIOME-BGC model, is the NPP data of global terrestrial vegetation. By far, MOD17A3 and MOD17A3H have been validated and applied to biomass estimation and global change diagnosis in different regions over the world (Fensholt et al. 2006; He et al. 2006; Turner et al. 2006). Based on the data of MOD17A3H from the year of 2001 to 2015, we investigated the spatio-temporal patterns of net primary production in southern Himalayas. The impacts of earthquake were also analyzed for the purpose of understanding the interaction between NPP change and seismic disturbances, so as to provide some implications for further discussing.

8.2 Study Area

Study area extends across an east–west strip of southern Himalayas, east to Kuru River (Bhutan) and west to the Mahakali River (Nepal), which is located between 26.8 and 30.4°N, 79.9 and 92.6°E (Fig. 8.1). It contains catchments of Ganges and Brahmaputra River in Himalayas, all are outflow basins, the total area of which is approximately 185,000 km^2. The terrain relief in the region is huge with the elevation between 287 and 8706 m, 2981 m on average. There are Higher Himalaya range, mid-elevation mountain range, lower-mountain/hilly range distributing from north to south in study area. It lies in a subtropical zone according to its latitude, where the annual average temperature is about 7.1 °C. Due to the impacts of Indian Ocean monsoon and topography, temperature varies from north to south. Precipitation is abundant, but distributed unevenly in time and space, which decreases from east to west. The average annual precipitation is about 1230 mm.

Tropical plants are mainly distributed below 400 m (Deng et al. 2016), where covered with broadleaf evergreen trees. Whereas subtropical plants are distributed in the mountain-valley regions at the altitude range of 300–1200 m and mainly with evergreen vegetation, such as hemlock, Himalayan pine and other coniferous vegetation. Temperate plants mainly grow in the regions within an altitude of 1200–2700 m, where the temperatures are relatively low and the plant species is dominated by mixed broadleaf-conifer trees (Pokharel 2012). Boreal plants mainly grow in the alpine zone above 2700 m and below the snow line, where coniferous trees account for the bulk. Shrubs and grasslands are distributed above the timber line

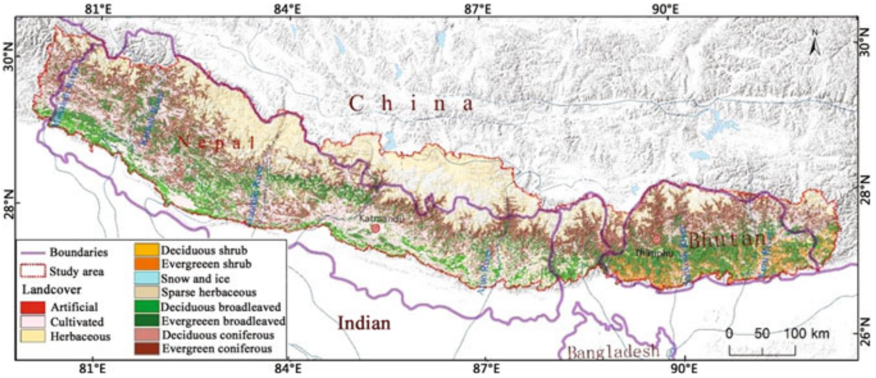


Fig. 8.1 Map of the study area with land cover feature

(4000 m), but become rare above 4500 m. At an altitude of over 5000 m, vegetation is sparse, where bryophytes are scattered on the bare rocks.

8.3 Data and Processing

Data used for analysis mainly include NPP product from MODIS data, digital elevation model (DEM), macroseismic data of the Ms8.1 earthquake in April 2015, and multi-period land cover change data.

MOD17A3H, data of annual NPP, was produced by Numerical Terra Dynamic Simulation Group (NTSG) from University of Montana, of which the spatial resolution is 500 m and the temporal resolution is 1a, (MOD17A3H could be downloaded from https://lpdaac.USGS.gov). MOD17A3H is estimated from 8-day synthesis data of LAI/FPAR. Compared with previous version, the accuracy of MOD17A3H got improved, since the latest biological property lookup table (BPLUT) and a new version of meteorological data from GMAO were used. In order to test the reliability of MOD17A3H in study area, NPP values of same vegetation types from similar geographic conditions were retrieved, with the combination of widely used MOD17A3 for comparison. As shown in Table 8.1, average values of MOD17A3H are within the range of reference data (Piao et al. 2001; Zhu et al. 2007; Zhang 2008; Dai et al. 2015; Chen and Zeng 2016), and consistent with MOD17A3 for the same type of vegetation.

SRTM3 (version 4) data sets were used for altitudinal classification of mountains, of which the resolution is 3″ (about 90 m), average accuracy of elevation on a world scale is up to ±17 m, and geometric precision is about ±20 m. In the ambient areas of Qinghai–Tibet plateau, the average elevation error of SRTM is a bit larger, about 30 m (Nan et al. 2015). Over all, SRTM3 can meet the accuracy requirements of this study.

Land cover data are extracted from Global Land Cover 2000 (GLC2000) data set produced by Space Applications Institute (SAI), EU. There are eight types of vegetation information in it, namely coniferous forest (deciduous and evergreen), broadleaf forest (deciduous and evergreen), shrub, grassland, farmland and sparse vegetation. The land cover change data in Nepal earthquake hit areas are derived

Table 8.1 NPP values (g Cm^{-2} a^{-1}) from MOD17A3H, MOD17A3 and references

Vegetation	MOD17A3H avg.	MOD17A3 avg.	Reference data
Coniferous forests	529.9	571.8	179–824
Broad-leaved forests	748.0	776.2	257–928
Scrub	357.8	361.4	283–368
Grassland	144.8	154.1	271–348

from data of multiphase land cover products produced by IMHE, CAS, with a spatial resolution of 30 m.

Temperature and precipitation data are obtained from the University of Delaware (downloaded from http://www.esrl.noaa.gov/psd/data/gridded/data.UDel_AirT_Precip.html), with a spatial resolution of 0.5° × 0.5°, and of which the time span from the year 2001 to 2015. Sub-dataset of southern Himalayas was extracted, with annual average calculated.

After Nepal earthquake, the seismic intensity distribution data are available from China Seismological Administration. The data are a result of comprehensive analysis with field survey data, remote sensing image, map of geohazard distribution and socioeconomic data from related institutions. According to the China Seismic Intensity Scale (Id: GB/T17742-2008), seismic fortification intensity zones are divided into four classes from level VI to IX.

8.4 Methods

8.4.1 Trend Analysis

Change rate of NPP is considered as a direct index to reflect the tendency in a long sequence. Thus, equation of unitary linear regression was used to calculate slope of NPP variation during 2001–2015, pixel by pixel. And F-test was introduced to estimate the optimal threshold. The unitary linear regression equation is as follows.

$$\text{slope} = \frac{n \times \sum_{i=1}^{n} (i \times \text{NPP}_i) - \sum_{i=1}^{n} i \sum_{i=1}^{n} \text{NPP}_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \tag{8.1}$$

where slope means linear inclination slope, if slope >0, NPP keeps a positive tendency, and on the contrary, it shows a reducing trend; NPP_i represents the NPP value in ith year, the unit of which is g Cm^{-2}; n represents length of time ($n = 15$); $i = 1, 2, \ldots, 15$ which are corresponding to 2001, 2002, …, and 2015, respectively.

Examination was made with F-tests on the regression result, the formula is as follows

$$F = \frac{\sum_{i=1}^{n} \left(\overline{\text{NPP}_i}^2 - \overline{\text{NPP}}^2\right)}{\sum_{i=1}^{n} \left(\text{NPP}_i - \overline{\text{NPP}_i}\right)^2} \sim F(1, n-2) \tag{8.2}$$

where $\overline{\mathrm{NPP}_i}$ is the regression value of NPP in the ith year; $\overline{\mathrm{NPP}}$ is the overall mean value for the research period; NPP_i is the NPP data of ith year, $i = 1, 2, \ldots, 15$, which are corresponding to 2001, 2001, …, 2015, respectively. By looking up the threshold table of F-distribution, the threshold values are 4.67 and 9.07 for $\alpha = 0.05$ and $\alpha = 0.01$, respectively. Based on this, the slope of NPP tendency is accordingly classified into three parts, namely nonsignificant, significant and extremely significant.

8.4.2 *Spatial Variation Analysis*

Spatial variation could be extracted from a couple of NPP data of two years directly. MOD17A3H data in southern Himalayas are used to calculate deltas to obtain absolute variation. In addition, we calculated the simulation value according to the slope of NPP tendency and contrasts with MOD17A3H data of the same year to get potential variation. Based on this, specific analysis consists of these two parts.

NPP values of different altitude belts were concerned. Among them, the elevation breakpoints were selected according to the distribution characteristics of vegetation. The breakpoints chosen are 400, 1200, 2700, 4000 and 5000 m.

8.4.3 *The Correlation Analysis*

By Pearson Correlation Coefficient, the correlation between NPP and climatic factors (air temperature and precipitation) is analyzed with mean annual value pixel by pixel. Formula is as follows.

$$r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \tag{8.3}$$

where x_i and y_i represent NPP values and climatic factors (temperature, precipitation) in the ith year; $\bar{x}$ represents the mean annual amount of NPP, $\bar{y}$ represents annual average value of temperature or precipitation; $n = 5$ represents the length of time series (from 2010 to 2014, and the reason why we choose this period is state below); and r_{xy} is the correlation coefficient. Assuming the probability density function of the correlation coefficient (r) fit the T-distribution when $r = 0$ that t test (formula 8.4) can be used to test the correlation coefficient.

$$t = \sqrt{n-2}\frac{r}{\sqrt{1-r^2}} \tag{8.4}$$

Given the significance level α, if $t > t_\alpha$, we reject the hypothesis mentioned above and consider that correlation coefficient is significant. On the 0.05 and 0.01 significance level, t value equals 3.18 and 5.84, whereby the correlation is divided into nonsignificant, significant and extremely significant association.

8.4.4 Analysis of Earthquake Effects

There is different connotation about earthquake influence, including post-earthquake damage and some pre-earthquake impact on regional scale. Post-earthquake impact is mainly caused by destruction of vegetation due to the earthquake. And pre-earthquake impact is possibly caused by tectonic activity that changes the land surface processes.

Landslide, collapse, debris flow were triggered by the earthquake, thereby causing damage to vegetation and disturbance to tendency of NPP. The subtraction of MOD17A3H values in 2015 and 2014 can intuitively reflect NPP variation before and after earthquake. It was observed that NPP descending plaques distributed along the major axis of the earthquake intensity region (Fig. 8.2). Under normal circumstances, serious seismic damages occur on the land surface along the major axis. It may preliminarily explain the distribution pattern of these descending plaques.

It is important to note that strong earthquake caused by tectonic movement would impact NPP in a certain period before and after the quake. Before earthquake, tectonic activity may disturb the process of precipitation in local area, which might impact the physiology and growth of vegetation and result in NPP variation.

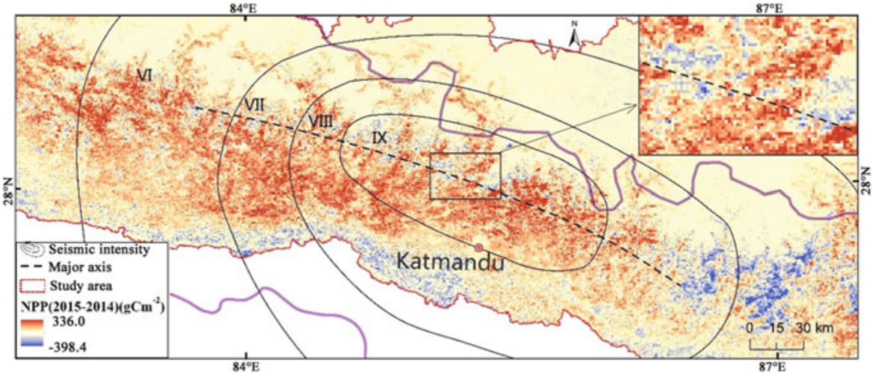


Fig. 8.2 Earthquake intensity zones and NPP variation (2014–2015)

Although the speculation is still in lack of credible evidence, it has been given attention and came under discussion after Wenchuan earthquake in China (on May 12, 2008). That study came to a conclusion that the seismogenic systems had an influence on NDVI along the Longmenshan fault (Ma et al. 2010). Around this topic, we tried some statistics methods to analysis and contrast NPP tendency in different sub-periods with MOD17A3H data.

8.5 Results and Analysis

8.5.1 Spatial Pattern

Values of NPP in southern Himalayas range from 0 to 1841 $\text{g Cm}^{-2}\ \text{a}^{-1}$, and in the past 15 years, the total average value is about 501 g Cm^{-2}, close to the average NPP value in the middle reaches of Yangtze River, China. The spatial distribution of NPP varies in different regions, which is consistent with land cover types in different altitudinal belts (Fig. 8.3). From south to north the value of NPP increases first and then decreases with altitude, while from west to east it increases gradually.

The eastern part of the study area is located in Bhutan, where NPP in lower mountains and hills below 3000 m is larger than any other areas. It is mainly covered with evergreen broad-leaved forest. Altitudinal vegetation belts in the region are typical with forest-shrub-grass in sequence. Middle and western parts of the study area are mainly located in Nepal, where the distribution mode of NPP is similar to that of Bhutan. But NPP is not as large as that of Bhutan, in the hills, alluvial–pluvial fan and plains, which are covered with arable lands and agroforest. Local agricultural activities weakened the vegetation NPP in this area.

NPP in the west is significantly lower than that in the eastern part, due to land cover differences. Subtropical broad-leaved trees such as bimbisara, banyan and rubber trees, are widespread in the east, while Himalayan longleaf pines are widespread in the west. Species and productivity differences are closely related to precipitation in southern Himalayas. From Table 8.2, it is evident that the average

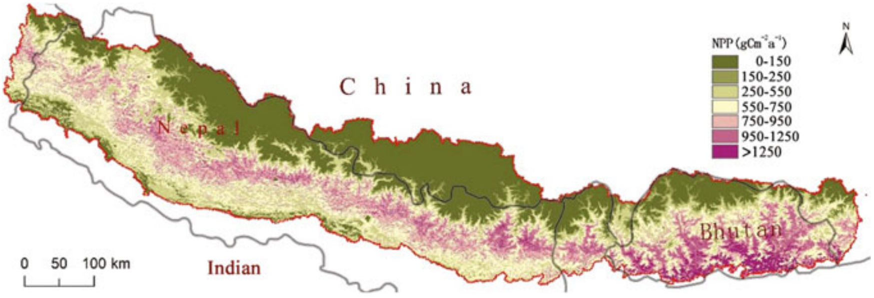


Fig. 8.3 Annual average of NPP in southern Himalayas

Table 8.2 NPP of different vegetation types (g $Cm^{-2}a^{-1}$)

	Broad-leaved evergreen forests	Deciduous broadleaf forest	Coniferous forests	Shrub	Grassland	Sparse
Eastern	1077.0	978.3	858.4	398.1	88.16	58.4
Western	668.8	499.0	598.9	344.3	117.7	22.7
Whole region	835.0	711.6	623.9	357.8	144.8	25.5

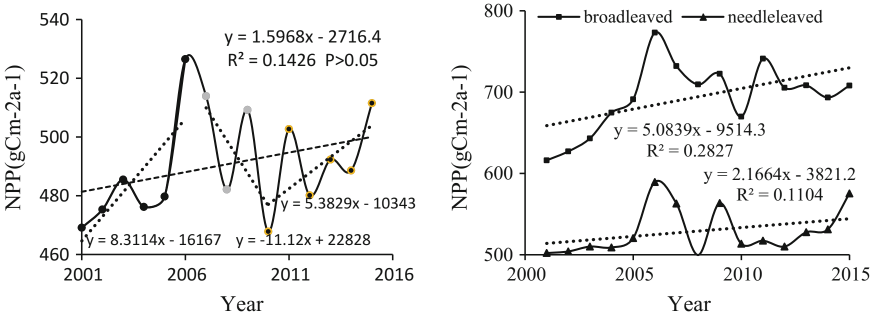
NPP is lower in the western part than that of the east. The NPP of evergreen vegetation is greater compared to the deciduous vegetation. NPP of broad-leaved forest is about 835.0 g Cm^{-2} a^{-1}, and deciduous broad-leaved forest NPP is about 711.6 g Cm^{-2} a^{-1}; coniferous forest NPP value (623.9 g Cm^{-2} a^{-1}) is slightly less than that of broad-leaved forest; The NPP value of grassland is around 144.8 g Cm^{-2} a^{-1}; while the average NPP value of sparse grasslands in high-altitude region is merely 25.5 g Cm^{-2} a^{-1} (Table 8.2).

8.5.2 Temporal Pattern

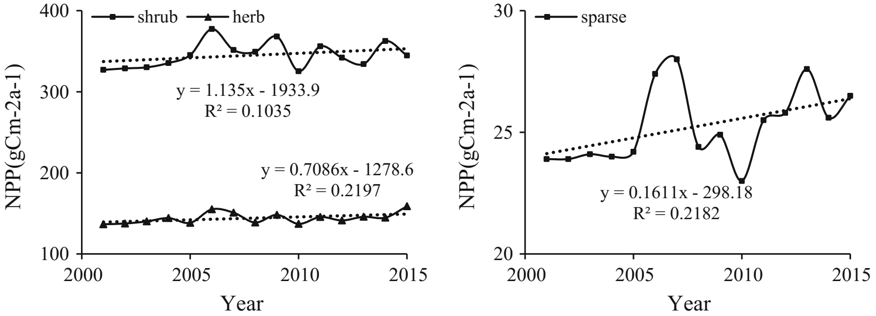
In southern Himalayas, the annual average value of NPP rose with fluctuation during 2001–2015 (Fig. 8.4a). The linear growth rate is about 1.60 g Cm^{-2} a^{-1}, but it is not so significant ($P > 0.05$). NPP increased from 467.1 g Cm^{-2} in 2001 to 511.5 g Cm^{-2} in 2015, with the maximum of 526.5 g Cm^{-2} in 2006, and the minimum of 467.8 g Cm^{-2} in 2010. The tendency of vegetation NPP kept increasing from 2001 to 2006 with an average of 8.31 g Cm^{-2} a^{-1}, and the overall trend is downwards during 2007–2010 with an average of −11.12 g $Cm^{-2}a^{-1}$; NPP went up in fluctuation during 2010–2015 with an average of 5.38 g Cm^{-2} a^{-1}. The inter-annual fluctuation characteristics of all types of vegetation NPP are almost the same. NPP reached a maximum in 2006 except that NPP of coniferous forest reached the minimum value in 2008, while the remaining natural cover types appeared minimum value in 2010 (Fig. 8.4b, d).

The tendencies of different vegetation in the past 15 years are similar. The increasing rate of broad-leaved forest which is larger than that of other vegetation types is about 5.08 g Cm^{-2} a^{-1}, followed by coniferous forest 2.17 g Cm^{-2} a^{-1}, shrubs 1.14 g Cm^{-2} a^{-1}, grass 0.701 g Cm^{-2} a^{-1} and sparse grass 0.22 g Cm^{-2} a^{-1}. The vegetation NPP variation is relatively stable during 2001–2005, but there was a significant increase in 2006. NPP entered a cycle of reduction during 2007–2010, and showing a rising trend with fluctuation after 2010.

It can be observed that 65.67% of the regional NPP changed little in this 15-year period. Only 4.24% of the area shows extremely significantly increasing trend, which lies mainly in the east of Nepal, and some parts of mid-elevation mountains in central Bhutan. And the significantly increasing parts are around the extremely



(a) annual average value (b) forest



(c) shrub and grassland (d) sparse grassland

Fig. 8.4 Variation of NPP during 2001–2015 in southern Himalayas

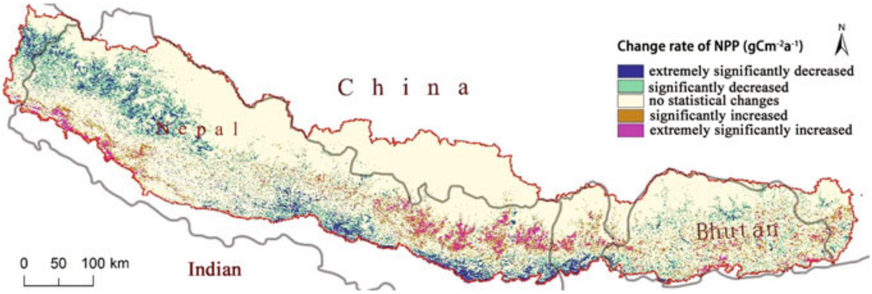


Fig. 8.5 Significance test of NPP variation in southern Himalayas during 2001–2015

significantly increasing regions, accounting for 9.52% of the area. The regions with extremely significant down trend of NPP account for 6.36% of the study area, which is mainly distributed in two regions, i.e., one in the east of Nepal covered with arable land and agroforestry, and the other in the west of Nepal covered with coniferous and broad-leaved forest; 14.2% of area appeared significantly declined, mainly distributed near the extremely significantly descending regions. Generally, NPP variation trend in Nepal is more remarkable than that of Bhutan (Fig. 8.5).

The vegetation types with significant NPP variation in the research area include needle-leaved and broad-leaved forests. Significantly increasing and reducing area, respectively, accounts for 6.14 and 5.96% of the total forest land. And the area with insignificant change accounts for 63.43 and 11.21%, respectively. The change of grassland and arable land is negligible; for instance, the NPP increasing area for grassland is 2.1%, while the reducing area is 4.47%. Similarly the increasing area for arable land NPP is 7.22%, and the reducing area is 4.05%.

8.5.3 Vertical Zonality of NPP and Its Variation

There are several typical geomorphic regions such as Higher Himalaya areas, mid-elevation mountain areas and lower-mountain/hill areas. As the weather and soil conditions vary in different regions, characteristics of vegetation NPP change. Taking 1200, 2700, 4000, 5000 m as threshold value of elevation, the NPP average value and the amount of change in each altitudinal belts were computed.

NPP value in southern Himalayas initially increases and then decreases with the increase of altitude (Fig. 8.6), which reaches to a maximum of 810.8 g $\text{Cm}^{-2}\ \text{a}^{-1}$ in the altitudinal range between 1200 and 2700 m. This region is mainly covered with subalpine forests that take 61.0% of the land surface, where arable lands take a small proportion. With limited agricultural activity vegetation is scarce above 5000 m, where the average value of NPP is only 16.3 g $\text{Cm}^{-2}\ \text{a}^{-1}$. The average in southern Himalayas at the altitude of lower than 1200 m varies from 612.1 to 712.3 g $\text{Cm}^{-2}\ \text{a}^{-1}$. Theoretically, the hydrothermal condition is better in lower elevation range, so the NPP value of similar vegetation is larger than that of vegetation at the altitude of 1200–2700 m. Agricultural activity has impacts on the average NPP value because the NPP of crops and agroforestry is lower than that of primary forests. Above 2700 m, the temperature is low, and NPP declines to an average of about 535.2 g $\text{Cm}^{-2}\ \text{a}^{-1}$; hence, these areas are normally covered with coniferous forests. The areas at the altitudes of 4000–5000 m above the forest level are mainly covered with meadows with an average NPP of 112.3 g $\text{Cm}^{-2}\ \text{a}^{-1}$.

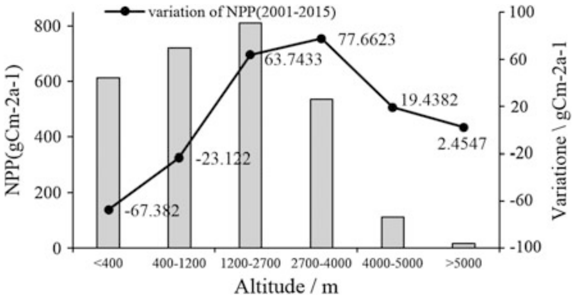


Fig. 8.6 NPP in different ranges of altitude

The variation which is negative in the regions lower than 1200 m reflects the strengthening trend of agricultural activities in these areas. The variation at other altitudes is positive. The increments from 1200 m to 2700 m (63.7 g Cm^{-2}) are close to that from 2700 to 4000 m (77.7 g Cm^{-2}), close to 1/10 of the average. The increments of grasslands are 19.4 g Cm^{-2} a^{-1}, and sparse vegetation is 2.5 g Cm^{-2} a^{-1} in high-altitude areas.

8.5.4 Earthquake Effects

8.5.4.1 Post-earthquake Response of NPP

Earthquake and secondary disasters often cause damage to local vegetation. On a macrolevel, it reflects the change of land cover types. From the article on 'Nepal Land Cover Change and Driving Factors in recent 25 years', (Chap. 3 of this book), five time nodes were selected, i.e., 1990, 2000, 2005, 2010 and 2015 to carry out remote sensing dynamic monitoring research of land cover in Nepal. The paper accordingly selects seismic intensity IX zone, 1542 polygons for bare rock/bare soil changes of land cover types in 2010–2015 are plotted in red in the figure (Fig. 8.7). Whereas the polygons of coniferous forest into bare soil are 431, 690, 171 polygons of arable lands into bare soil and 250 polygons of the changed grass. Due to the short-term (in 2014–15) NPP difference, direct impact of earthquake was analyzed.

According to the statistics, within earthquake intensity IX area, the NPP value of vegetation damaged area declined significantly, as shown in bar graph (Fig. 8.7). The average NPP for damaged arable land plaques reduced by 64.4 g Cm^{-2} a^{-1}, grassland plaques by 53.0 g Cm^{-2} a^{-1}, deciduous broad-leaved forest plaques averagely reduced by −25.2 g Cm^{-2} a^{-1}, evergreen broadleaf forest plaques averagely reduced by −18.1 g Cm^{-2} a^{-1} and coniferous forest plaques increased by an

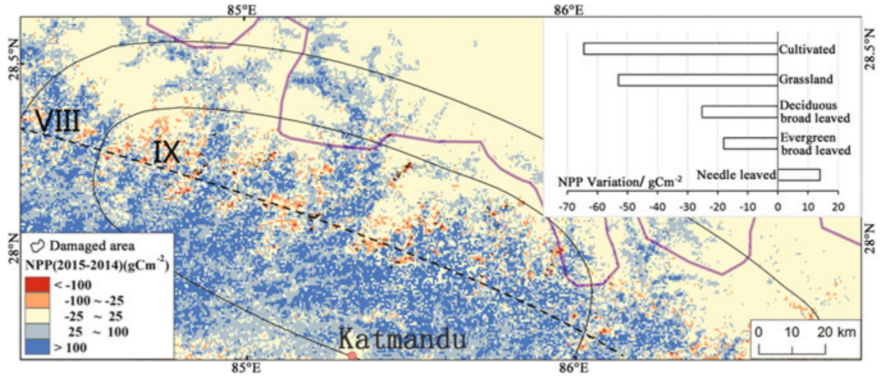


Fig. 8.7 NPP change of intensity IX damaged surface (2015–2014)

average of 14.0 g Cm^{-2} $a^{-1.}$ When comparing with the average annual variation (1.6–11.1 g Cm^{-2} a^{-1}) (Fig. 8.4a) caused by climatic fluctuation, the local NPP value variation caused by earthquake is significant.

8.5.4.2 Pre-earthquake Impacts

It can be observed from the above analysis that NPP value in southern Himalayas, in 2001 to 2015, shows an overall growth trend, whereas the period of 2010–2015 is a typical sub-cycle period of high volatility (Fig. 8.4a); woodland in IX intensity earthquake area accounts for a large proportion (about 62.6%), the average NPP is quite high between 510.5 g Cm^{-2}–8.23.5 g Cm^{-2} (Fig. 8.3); From the point of view of NPP variation from 2014 to 2015, NPP in IX intensity zone still show positive (growth), the negative (reduced) area is mainly distributed sporadically along the long axis of earthquake damage area (Fig. 8.7). The above discussion does not reflect the impact of earthquake on the trend of NPP, rather long time-series regression trend analysis possibly conceals the effective information due to plurality of fluctuation cycles in the past 15 years.

Based on the earthquake impact analysis, time node to the nearest rising period was shortened (2010–2015), and according to formula (8.1) pixel, linear curve was made fit for NPP variation in southern Himalayas and obtained NPP variation trends from 2010 to 2015. It was observed that east-west NPP attenuation band appears along the long axis direction of IX intensity area (Fig. 8.8a). In the trend analysis of 2001 to 2015, this attenuation band was not found (Fig. 8.8b), whereas in the NPP difference data of 2014–2015 (Fig. 8.2) there is no sign of a large area of attenuation. These results suggest that it is an abnormal phenomenon that the negative growth zone appears in a large area of zonal distribution at the forefront of a particular direction before earthquake. The negative value area between two dashed lines is most concentrated (see Fig. 8.8a). According to the statistics, the

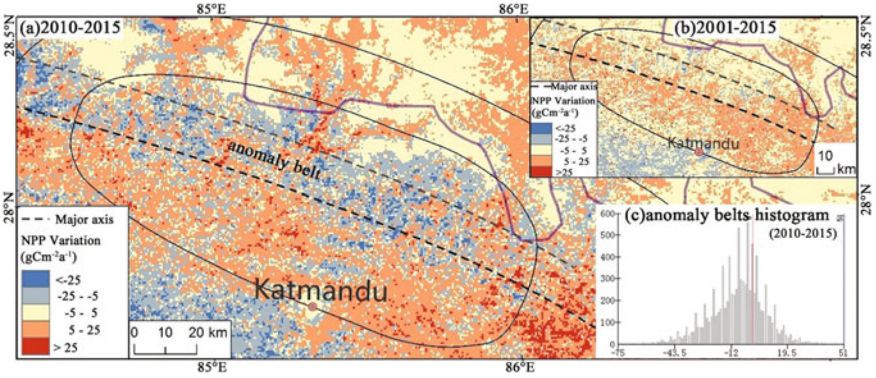


Fig. 8.8 Earthquake impact on the trend of NPP

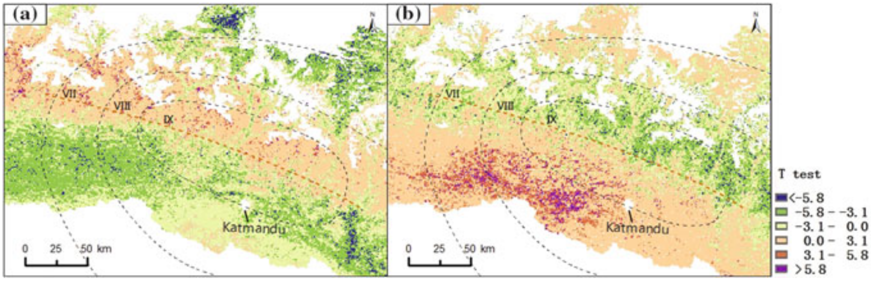


Fig. 8.9 **a** Significance test of the correlation coefficient between NPP and temperature; **b** significance test of the correlation coefficient between NPP and Precipitation

area ratio accounts for 72.7% of the total area of the strip, the minimum value is -75.0 g Cm^{-2}, the average value is about -14.5 g Cm^{-2}. And forming a sharp contrast with the growth rate of 5.37 g Cm^{-2} in the whole region from 2010 to 2015. At the same time, its spatial distribution range is much larger than the area where NPP was reduced due to earthquake secondary disasters.

We analyzed the trends of temperature and precipitation in the study area from 2010 to 2014 with formula (8.1) and discussed the correlation between NPP and climate factors.

Through statistics (Fig. 8.9), it can be observed that from 2010 to 2014, it is positively correlated with precipitation. Significant and extremely significant correlation areas account for 6.7% of low-value abnormal zone; hence, correlation is not obvious. It is negatively correlated to precipitation, significant and extremely significant correlation areas account for 43.5% of low-value abnormal zone, which represents a significant correlation. Correspondingly, the local NPP moderating trend before the earthquake in southern Himalayas has a certain relationship with precipitation.

8.6 Conclusions

Based on MODIS NPP product, this paper analyzed the spatial pattern of NPP in southern Himalayas during 2001–2015 and discussed NPP variation in different altitudinal ranges as well as impacts of the Nepal Ms8.1 earthquake. The results indicate that:

(1) NPP in southern Himalayas ranges from 0 g Cm^{-2} a^{-1} to 1841 g Cm^{-2} a^{-1}, with annual average amount of 501 g Cm^{-2}, close to that in the middle reaches of Yangtze River. In the past 15 years, NPP in southern Himalayas maintains a growth trend in general, with an average annual growth of 1.60 g Cm^{-2} a^{-1}. The rate of growth is not that significant, on account of multiple ascending/descending sub-cycles within this 15-year period. According to the

tendency of NPP values, it could be divided into three sub-periods. The first sub-period is from 2001 to 2006, which went through a growth cycle with an average change of 8.31 g Cm^{-2} a^{-1}; the sub-period of 2007 to 2010 is a volatile decline cycle with an average change of −11.12 g Cm^{-2} a^{-1}; and during 2011–2016, NPP values rise again with an average of 5.38 g Cm^{-2} a^{-1}.

(2) NPP distribution and variation in southern Himalayas change with the altitudes. The average value of NPP in the mid-elevation mountains (1200–2700 m) reaches to a maximum of 800 g Cm^{-2} a^{-1}, while the average in the lower-mountain area (400–1200 m) is lower than that of mid-elevation mountains, with a difference within 200 g Cm^{-2} a^{-1} which is a reflection of the average value of arable land. When it comes to higher places (>2700 m), average NPP values decline as the altitudes increase, which is closely related to land cover change. In areas above 4000 m, where the average NPP gets no more than 150 g Cm^{-2} a^{-1}, grassland becomes the main type of vegetation. NPP variation characteristics are different in each elevation range, e.g., the negative variation trend at low altitude reflects the increasing impact of human activities (especially agricultural development); the positive NPP variation trend in intermediate altitude and above is positive reflects a certain degree of climate variation on regional scale. In addition, NPP regional differences are significant, decreasing from east to west. The average NPP value in Bhutan is higher than that in Nepal. In the past 15 years, areas where NPP changed significantly are relatively centralized. For instance, the increasing areas are mainly distributed in Sun Kosi River Basin (Nepal), Arun River Basin (Nepal) and Eastern Trongsa River Basin (Bhutan) in the middle section of the study area. While the decreasing area is mainly distributed in the regions among the middle reaches of western part of Karnali River and the middle reaches of Mahakali River as well as the south area close to the Terai Plain. Overall, NPP fluctuation trend in Nepal is more significant than that of Bhutan.

(3) The NPP of evergreen vegetation in southern Himalayas is greater than that of deciduous vegetation with the same type. In this area, average value of NPP of broadleaf forest is larger than the other types, while of evergreen broad-leaved forest it is about 835.0 g Cm^{-2} a^{-1}, of deciduous broad-leaved forest it is about 711.6 g Cm^{-2} a^{-1}; NPP value of coniferous forest is slightly lower than that of broad-leaved forest, about 623.9 g Cm^{-2} a^{-1}; of grassland is about 144.8 g Cm^{-2} a^{-1}; and of sparse grasslands at high altitude is about 25.5 g Cm^{-2} a^{-1}. In the past 15 years, NPP variation characteristics for different vegetation are different, the broad-leaved forest increasing faster than the others, about 5.08 g Cm^{-2} a^{-1}, followed by coniferous forests whose rate is 2.17 g Cm^{-2} a^{-1}, while shrub 1.135 g Cm^{-2} a^{-1}, grassland 0.7086 g Cm^{-2} a^{-1} and the sparse grass the lowest, only 0.22 g Cm^{-2} a^{-1}.

(4) There may be disturbance to NPP variation trend from the earthquakes in some areas. For example, from 2010 to 2015, there appeared an NPP abnormal zone in zonal distribution near the vicinity of long axis in high-intensity earthquake region, and in this 15-m-wide band, about 72.7% of the area is NPP decreasing region, with an average value of −14.5 g Cm^{-2}, which formed a sharp contrast

to the growth form in the same period in this region. And also, its distribution range is much larger than the direct impact range of disaster after the earthquake in 2015. According to the analysis, the variation characteristic of this descending band is positively correlated to the temperature in the same period, but the correlation is insignificant; when it is negatively correlated to the same period of precipitation the correlation is significant. According to the initial speculation, if the development process of earthquake has any impact on NPP, it may be caused by the disturbance of local precipitations.

Research of long-sequence NPP variation in southern Himalayas is helpful to reveal dynamic variation of NPP, so as to support decision making of land development, as well as environment protection strategies. It can also provide useful information for climate change analysis and ecological estimation.

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Chapter 9
Assessments of Climate Change Indicators, Climate-Induced Disasters, and Community Adaptation Strategies: A Case from High Mountain of Nepal

Binod P. Heyojoo, Nabin K. Yadav and Rajan Subedi

Abstract Rainfall, temperature and snow cover are widely used indicators to define climate change pattern. This research analyzed a series of climatic and satellite data to determine the trend of climate, snow cover and vegetation cover dynamics in the context of changing climate. Also, community's adaptation practices and challenges to face severe climate-induced disaster were explored for the Seti Khola catchment of western Nepal. Temporal Landsat images were used for quantifying snow and vegetation covers based on NDSI and NDVI indices. Household surveys, key informant interview, and direct field observation were used to verify the status of climate change indicators and to document community response for adaptation and reduction of existing and potential damages from climate-induced disasters. The annual average maximum and minimum temperature increases at the rate of 0.043 and 0.023 °C, respectively; precipitation is decreasing by 11.17 mm per annum with the erratic pattern. Melting of snow, occurrence of landslide and conversion of snow mountain to barren land and then vegetation are some distinctly noticed scenario associated with climate change. More than 25% people residing in the area seems highly vulnerable to floods and landslides caused primarily by climatic variability and an accelerated rate of snowmelt. Lack of knowledge, lack of political leadership and institutional mechanism were key issues for adaptation strategies. Regular monitoring of climatic indicators and assessment of damages and risks from the climate-induced disaster are important to formulate future climate change mitigation and adaptation strategy.

Keywords Snow · Vegetation · Vulnerable group · High mountain

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9.1 Introduction

The climate change truth is now an undisputed issue and no country in the globe remains unaffected by its impact. The least developed and mountainous country like Nepal is at the forefront to face difficult challenges caused by the climate change. Many indicators have already revealed discernible impacts of climate change, highlighting the urgency for the state, local government, and others to act for mitigation and adaptation strategies (Mazur et al. 2010). Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia resulting into warming of the atmosphere and ocean (IPCC 2013). According to IPCC (2007), eleven of the last twelve years (1995–2006) rank among the twelve warmest years on record for global surface temperatures since 1850. Many scientific studies regarding changing climate in Nepal have reported temperature rise. Dahal (2011) has found temperature rise at the rate of 0.06 °C per annum. However, this rise is not uniform across the country, having the mountains and Himalaya with a higher value (0.08 °C) than the low-lying terai (0.04 °C) (Gautam and Pokhrel 2010).

Past long-term rainfall data across Nepal show inconsistency in the rainfall pattern across Nepal with higher intensities of rain and less rainy days (Malla 2008) resulting both long droughts for some time and heavy rain in some other periods. In Nepal's Himalaya, total estimated ice reserve between 1977 and 2010 decreased by 29% (MOPE 2016). The number of glacier lakes increased by 11%, and glaciers recede on an average by 38 km^2 per year during the same period.

Nepal, mostly covered with fragile mountains and rugged topography, has been continuously experiencing disasters like landslides, floods with tragic loss of human and limited infrastructure. The increased frequency of extreme weather caused by changing climate increases not only the loss of human lives but also social costs. According to Climate Change Vulnerability Index (CCVI), Nepal is the fourth country in the world most vulnerable to climate change (Maplecroft 2010). Climate change scenarios indicate that snow and ice coverage at higher elevations will reduce, leading to an increase in the frequency of climate-related disasters, including floods and droughts, as well as cause changes in precipitation at a regional scale (Sherchand et al. 2007). Geographically, over 75% of Nepal is composed of rugged hills and mountains. Increased occurrences of intense rains concentrated during the monsoon season and compounded by frequent occurrences of glacial lake outburst floods have increased soil erosion, floods and landslides in the region (Shrestha 1999).

Extent of Infrastructure Damage by 2012 Flash Flood

An unexpected flash flood, initiated in a tributary of Seti River and originated from the east of Mount Machhapuchhre, in Kaski district of West Nepal swept away river side settlements and destroyed many houses, businesses, crops, and livestock. The flood washed away major water supply pipeline, thus hit badly in water supply system of Pokhara city causing reduction of water supply to the city by half. Pokhara Water Supply Project faced a major damage with 42-m-long steel truss bridge along with about 450 m pipe of 20-in. diameter ductile iron main water pipe line laid on top of the bridge. Similarly, three suspended bridges were completely washed away and three other suspended bridges were severely damaged at different locations (Gurung 2013).

Nepal's contribution for causing climate change is negligibly small. Nepal with its total population less than 0.4% of the word is responsible for only about 0.025% of annual greenhouse emissions (Karki 2007) but Nepal's vulnerability to damage from climate change, however, is large.

The socioeconomic status of the people in mountain region limits institutional capacity, and greater reliance on climate-sensitive sectors like agriculture increases the degree of vulnerability (Regmi and Adhikari 2007). Further, the mountain communities are more vulnerable to climate change because of their direct and more exposed. Thus, a sensitive indicator of climate change impacts more at the community level (Adger et al. 2003; OuYang 2009; Bharati et al. 2012; Gurung 2013). For communities, adaptation is a process of social learning, developed through their perception and the policy interventions. It is very important to understand how the community is perceiving global climate change, what are their impacts in order to develop proper adaptation solutions to minimize the risk associated with such changes.

Although climate change is a very complex phenomenon and associated with many variables, simple measurements can be used as indicators of the whole process of climate change. Among the many variables of climate, the temperature is a direct way of measurement of climate warming, and most of the other variables are associated in some way to it. Rainfall may be an indicator of equal or greater importance for global climate change because of the impacts associated with water shortages and quality (Shrestha 1999). Similarly, temporal snow cover change measurement, one of the key indicators adopted in other parts of the globe, can also be a valuable means to assess the climate change because snow cover is not just something that is affected by climate change; it also exerts an influence on climate. Several studies abroad (Baker et al. 1995; Panigrahy et al. 2010; Bharati et al. 2012 and few national biological climate change impact studies including Gaire et al. 2014) and a review article by Subedi (2009) have revealed change in species composition of ecological communities, range and distribution upward shift of species as well as changes in phenology of the organisms.

Thus, evidence of climate change can be ascertained by analyzing the instrumental measurements of temperature, rainfall and relating them to the altitudinal shift of vegetation and snow cover changes. This study was focused on Seti sub-watershed of Western mountain region of Nepal aiming to fulfill with three specific objectives: (i) assessing the temperature, rainfall and snow cover trend of the study area; (ii) analyzing the snow and vegetation cover change pattern in different elevation zone and; (iii) determining community vulnerability with most sensitive climate-induced disasters and local communities' prioritised adaptation practices coupled with associated barriers. The study site was deliberately chosen to represent western high mountain watershed, identified as one of the rapidly warming geographic zones and possessing long-term hydrological and metrological data. Moreover, the area characterized by frequent landslides and floods had notoriously catastrophic flash flood in 2012 May leaving 72 people dead and significant infrastructures damaged (Box 9.1).

9.2 Study Area

The Seti Khola sub-watershed (28° 35′ 59.11″N–28° 17′ 9.97″N latitude, 84° 0′ 15.74″E–83° 56′27.77″E longitude) with elevation ranging from 1034 to 7546 m lies 20–30 km northwest from Pokhara of Kaski district, Nepal. The study area (Fig. 9.1) lying within Annapurna Conservation Area is a typical mountain region. Its landscape of rugged topography ranges from Northern Mahabharata to Himalayan belt with Mt. Machhapuchhre in the north of Annapurna IV range.

The region having geological variation from middle hill to northern Himalaya is characterized by rich biodiversity fragile region of Nepal. The climate of the area varies from sub-temperate at a lower altitude to subalpine at higher altitudes with average annual rainfall 3345.755 mm and average maximum air temperature 27.17 °C and minimum air temperature 15.50 °C. More than 80% of total rainfall occurs between June and September, i.e., during the monsoon period. The forest is the primary land cover types of the area followed by pasture at high altitude and terrace agriculture at lower belt surrounding the settlement. *Schima castanopsis*, oak, fir, rhododendron are the major forest types in the catchment. The upper part of the catchment is covered by alpine meadow, pasture and snow mountain. Based on political boundary, the study area covers the four VDC's namely Machhapuchhre, Sardikhola, Gahachowk and Puranchaur of Kaski district. Among the four, Machapuchhre VDC was selected for the survey to understand the community perceptions and their response activities towards climate induced disasters. The selection was based on high diversity of ethnic population and recent damage due to 2012 flash floods.

The area comprises 395 households with an average family size of 4.38. Its population comprises 794 males and 935 females. Ethnic groups constitute the majority of the population with smaller groups of Dalits, Brahmin, Chhetri (CBS 2012).

9.3 Methodology

Figure 9.2 details the methodological process followed in the study. The study includes daily rainfall and temperature data of more than 30 years from the nearby meteorological station, Landsat imagery of October of four different time periods

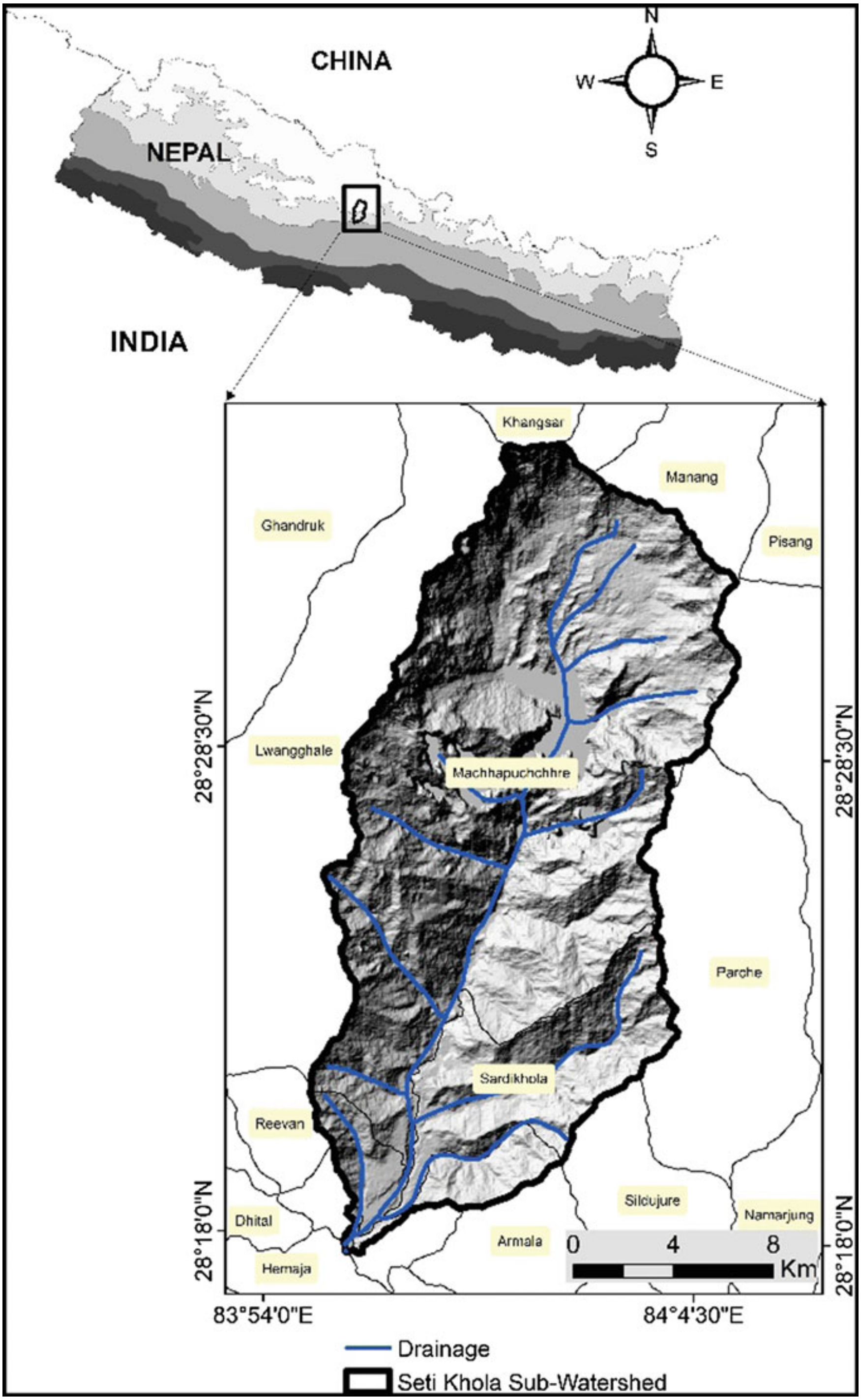


Fig. 9.1 Map of the study area

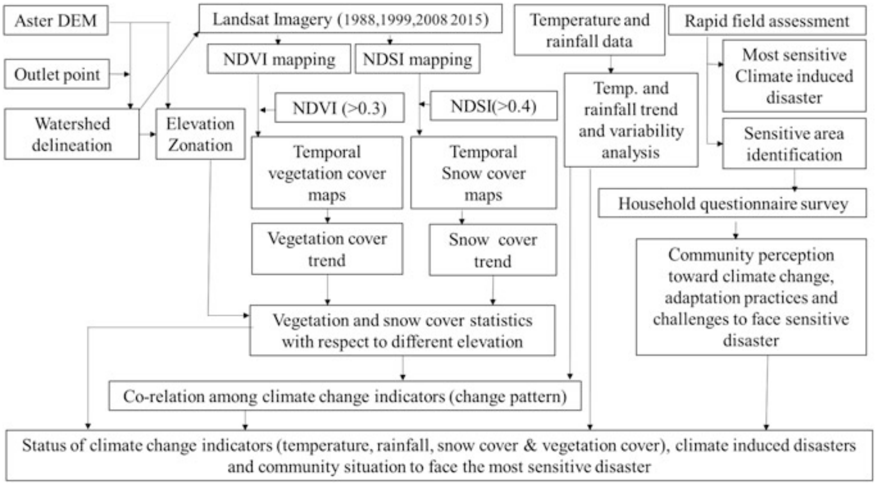


Fig. 9.2 Methodological flow chart of the study

(1988, 1999, 2008 and 2015). The local people's perception and ground reality captured through field observation, focus group discussion (FGD) and key informant survey (KIS) were analyzed to determine the status and scenario of climate change indicators, associated disasters and local adaptation practices and challenges to face them.

Aster DEM (30 m resolution) available at http://earthexplorer.usgs.gov/ was used for automated watershed delineation with aid of Arc Hydrology tool to define the Seti sub-watershed area as the study site. Temperature data of the year 1968–2013 and rainfall data of the year 1972–2015 from Pokhara airport station and Lamachaur station, respectively, representing the study area were collected from Department of Hydrology and Metrology (DHM) to analyze the climatic trend and variability. The result thus obtained was also verified from community people's observations. Annual temperature and rainfall trends were computed by using least square curve-fitting technique to find a linear trend in the data. The linear trend between the time series data (y) and time (t) is given by the equation; $y = a + bt$, where y = temperature or rainfall, t = time (year) "a" and "b" are constant estimated by the principal of least square.

Moreover, the research aimed at analyzing snow and vegetation cover dynamics in the mountain range with respect to climate change presuming that temperature rise accelerates snowmelt and reduces snow cover, increasing the likelihood of vegetation's appearance in the snow land. In order to determine the temporal snow and vegetation cover, Landsat images of every October of the years 1988, 1999, 2008 and 2015 were downloaded from the same Web site and processed to derive Normalized Difference Snow Index (NDSI) and Normalized Difference Vegetation Index (NDVI). The NDSI maps were generated by using Green and SWIR band, while NDVI maps by using Red and NIR band as shown in the equations:

$$\mathrm{NDSI} = \frac{\mathrm{Green} - \mathrm{SWIR}}{\mathrm{Green} + \mathrm{SWIR}} \tag{9.1}$$

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{9.2}$$

Thus, prepared NDSI and NDVI maps were used to create snow and vegetation cover maps, where minimum threshold value considered for NDSI is 0.4 and the minimum threshold value for NDVI is 0.3 to separate snow and other areas and vegetation and other areas, respectively. The sub-watershed area was divided into four elevation zones such as <3000, 3000–4000, 4000–5000 and >5000 m from the DEM. Snow and vegetation cover statistic in each elevation zone were then created based on the temporal Landsat imagery to carry out snow and vegetation cover trend analysis.

Intensive literature review followed by deeper consultation with district levels government institutions such as District Development Committee (DDC), District Forest Office (DFO), and District Soil Conservation Office (DSCO) was carried out to identify most vulnerable VDC. Rapid field assessment approach including direct field observation, FGD and KIS were employed to identify one most serious problems related to climate change that community people are facing in the area (Fig. 9.3).

After identifying the major climate change induced disaster in the focused VDC, a questionnaire survey of 41 HHs (10% sample size) using semi-structured questionnaire was conducted. The goal of this survey was to deeply explore climate change-related issues, especially people's socioeconomic status, their perception of the problem, adaptation practices they are adopting with associated barriers. Most

Fig. 9.3 Rapid field assessment

experienced and oldest persons in households having more than 20 years' residency in the study area were prioritized for the survey. The conceptual framework provided in the third assessment report of IPCC 2001, which defines vulnerability as a function of exposure, sensitivity and adaptive capacity, was followed, and gateway analysis method was used to calculate the vulnerability index of each HHs. The exposure component includes the distance of house and land from the stream and landslide and extent of damage to land and home. Similarly, sensitivity includes education status, landholding, livelihood opportunity and food sufficiency. Likewise, adaptive capacity includes financial strength, social network. The priority in adaptation practices was measured by Friedman test in IBM SPSS, whereas the barriers to adaptation at the local level were calculated in percentage response.

9.4 Result and Discussion

9.4.1 Pattern of Climatic Indicators

Among the climatic indicators, temperature, precipitations, and snow cover trend were analyzed for this study. The temperature observation included average annual and seasonal trend. Total annual and seasonal rainfall trends were computed for precipitation analysis. Then, snow cover of October months for the four successive years was estimated for snow cover analysis. And vegetation cover of the respective year was determined to see the vegetation pattern with respect to snow cover and other climatic parameters.

9.4.1.1 Temperature Trend

Temperature records from nearby meteorological stations show that annual average maximum and minimum temperatures are increasing at the rate of 0.043 and 0.023 °C per annum, respectively (Fig. 9.4). The average maximum and minimum temperatures of the area for the period of 1972–2015 were found 26 and 14 °C, respectively.

The seasonal temperature of about the last thirty years' period is also found in increasing trend. Summer temperature is increasing more than winter temperature. The average maximum and minimum temperatures in summer were found increasing at the rate of 0.0401 and 0.0258 °C, respectively (Fig. 9.5), whereas the average maximum and minimum temperatures in winter were found increasing at the rate of 0.038 and 0.025 °C, respectively, as shown in (Fig. 9.6).

Most of the Nepalese climate change studies are found to be temperature focused. As stated earlier temperature rises at the rate of 0.06 °C per annum but varies across the country, being higher in the mountains and Himalaya (0.08 °C) than in low-lying terai (0.04 °C). The pattern of temperature rise of the area is

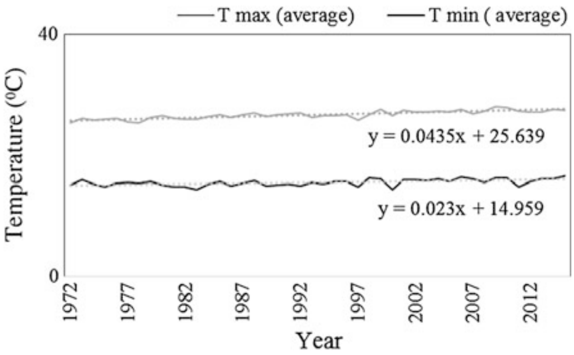


Fig. 9.4 Annual average maximum and minimum temperature

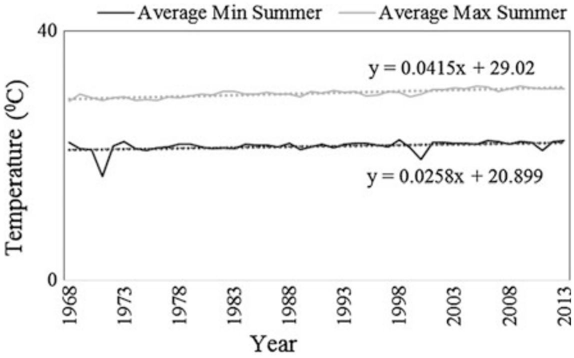


Fig. 9.5 Average maximum and minimum temperature of the summer season for the period 1968–2013

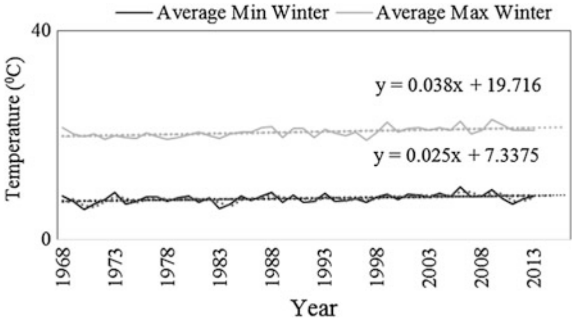


Fig. 9.6 Average maximum and minimum temperature of the winter season for the period 1968–2013

slightly lower than that of other mountain regions. However, the temperature has been rising continuously since 1972. Previous studies have mentioned that the atmospheric temperature of Nepal has been increasing regularly after the mid-1970s at a greater rate than the global average (Shrestha 1999; IPCC 2007).

The warming has been found to be even more distinct in the high altitudes of the Nepal Himalaya (Shrestha 1999). The results of this study also validate those findings.

9.4.1.2 Rainfall Trend

Rainfall data from the stations show that the annual rainfall in the area is decreasing and the patterns of rainfall across the months and season are unpredictable. The average annual total rainfall of the area is 4675 mm, and the rainfall amount is decreasing at the 11.17 mm per annum (Fig. 9.7).

Five years' moving means of total annual rainfall also indicate the decrease in rainfall amount in recent years. There are fluctuations in rainfall, and the graphical trend is not showing any clear pattern (Fig. 9.8).

Similarly, in the case of monthly rainfall, there is a slight decrease in monsoon rainfall. The highest rainfall received in the month of July, and most of the rainfall occurred in between May and September (Fig. 9.9).

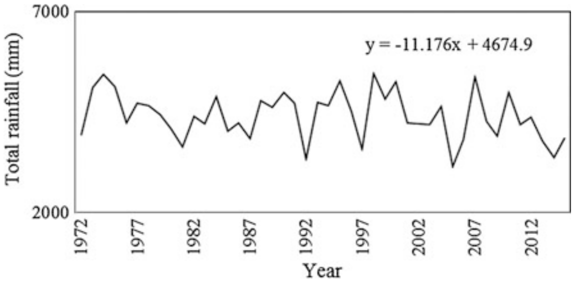


Fig. 9.7 Total annual rainfall of the area for the period 1972–2015

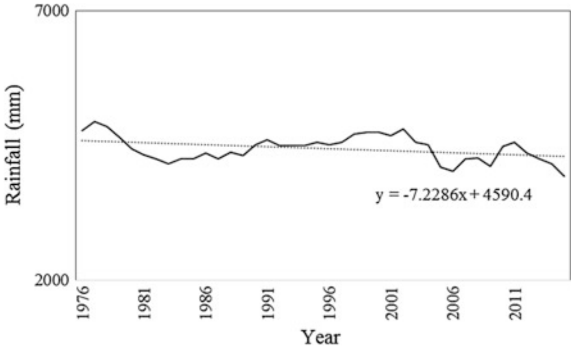


Fig. 9.8 Five years moving mean of annual total rainfall

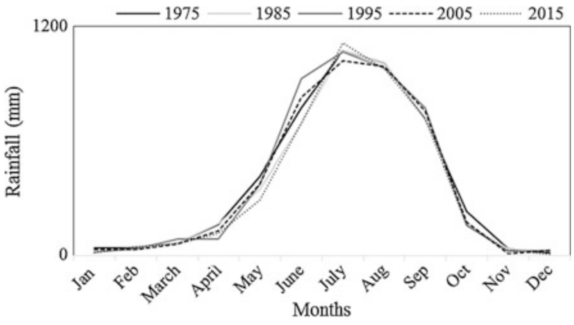


Fig. 9.9 Ten years moving mean of monthly total rainfall

Table 9.1 Correlation matrix between daily temperature and rainfall

	T_{max}	T_{min}	Rainfall
T_{max}	1.00		
T_{min}	0.92	1.00	
Rainfall	−0.05	−0.03	1.00

T_{max} maximum temperature, T_{min} minimum temperature

Correlation matrix in between daily temperature and rainfall for the period 1972–2015 is shown in Table 9.1. This indicates their strong correlation between minimum and maximum daily temperature as there is an increase in minimum temperature with increase in maximum temperature. Temperature and rainfall have a negative relation to the occurrence of rainfall reduces the temperature.

9.4.1.3 Snow Cover Trend

Snow cover in the month of October for the year 1988, 1999, 2008 and 2015 derived from NDSI is in blue color (Fig. 9.10). The permanent snow cover area lies in higher altitude, i.e., above 5000-m elevation. The snow cover area on different dates is found different, and this might be attributed to the variation of temperature, rainfall and snowmelt caused by climate change phenomena. Looking at the snow cover status of the study area on different dates, the overall area of permanent snow cover is reducing in recent times. The occurrences of several events in a recent decade such as floods, landslides, Lake outburst can be attributed to increasing snowmelt in mountains.

Temperature and precipitation have a direct relation with snow cover. The increase in temperature will accelerate the snowmelt and thus reduce the snow cover area. On the contrary, the occurrence of precipitation contributes to snowfall, lowers the temperature and thus reduces snowmelt rate.

As shown in Table 9.2, snow cover has a negative correlation with temperature and positive correlation with rainfall. A similar result was observed in snow cover map: hotter October has less snow cover than cold October. The effect of warming temperature in the Nepal Himalaya is more reflected by shrinking permafrost areas (Fukui et al. 2007) and rapidly retreating glaciers (FUJITA et al. 1998; Yao et al. 2012) among other phenomena.

9.4.2 Vegetation and Snow Cover Change Pattern

The vegetation covers of the study area for the selected date derived through NDVI are shown with green color (Fig. 9.11). There is also variation in vegetation cover in different time periods, which could be due to several natural and anthropogenic causes. The low-lying area is more accessible and has high human pressure, which led the vegetation areas to convert into agriculture and settlements. In comparison

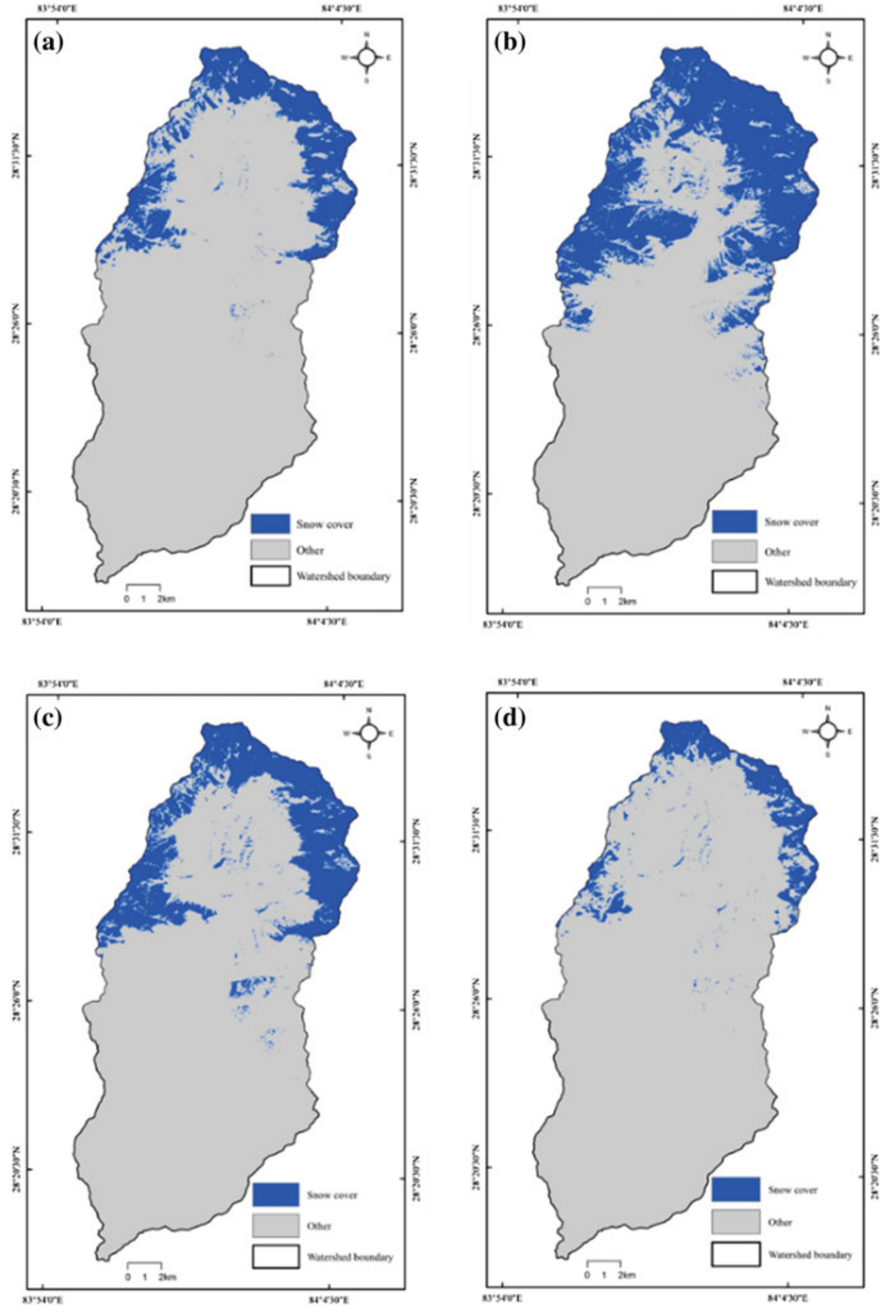


Fig. 9.10 Snow cover of the October month; **a** 1988, **b** 1999, **c** 2008 and **d** 2015

Table 9.2 Correlation matrix in between snow cover, temperature, and rainfall

	$T_{\max}$ (Oct)	$T_{\min}$ (Oct)	Rainfall (Oct)	Snow (Oct)
$T_{\max}$ (Oct)	1.00			
$T_{\min}$ (Oct)	−0.38	1.00		
Rainfall (Oct)	−0.41	0.93	1.00	
Snow (Oct)	−0.84	−0.09	0.09	1.00

Oct October

with the lower belt of the catchment, there is lower human pressure in high altitude. The observation showed that there is an improvement of vegetation cover in high altitude area. The snow and other barren area are slightly converting to grassland and alpine forest.

Altitude wise snow and vegetation cover data derived from the study (Table 9.3) show that snow is dominated in the higher elevation zone, while vegetation is found dominantly from a lower elevation and up to snow line. The variation of data is primarily due to the presence of temporary snow in high altitude areas particularly for the year 1999 and 2008.

There is a negative correlation in between the snow and vegetation cover data (Table 9.4). The greater appearance of snow in the image means less vegetation cover. Though there are some errors in temporary snow cover and vegetation statistics, the overall data show the past snow cover areas are slightly converting to vegetation.

Image analysis of the different dates (Fig. 9.12) shows that vegetation covers of the area had decreased from 1988 to 2008 and then increased where permanent snow cover decreased from 1999 onward. The major fluctuation in the trend line is basically due to the variation of snowfall which is clearly indicated by respective temperature and rainfall records. Looking at the temperature, rainfall and snow cover pattern of different dates, we can say that the permanent snow cover of the area is reducing. At the same time, vegetation and other land status show the snow areas were first converted to barren then gradually converted to vegetation in the absence of any direct human influences. As such there is no any negative consequence of climate change on vegetation cover in terms of area but it has several hydrological implications and disasters which have been altering the native ecosystem and services.

9.4.3 *Climate-Induced Disasters Vulnerability and Community Adaptation with Associated Barriers*

The area considered for the social survey is dominated by poor and illiterate people. The majority of them are Janjati (Gurung, Magar, Pun, Tamang) followed by Dalits (Nepali, B.K., and Periyar) and Brahmin/ Chhetri. The area is food deficit despite

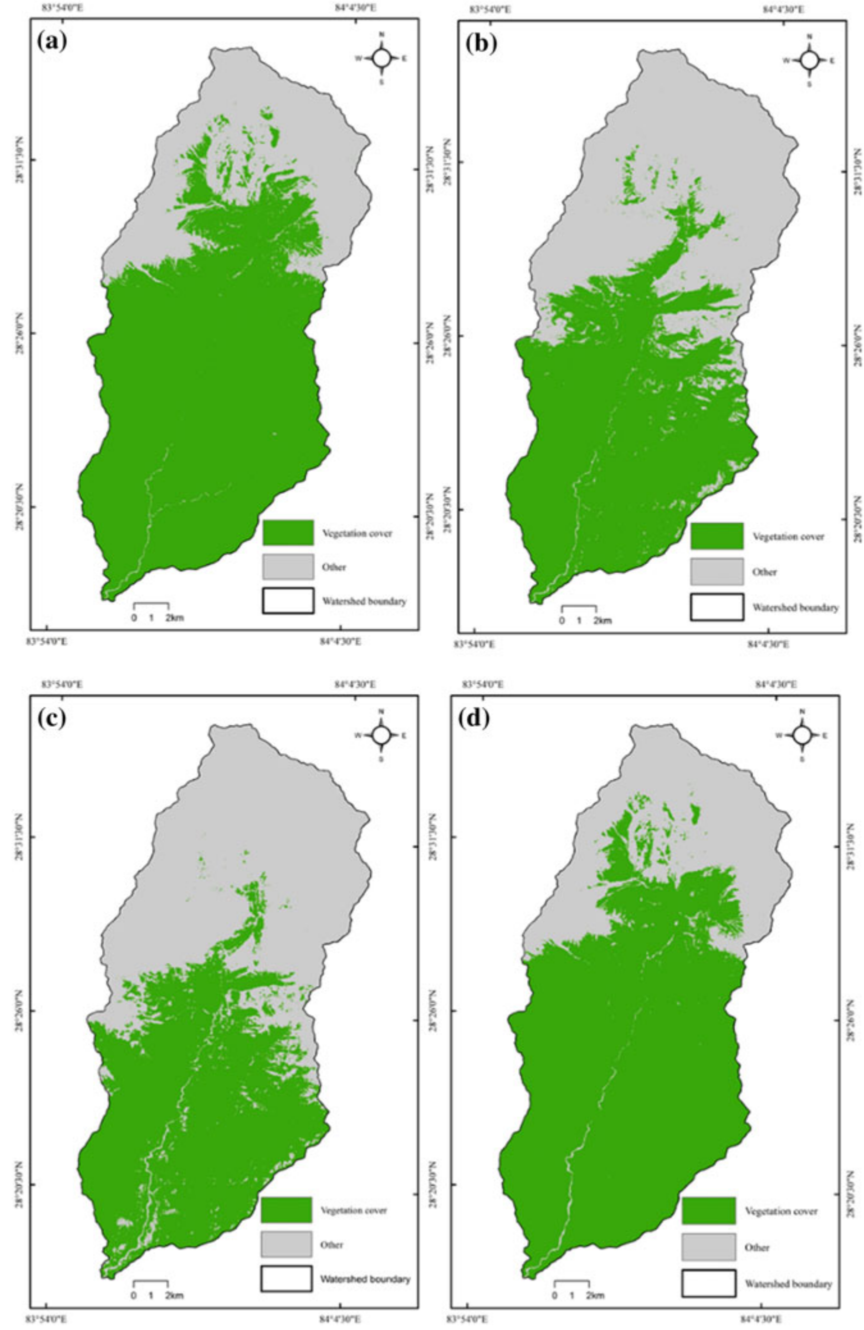


Fig. 9.11 Vegetation cover of the October month; **a** 1988, **b** 1999, **c** 2008 and **d** 2015

Table 9.3 Temporal statistics of snow and vegetation cover in different elevation zone

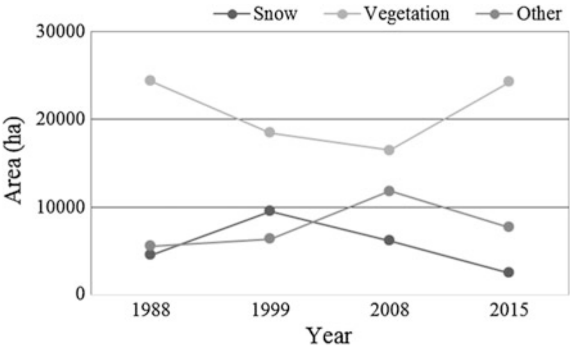
Year	Elevation	Vegetation cover (ha)	Snow cover (ha)	Other land (ha)
1988	<3000	13,472.50	8.91	67.54
	3000–4000	7766.60	38.79	914.56
	4000–5000	3096.50	901.26	3354.08
	>5000	2.10	3575.34	1217.93
1999	<3000	12,970.20	0.63	578.12
	3000–4000	5194.20	768.51	2757.24
	4000–5000	289.70	4566.33	2495.81
	>5000	0.70	4227.93	566.74
2008	<3000	12,801.80	57.78	689.37
	3000–4000	3585.70	183.33	4950.92
	4000–5000	39.50	1706.49	5605.85
	>5000	0.00	4218.12	577.25
2015	<3000	13,429.40	5.31	114.24
	3000–4000	7718.10	43.65	958.20
	4000–5000	3105.70	97.38	4148.76
	>5000	0.20	2339.28	2455.89

ha hectare

Table 9.4 Correlation between snow, vegetation, and other land cover

	Snow cover area	Vegetation cover area	Other land area
Snow cover area	1.00		
Vegetation cover area	−0.75	1.00	
Other land area	−0.05	−0.52	1.00

Fig. 9.12 Temporal land cover status of the watershed



agriculture being main livelihood option in the area. The region is also identified as high climate change vulnerable area categorized by NAPA (2010).

Table 9.5 Vulnerability classification toward floods and landslides

S. No.	Ethnicity	High vulnerable		Moderately vulnerable		Low vulnerable		Total
		Frequency	%	Frequency	%	Frequency	%	
1	Janajati	9	22	12	29	7	17	68
2	Dalit	2	5	4	10	3	7	22
3	Brahmin/Chhetri	0	0	2	5	2	5	10
Total		11	27	18	44	12	29	100

% Percent of household

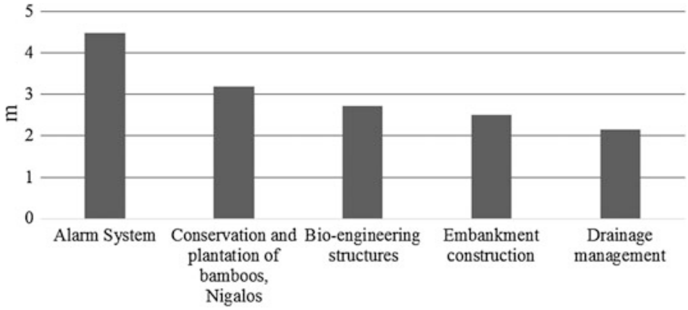


Fig. 9.13 Adaptation practices and priorities to Floods (*m* represents mean value of rating)

Flood and landslides among others were reported as main disasters in terms of both frequency and extent of the damage. They have crushed the limited agriculture land area, pushing the study area to be more food shortage zone. The gateway analysis reveals that 27% people are highly vulnerable followed by 44% as moderately vulnerable and 29% as low vulnerable (Table 9.5). The Janjati, on the basis of ethnicity, is found to be high vulnerable with 22% weight. The finding of Janjati community dominated by illiterate and financially stressed, being a high vulnerable group, matches with the conclusion drawn from a comprehensive study carried out by Samir (2013).

The 2012 flash flood caused serious damage to Sandal village, ward no. 9 of the VDC forcing community to relocate to Pipar village. The field observation and FGD suggest that the village named Jimmirbari as well as Karuwa is also in great danger following the 2012 flash flood in Seti River.

The majority of respondents said that they have no sufficient adaptive capacity to cope with such likely upcoming disaster in future. Some of the local adaptation and mitigation practices found to cope with floods and landslides in the study area includes crop diversification, protecting plant species, gabion wire construction, flood alarm warning system, etc. Local level adaptation seems to be insufficient and unsustainable in the study area and requires further widening up and strengthening. The priority-wise adaptation practices against flood risk found alarm system to be first among five other listed practices (Fig. 9.13). The warning system directly relating to the safety of life has received top priority in another part of Nepal.

Similarly, a plantation in the barren land is most preferred practice against the landslide risk among other five listed practices (Fig. 9.14). This is due to local's perception that plantation not only helps to reduce landslide but also provides forest products to fulfill their needs. Although haphazard stone quarrying seriously triggers landslides, it is commonly practiced. But stopping it is less prioritized because of the cash income the locals derive from it and elite groups are involved in this business.

The study reveals 13 types of barriers to adaptation practices perceived by the local community (Fig. 9.15). About 97% of people perceived a lack of knowledge as the main barrier to adoption of adaptation strategies which is similar to the findings of Bryan et al (2011). After that lack of leadership, lack of technology, lack of institution, shortage of labors, poor infrastructures, pest and diseases, no access to money, lack of coordination and cooperation within villagers are the major

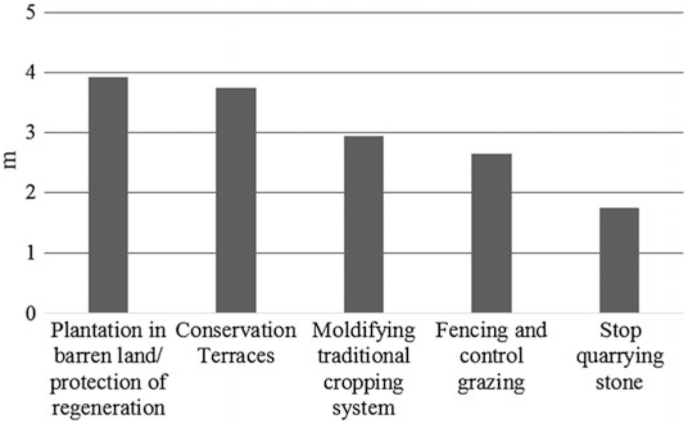


Fig. 9.14 Adaptation practices and priorities to Landslides (*m* represents mean value of rating)

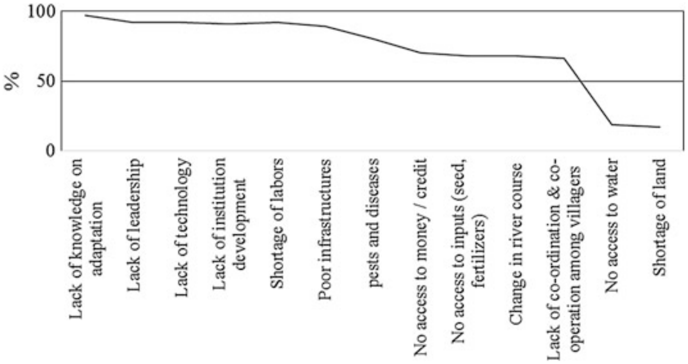


Fig. 9.15 Barrier to adaption strategies (% represents Respond of household)

barriers. In triangulating with the KII and FGD, it was concluded that lack of leadership, lack of technology and lack of institution are the major barriers to adoption of adaptation strategies.

Sensitization and education on climate change impacts, individual capacity building, strengthening local instructions and implementation of adaptation strategy are ensured by a national framework of local adaptation plan of action (LAPA). If these are executed in the study site, they will help the community become more adaptive and resilient against the disasters (GoN 2011).

9.5 Conclusion

The study has supported the reality of climate change happening in line with similar studies carried out in Nepal and elsewhere with evidence of following the trend of key climatic indicator data such as temperature, rainfall, and permanent snow cover. Both increases in seasonal and annual temperature and a decrease in rainfall, as well as overall reduction of permanent snow cover, lead to the conclusion that climate has been changing in the study area. The poor and illiterate community of the study area, found as a most vulnerable group against flood and landslide, are not practicing adequate and sustainable adaptations. Despite the local's prioritized adaptation practices being very genuine, they seriously lack leadership, institutional, and financial supports leading to no systematic adaptations strategy in place. This study demonstrate the applicability of Landsat images to analyze land cover dynamics particularly snow and vegetation that can reflect the consequences of climate change in mountain landscape.

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Chapter 10
Geo-information-Based Soil Erosion Modeling for Sustainable Agriculture Development in Khadokhola Watershed, Nepal

Umesh Kumar Mandal

Abstract Geo-spatial technology as an emerging geo-information science was attempted to estimate the potential and actual soil loss and its correlative interpretation with land system units and land use and cover types in an agricultural watershed, Khadokhola, Eastern Region of Nepal. Among several empirical and physically based soil erosion models, widely used RKLS and Revised Universal Soil Loss Equation (RUSLE) were employed to estimate the potential and actual soil loss in the present investigation, respectively. Forty years of rainfall, topographic contour, and soil map were basically used as source of information for in-depth investigation. Khadokhola watershed originated from Chure/Siwalik range was found highly sensitive or prone to soil erosion. A total of 253.1 and 27.9 million tons soil was potentially and actually estimated annually being lost from Khadokhola watershed. Erosion rates were found highly correlated with the slope of land system units. 64.41% of the total potential soil loss was mainly contributed only by land system unit 8 with the spatial coverage of 17% of the watershed area. This unit was characterized by steeply to very steeply sloping hilly and mountainous terrain having dominant slope greater 20°. Such land system unit was also found highest proportion of soil loss among the averages. Subsequently, degraded forest was investigated contributing significantly as of 64% total potential soil loss. Agriculture as a lifeline of livelihood of rural communities, spatially concentrated in 74.31% of the watershed area, was contributing significantly as of 28% of the total potential soil loss and 65% of actual total soil loss in the study area. Similarly degraded bush land and scattered tree areas contributed 34,162 and 21,994 tons/ha/year on a potential average, respectively. Undulating erosional alluvial fan upper piedmont and steeply to very steeply sloping hilly and mountainous terrain having soil loss highest must be given higher priorities for soil conservation and optimum land use planning required for sustainable agricultural development. Lower percentage of actual soil to the potential loss indicated the fact of contribution of crop management and erosional control practice factor in reducing soil erosion in existing situation.

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Keywords Soil erosion · Cultivation · Land system units · RKLS · RUSLE · Geo-information science

10.1 Introduction

Ecological degradation has been increasing in Nepal to the point where it has been estimated that over 240 million m^3 of top soil is being eroded annually from the hills of Nepal to the Bay of Bengal. According to a nationwide inventory of watershed conditions, 13% of Nepal's land area has deteriorated seriously and 10,000 km^2 are devoid of sufficient vegetation and are in danger of desertification (Nelson 1980). Top soil lost from the mountain is raising the riverbeds in the Tarai at an estimated annual rate of 15–30 cm. It increases the incidence of floods and reducing the fertility of fertile lands, damaging irrigation channels, dams and hydropower projects. Soil loss from cultivated and grazing land is a major factor in decline of soil fertility. About 1.8 million tons of plant nutrients estimated are being removed by crop harvesting (0.5 million tons) and soil erosion process (1.3 million tons). Out of this only 0.3 million tons (16%) are replenished by organic and mineral fertilizer sources (Joshi et al. 1997).

Soil degradation as one of constituents of ecological degradation is recognized as a serious problem in Nepal because more than 80% terrain is rugged and characterized by unstable and steep slopes making it vulnerable to exogenous factors, landslide and soil erosion (UNEP 2001). The rapid growth of human and livestock population is putting severe pressure on Nepal's natural resource especially soil. The decline of soil fertility through topsoil erosion is one of the major ecological crises facing Nepal today, and it is in this area that soil conservation programs have an important role to play. Throughout the hill region of Nepal, soil loss on cultivated and grazing land is a major factor in soil fertility management. Any techniques used to enhance the productivity must consider soil conservation measures. Conversely any techniques used to reduce soil erosion must consider land productivity.

Surface erosion is less conspicuous than mass wasting, but it is much more damaging to the livelihood of Nepalese people. Many of men's activities cause the soil to become less protected than it would be in a natural state. The loss of one or two mm of topsoil every year may not make spectacular visual impact, but cumulative effect is the impoverishment of the soil base. Topsoil having highest level of nutrients is more productive for plant growth than lower horizons. Top soil erosion is threatening the soil fertility of many rainfed agricultural fields in the middle mountains of Nepal (Nakarmi and Shah 2000).

Erosive rainfall, vegetation cover, soil erodibility, topography and protection measures are determining factors for estimation of soil loss. In the last 60 years, empirical, conceptual or physically based models have been built including former models of USLE (Wischmeier and Smith 1958, 1978). MUSLE (Williams and Berndt 1977), SLEMSA (Stocking 1981), Morgan et al. (1984), RUSLE (Renard et al. 1997; SWCS 1993), latter models of WEPP (Flanagan et al. 2001), EUROSEM (Morgan et al. 1998) were models used in order to represent and to quantify the process of detachment, transport and deposition of eroded soil with the aim of implementing assessment tools for either scientific or planning purposes.

The most common models used in Nepal are Morgan et al. (1984) in Middle Mountain (Shrestha 1997), RUSLE in Bhote Koshi catchment, Nepal Himalaya (Andermann and Gloaguen 2009), RUSLE and RMMF in Kalchi Khola in mountainous watershed. Beside this, USLE was successfully applied to assess soil erosion in Trijuga, Kulekhani, Pakhribas, Hamsingha Watersheds of Nepal by Sah, Kharel, Sherchan and Dhungana, respectively, with satisfactory results (Sah 1996; Kharel 1999; Sherchan 1991; Dhungana 2002 cited in Jha and Paudel 2010).

Even though, a number of parametric models for predicting soil erosion exist, this study explores potential application of Revised Universal Soil Loss Equation (RUSLE) based on the integration of remotely sensed data and GIS for the Eastern Terai Region of Nepal. RUSLE uses the same empirical principles as the USLE but includes improved rainfall erosivity factor incorporating the influence of profile convexity/concavity using segmentation of irregular slopes and improved empirical equation for computing slope factor (LS).

10.2 Materials and Methods

10.2.1 Study Area

The study area, Khadokhola watershed is originated from Siwalik as an youngest range of Himalaya. The study area spatially covers central part of the geographic extent of Saptari district. The study area is roughly elongated in shape averaging about 30.74 km in length by 8.23 km in width on an axis running from north to south. The total geographic area covered is 253.32 km^2 (25,332.0 ha). Geometrically, the location of the study area ranges from 86° 41′ 15″E to 86° 51′ 15″E and 26° 26′15N to 26° 42′30″N. It is bounded by Chure/Siwalik in north and by India border in south and by Koshi watershed in the east. The lower part of the study area belongs to Lalapati village development committee (64 m from msl) where as upper part of Nakati Raypur (303 m from msl). In altitude, the study area ranges from 64 m above mean sea level in Lalapati VDC in south to 378 m in Thulo Musharniya Dada in the north. The study area falls within 6 topo sheets viz. 2686 07B, 2686 07D, 2686 08A, 2686 08C, 2686 12A and 2686 11B having the scale at 1:50,000. The climate is tropical that varies from south to north. Geologically, the study area consists of active alluvial plain. The land unit consists of present river channel, sand and gravel bars. Geomorphically, the study area is characterized by active depositional plain. Bhaluwahi dhar is the main tributary of Khado khola drainage system followed by many other tributaries such as Dudhiya khola, Damra khola and Jurpaniya khola.

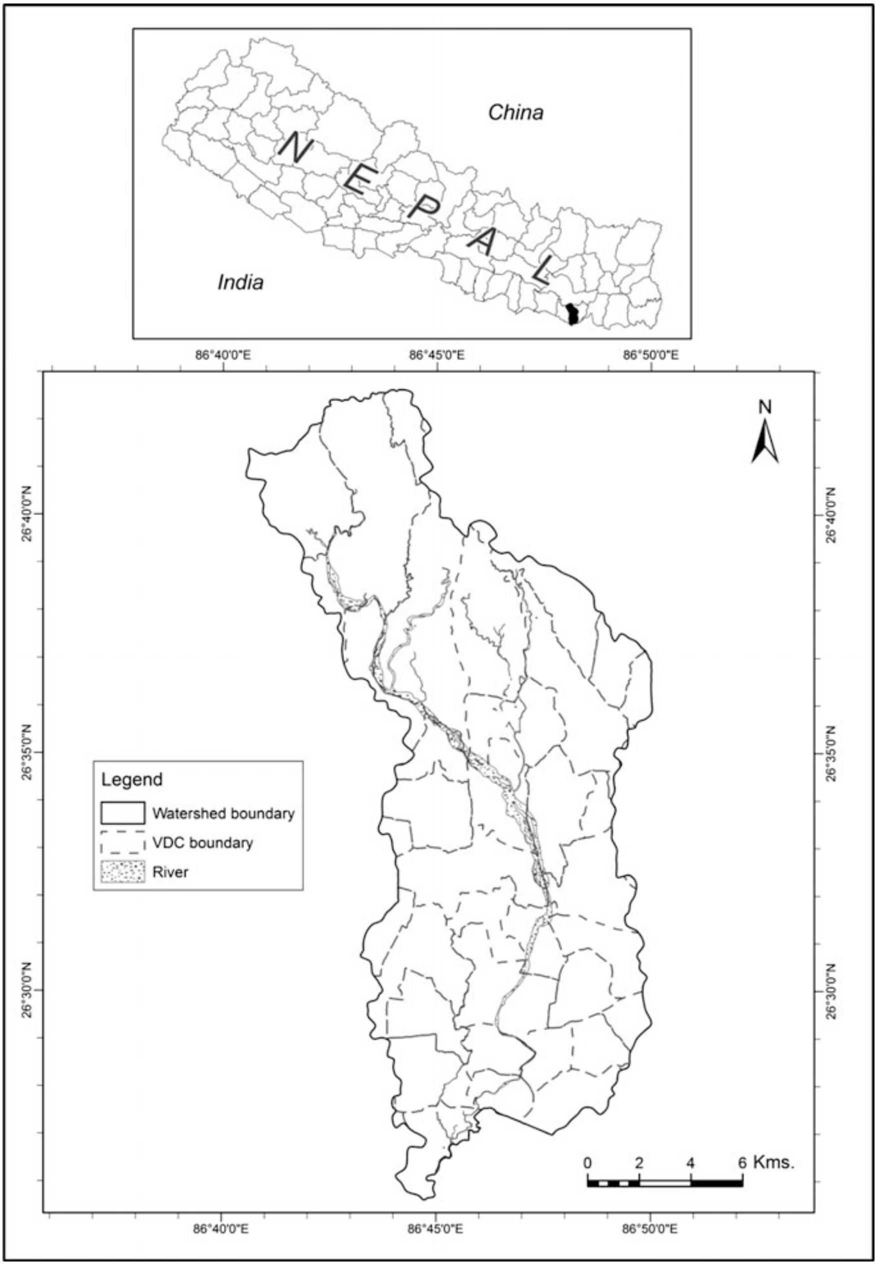

Fig. 10.1 Map of location Khadokhola watershed

Khado river joins Koshi watershed near India border. At higher elevations, land cover is mixed forest which mainly consists of Sal (Shorea robusta) and sakhuwa and crops include rice, wheat and maize. The location of study area is shown in Fig. 10.1.

10.2.2 Explanation of Model Parameters in Conceptual Framework

USLE developed by Wischmeier and others with USDA, ARS and SCS in late 1950 and revised in 1978 is a powerful tool widely used by soil conservationists in the United States and many other countries. Wise use of prediction technology requires the user be aware of a procedure's limitations. The USLE/RUSLE is an equation of estimating average annual soil loss by sheet and rill erosion on those portions where erosion, but not deposition is occurring. It does not estimate deposition at the toe of concave slopes, and not estimate sediment yield at a downstream location by not including ephemeral gully erosion. It also does not represent fundamental hydrologic and erosion processes explicitly (Renard et al. 1997). The application of USLE/RUSLE as a tool to assist soil conservationists in farm planning by estimate of soil loss on specific slopes in specific fields. Thus, the USLE/RUSLE helps to tailor erosion control practices to those specific sites where soil loss exceed acceptable limits and then it guides the conservationist and farmer in choosing a appropriate practices controlling erosion adequately while meeting the needs and wishes of the farmer.

The conceptual framework and the six major parameters associated with the soil loss estimation are shown in Fig. 10.2, and its explanation has been given below.

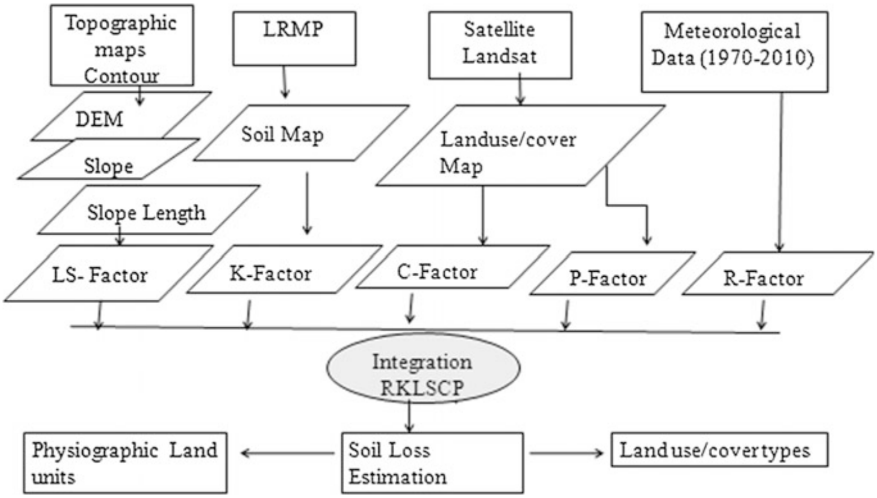

Fig. 10.2 Conceptual framework for soil loss estimation

10.2.2.1 Rainfall Erosivity (*R*)

Soil loss is related to kinetic energy of rainfall through the detachment power of raindrops striking the soil surface and the entrainment of the detached soil particles by runoff water down slope. The kinetic energy of rainfall is dependent on annual rain and rainfall intensity. For annual rain, rainfall data were collected during 40 years period (1970–2010) of six stations located inside and the vicinity of Khadokhola watershed. Ensuring that no rain shadow area exists in the watershed, a regression analysis of annual rainfalls with different elevations can be performed and if the correlation coefficient is found to be significant and high enough, an equation can be derived to compute rainfall map from elevation data (Morgan 1986; Morgan et al. 1984). Ten meter contour intervals and spot height from a topographic base map was used to generate digital elevation model (DEM) by interpolation procedure.

In Khadokhola watershed, significant correlation coefficient at 95% confidence level was found between annual rainfall (E) and elevation ($r = 0.59$) and thus used to generate a rainfall map using regression equation as follows:

$$E = 1916 + 0.33 \times \mathrm{DEM} \tag{10.1}$$

Rainfall erosivity factor (R) is based on kinetic energy considerations of falling rain and represents a measure of the erosive force and intensity of rain in a normal year (Goldman et al. 1986). Two components of the factor are the total energy (E) and the maximum 30-min intensity of storms I30 (Wischmeier and Smith 1978). The R factor is the sum of the product of these two components for all major storms in the area during an average year. Even though E and I30 are the most reliable source for computing R, other equations might be used where E and I30 are not available. The equation ($R = 38.5 + 0.35P$, where P represents mean annual precipitation) providing acceptable erosivity index for tropical and subtropical ecological zone is one of them (Eiumnoh 2000). Other equations such as Eq. 10.2 (Morgan 2001) and Eq. 10.3 (Renard and Freimund 1994) are generally accepted equations for the mountainous tropical climate.

$$R = (9.28 \times P - 8838.15) \times 0.102 \times \mathrm{I30}/173.6 \tag{10.2}$$

$$\begin{cases} R = 0.0483 \times P^{1.61}, & P < 850\ \mathrm{mm} \\ R = 587.8 - 1.219 \times P + 0.004105 \times P^2, & P > 850\ \mathrm{mm} \end{cases} \tag{10.3}$$

Rainfall intensity is an essential component for assessing soil erosion, since splash detachment is a function of rainfall energy, soil detachability and rainfall interception by crops. Rainfall showers less than 12.5 mm in a given days are assumed too small to have practical significance and are not considered as erosive (Wischmeier and Smith 1978). But such interval of rainfall is not available from recorded stations. In this study, average rainfall intensity has been used in the following equation for estimation of R factor:

$$R = E(11.87 + 8.73\log_{10} I) \tag{10.4}$$

where R = rainfall erosivity (J m^{-2}) E = annual rainfall (mm), I = rainfall intensity (mm/24 h) obtained from total amount of rain divided by number of rainy days of the stations located in and around the watershed. The location map of Meteorological Stations has been shown in Table 10.1 and Fig. 10.3.

10.2.2.2 Soil Erodibility (*K*)

Soil erodibility (K) defines the inherent resistance of the soil to both detachment and transport that is influenced by soil structure, organic matter content, soil texture and soil permeability, and it should be based on measured value wherever possible. Soil texture, structure, permeability and organic matter content are parameters that can be obtained from soil profile descriptions, and K values were also estimated from soil erodibility nomograph for those cases silt fraction does not exceed 70% (Wichmeiser and Smith 1978) derived from the equation:

$$K = 2.1 \times 10^{-6}(12 - P_{\mathrm{om}}) \cdot f_{\mathrm{p}}^{1.14} + 0.0325(S - 2) + 0.025(f_{\mathrm{perm}} - 3) \tag{10.5}$$

in which

$$f_{\mathrm{p}} = P_{\mathrm{silt}}(100 - P_{\mathrm{clay}}) \tag{10.6}$$

where P_{om} is the percent organic matter, f_{p} is the particle size parameter, S is the soil structure index, f_{perm} is the profile-permeability class factor, P_{silt} is the percent silt

Table 10.1 Climatic station site characteristics

Climatic stations				Lat. *N* (deg/min)	Long. *E* (deg/min)	Elev. *m* (amsl)	Date established
No.	Districts	Name	Code				
1	Siraha	Lahan	1215	2644	8626	138	1 Nov. 1955
2	Udaypur	Udaypur Gadhi	1213	2656	8631	1175	1 Jul. 1947
3	Saptari	Rajbiraj	1223	2633	8645	91	Dec. 1971
4	Saptari	Barmajhiya	1226	2636	8654	85	Sep. 1975
5	Saptari	Fatepur	1212	2644	8651	100	Jul. 1976
6	Sunsari	Chatara	1316	2649	8710	183	1 Jun. 1948

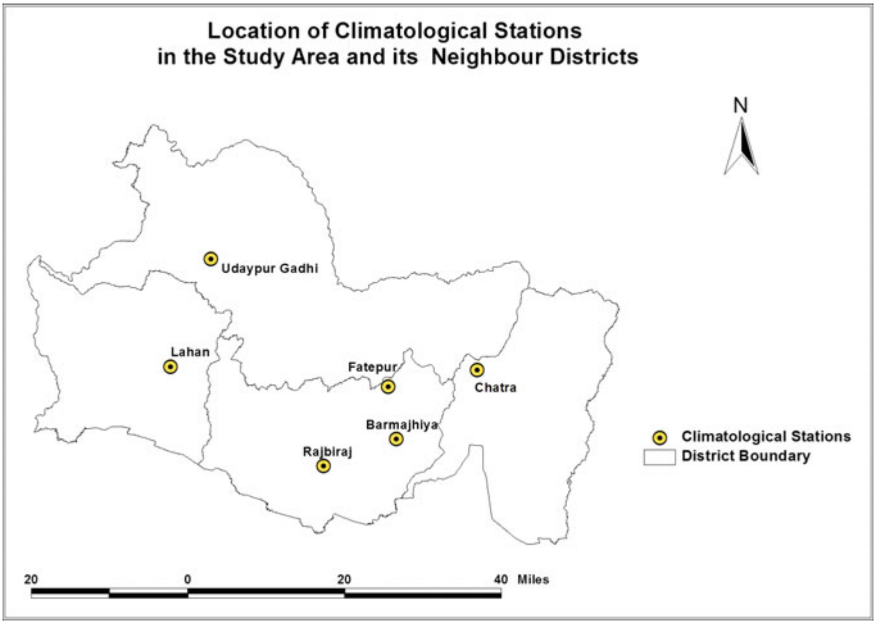

Fig. 10.3 Location of climatological stations

Table 10.2 Soil parameters used for estimation of *K* value (Morgan et al. 1984)

Surface texture	Soil moisture content at field capacity (%)	Soil detachability index
Coarse texture (less than 15% clay: sandy loam, loam)	0.30	0.3
Medium texture (less than 35% clay: loam, sandy clay loam, silty clay loam)	0.34	0.4
Fine texture (more than 35% clay: silty clay, sandy clay)	0.37	0.4

and P_{clay} is the percent clay. The *K* value can be calculated with the use of nomograph, derived by Wischemier and Smith (1978), when all the values of *K* influencing factors are available. In this study area, the soil parameters used are based on the average values of the laboratory data from the soil samples obtained from Land System Report. The soil detachability index (*K*) is based on the value suggested soil parameters in Morgan et al. (1982) and given in Table 10.2. In general terms, the less the proportion of sand or silt, the higher the organic matter content, the more developed the soil structure, and the higher infiltration rate, the less erodible the soil will be (LRMP 1986).

Lack of detailed soil map in Nepal forced to use data from The Soil Landscape of Nepal (LRMP 1986). Five samples based on land units were taken evenly distributed over existing soil series across the watershed. A polygon vector file of the physiographic soil map was used to generate K value map using relationship with soil texture given in Table 10.2.

10.2.2.3 Topographic Factors: Slope Length and Steepness (LS)

The potential for surface soil erosion will increase as the topographic factors, slope steepness and length are steeper and longer, respectively. The higher the velocity and greater the concentration of water, greater will be the erosion. Thus, the slope factors are key component for estimating soil erosion hazard. The factors of slope length (L) and slope steepness (S) are combined in a single topographic index termed as LS factor. Wischmeier and Smith defined the slope length as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel. Slope steepness in percentage for the present watershed was derived from digital elevation model (DEM). Slope = (hyp(dx, dy)/pixel size)*100 and slope length was estimated by the relationship as: $L = 0.4*S + 40$.

The original USLE formula for estimating the LS factor was used for slope steepness up till 21%. The equation is:

$$\mathrm{LS} = (L/72.6)^m \cdot \left(65.41 \sin^2 S + 4.56 \sin S + 0.065\right) \tag{10.7}$$

where m is a slope contingent variable. The Gaudasasmita equation given below was used for the slope steepness of 21% or more:

$$\mathrm{LS} = (L/22.1)^{0.79} \cdot \left(6.432 \cdot \sin(S^{0.79}) \cdot \cos S\right) \tag{10.8}$$

Finally, topographic factor was generated by combing maps derived from Eqs. 10.7 and 10.8.

10.2.2.4 Crop Management Factor (*C*)

The ratio of soil loss under given crop to that from bare soil is represented as crop management factor (C). The C factor combines plant cover, its production level and the associated cropping techniques. It varies from 1 on bare soil to 1/1000 under forest, 1/100 under grasslands and cover plants, and 1 to 9/10 under root and tuber crops. Knowing the land use, its value can be simply obtained from published tables. So, in the simplest form, as in the USLE, the C factor is estimated based on the land use categorization of the concerned area. But in RUSLE, this factor is greatly revised and is estimated with the soil loss ratio (SLR) algorithm which incorporates several subfactors like prior-land-use (PLU), canopy-cover (CC), surface-cover (SC), surface-roughness (SR) and soil moisture (SM) (Renard et al.

1991). Indirectly through the vegetation parameters like Normalized Difference Vegetation Index (NDVI) or Leaf Area Index (LAI) as used for estimation of *C* factor (Suriyaprasita and Shrestha 2008), in order to determine *C* factor in Khadokhola watershed, supervised classified land use map generated from integrated use of Landsat ETM+ images (2010), aerial photographs and toposheets was used. *C* values used in this analysis were defined 0.004 for dense mixed sal forests, 0.02 for bush land and grass lands, 1 for bare land and 0.377 for agriculture land as recommended by Morgan.

10.2.2.5 Erosion Control Practice Factor (*P*)

The *P* factor mainly represents how surface conditions affecting flow paths and flow hydraulics. This factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment. Therefore, erosion control practice factor is based on the soil conservation practices such as contouring operated in a particular area. Details of procedure of calculation are obtained from Agricultural Handbook 703 (Renard et al. 1997). But practically, the data of the adopted erosion control practices in the agricultural area are, in general, ranging from 1 for non-agriculture assuming that no conservation measures are implemented to 0.5 for agriculture land and its further redistribution spatially among different slope categories: 0.1 for 0–5% to 0.33 for 50–100% (Wischmeier and Smith 1978) and accordingly, *P* value map was generated.

10.3 Results and Discussions

10.3.1 Potential and Actual Soil Loss Estimation in Khadokhola Watershed

Potential soil loss has been considered as the erosion susceptibility derived from rain erosivity, soil erodibility and the factor slope with ought taken into account the crop cover and erosion control management practices (Toxopeus 1997) Similarly, actual soil loss was conceptualized considering the natural occurring factors estimated from RUSLE equation. In this line, the results of soil loss estimation derived from RKLS representing as potential and RUSLE as actual soil loss model in Khadokhola Watershed were presented and discussed in two ways of analysis units: physiographic land units and land use and cover types as below.

Based on the erosion rates, the study area was classified into five erosion classes ranging from 446 to 125,663 tons/ha/year in case of potential and 0.75 to 117,000 tons/ha/year for actual soil loss. As compared to potential soil loss, 46.36% of watershed area is fallen within the highest category of class with erosion rates greater than 3500 tons/ha/year, whereas only 2.5% of watershed area is found

Table 10.3 Potential and actual soil loss in Khadokhola watershed

Erosion classes	Potential soil loss		Actual soil loss	
	Area (ha)	%	Area (ha)	%
<100 tons/ha/year	0.0	0.00	192.2	0.76
100–500 tons/ha/year	177.2	0.70	3128.1	12.35
500–1500 tons/ha/year	2123.5	8.38	18,543.4	73.20
1500–3500 tons/ha/year	11,286.7	44.56	2829.7	11.17
>3500 tons/ha/year	11,744.5	46.36	638.5	2.52
Total	25,332.0	100.00	25,331.9	100.00

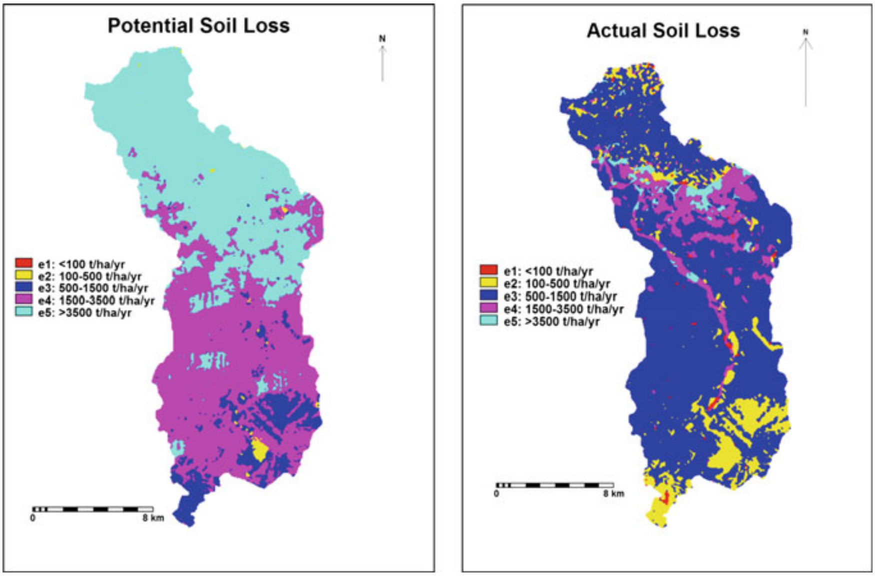

Fig. 10.4 Potential and actual soil loss estimation in Khadokhola watershed

under the same category in case of actual soil loss estimation (Table 10.3 and Fig. 10.4). Spatial distribution of such rate shown in Fig. 10.4 indicates that land cover as forest, bush, shrub and grass present in the natural condition in the northern part of watershed has positive impact to reduce the soil erosion. There is significant variation found in geographic area distribution of watershed in both situations as potential and actual estimation.

A total of 253.1 million tons is estimated as potential soil loss using RKLS annually being lost from the watershed. In the natural condition, a total of 27.9 million tons is estimated as actual soil loss using RUSLE model representing 11.05% of potential soil loss (Tables 10.4 and 10.5). The mean annual soil loss estimated for the land use land cover in the study area was found to be 10,279 tone/ha as potential soil loss and 1227 tons/ha as actual soil loss (Tables 10.6 and 10.7) that is seemed more in terai agriculture watershed as compared to Hill (Mandal et al. 2015).

Table 10.4 Potential soil loss by physiographic land units

S. no.	PHYSOIL	Potential soil loss (tons/ha)					
		Area (%)	Total	Soil loss (%)	Average	Min	Max
1	Sand and gravel bars (1b)	3.80	4,153,465.81	1.64	4309.69	117.92	33,165.42
2	Higher terraces (1d)	3.71	2,109,223.38	0.83	2241.47	118.02	12,424.63
3	Depressional recent alluvial plain lower piedmont (2a)	37.18	21,047,651.41	8.32	2233.59	157.36	124,657.52
4	Intermediate position level (2b)	27.09	32,451,612.69	12.82	4725.91	157.07	69,185.45
5	Intermediate position undulating (2c)	3.66	1,922,899.01	0.76	2074.32	157.50	18,029.47
6	Undulating erosional alluvial fan upper piedmont (3c)	7.53	28,405,909.51	11.22	14,874.15	116.57	167,524.49
7	Steeply to very steeply sloping hilly and mountainous terrain (8)	17.02	163,024,799.36	64.41	37,785.33	112.43	1,826,500.53
	Total	100.00	253,115,561.17	100.00	68,244.46	936.88	2,251,487.50
	Average	14.29	36,159,365.88	14.29	9749.21	133.84	321,641.07

Table 10.5 Actual soil loss by physiographic land units

S. no.	PHYSOIL	Actual soil loss (tones/ha)					
		Area (%)	Total	Soil loss (%)	Average	Min	Max
1	Sand and gravel bars (1b)	3.80	1,531,567.76	5.47	729.56	0.66	25,132.77
2	Higher terraces (1d)	3.71	610,484.34	2.18	798.44	0.48	3230.40
3	Depressional recent alluvial plain lower piedmont (2a)	37.17	5,676,393.34	20.29	5792.99	0.25	30,765.09
4	Intermediate position level (2b)	27.11	9,064,030.88	32.40	2066.92	0.25	16,463.79
5	Intermediate position undulating (2c)	3.66	540,198.58	1.93	1549.26	0.32	4687.66
6	Undulating erosional alluvial fan upper piedmont (3c)	7.54	4,658,528.36	16.65	983.93	0.19	17,344.70
7	Steeply to very steeply sloping hilly and mountainous terrain (8)	17.01	5,896,610.43	21.08	2945.18	1.80	40,961.52
	Total	100.00	27,977,813.69	100.00	14,866.28	3.95	138,585.94
	Average	14.29	3,996,830.53	14.29	2123.75	0.56	19,797.99

Table 10.6 Potential soil loss and land use/cover types

Land use/cover	Potential soil loss (tons/ha)					
	Area (%)	Total soil loss	Total soil loss (%)	Average	Min	Max
Bamboo	0.59	547,064.46	0.22	3665.42	118.23	12,130.33
Barren land	0.68	1,923,429.30	0.76	11,102.05	117.82	29,250.25
Built up	0.91	811,200.66	0.32	3523.13	157.36	8754.27
Bush	1.45	12,554,846.68	4.96	34,162.85	112.43	119,770.53
Canal	0.23	155,230.39	0.06	2687.97	158.32	4231.16
Cultivation	74.31	69,889,646.63	27.61	3711.17	117.63	122,222.80
Forest	17.21	161,929,424.98	63.98	37,127.00	114.09	1,706,730.00
Grass	0.21	123,532.35	0.05	2298.28	118.65	3402.60
Pond	0.80	601,855.00	0.24	2950.27	118.95	11,068.29
River	0.49	394,085.33	0.16	3190.97	118.03	13,807.29
Sand	3.05	3,836,336.04	1.52	4969.35	116.99	39,659.25
Scattered tree	0.06	335,410.45	0.13	21,994.13	486.55	14,835.68
Swamp	0.01	4494.75	0.00	2247.37	158.33	1459.58
Total	100.00	253,106,557.01	100.00	133,629.96	2013.37	2,087,322.03
Average	7.69	19,469,735.15	7.69	10,279.23	154.87	160,563.23

10.3.2 Potential and Actual Soil Loss in Physiographic Land Units

Potential and actual soil losses in Khadokhola watershed were estimated by physiographic land units in order to understand the degree of influence and role of physiographic landforms in accelerating erosion. The spatial extent of potential and actual soil loss by physiographic land units and its descriptive statistics are given in Tables 10.4 and 10.5. Erosion rates were found highly correlated with the increasing slope of land units in both situations: potential and actual. It was evident by the fact that land units such as 3c and 8 having degree of slope less than 20° and more than 20° were found with 11.22 and 64.41% of total potential soil loss in the watershed, respectively (Table 10.4). Similarly, in the case of actual soil loss estimation, land unit 8 contributes less (21.08%) than potential soil loss. It is because of the presence of land cover, but the proportion of actual soil loss is found more (16.65%) in comparison with potential in land unit 3c due to the degraded condition of land unit.

The average and maximum potential soil loss were found highest (37,785 tons/ha) and (1,826,500 tons/ha), respectively, in land unit 8 that is characterized as steeply to very steeply sloping hilly and mountainous terrain. Such land

Table 10.7 Actual soil loss and land use/cover types

Land use/cover types	Actual soil loss (tons/ha)						% of actual to potential soil loss
	Area (%)	Total soil loss	Total soil loss (%)	Average	Min	Max	
Bamboo	0.59	873.95	0.00	2.72	0.19	19.41	0.16
Barren land	0.68	1,923,429.30	6.88	3807.65	117.82	29,250.25	100.00
Built up	0.91	283,697.45	1.01	545.96	55.08	3063.99	34.97
Bush	1.45	200,875.01	0.72	183.53	1.80	1916.33	1.60
Canal	0.23	38,931.16	0.14	440.59	39.60	1057.79	25.08
Cultivation	74.31	18,171,308.13	64.95	5075.86	30.58	31,777.93	26.00
Forest	17.21	3,889,171.59	13.90	2820.46	2.74	40,961.52	2.40
Grass	0.21	691.78	0.00	7.14	0.66	19.05	0.56
Pond	0.80	1203.71	0.00	2.81	0.32	22.14	0.20
River	0.49	394,085.33	1.41	1247.50	118.03	13,807.29	100.00
Sand	3.05	3,066,280.82	10.96	1701.66	93.59	31,727.40	79.93
Scattered tree	0.06	5549.81	0.02	119.79	0.89	505.98	1.65
Swamp	0.01	7.26	0.00	1.56	0.51	2.36	0.16
Total	100.00	27,976,105.29	100.00	15,957.23	461.80	154,131.43	11.05
Average	7.69	2,152,008.10	7.69	1227.48	35.52	11,856.26	11.05

unit was characterized by lithic ustorthents as dominant soil and loamy skeletal as the dominant soil texture. In overall comparison in terms of average soil loss estimation, it was found substantially reduced in actual model using RUSLE as of 2123 tons/ha rather than of 9749 tons/ha in potential model (Tables 10.4 and 10.5).

10.3.3 Potential and Actual Soil Loss in Land Use/Cover Types

Potential and actual soil losses in Khadokhola watershed were estimated by land use and cover types in order to understand its role in determining erosion rate. The potential and actual soil loss by land use and land cover types and its summary statistics are given in Tables 10.6 and 10.7, respectively. Soil erosion rates were found highly correlated with the increasing exposure of land surface. In potential soil loss estimation, forest area sharing 17.21% of the entire watershed area was contributing almost 63.98% of the total soil loss in the watershed. Similarly, in case of agriculture land sharing, 74.31% of total land use land cover in the watershed was causal to almost 27.61% of the total soil loss in the watershed and such rate was found less in terai agriculture watershed as compared to mountainous hilly watershed (Mandal et al. 2015). In both cases, differential nature of soil erodibility and topographic factors affect the varied rate of soil erosion. Similarly, bush land and scattered tree areas were also considered as most influencing factor of soil erosion which were contributing 34,162 and 21,994 tons/ha on an average potential soil loss, respectively. Land use types as forest and agriculture along with sand areas were also recorded as maximum potential soil loss (Table 10.6).

After applying crop management (C factor) and erosion control practice (P factor) in actual soil loss estimation, RUSLE, the scenario of erosion condition was quite inverse supporting the fact that agriculture land sharing 74.31% of total land use land cover in the watershed, was contributing highest, 64.95% of the total soil loss in the watershed that is seen more as compared to forest contribution sharing 13.9% of the total soil loss. It was due to the fact that erosion control practice as forestry was relatively better than unmanaged agriculture practices. Similarly, these two land use types were also found as most determining factor of soil erosion control which was contributing more not on an average but also in maximum statistics (Table 10.7). The figure of percentage of actual to potential soil loss depicted in last column of Table 10.7 indicates the higher contribution of crop management and erosion control practices with its decreasing value.

10.3.4 Prioritization for Sustainability of Agriculture Development

After assessment of actual soil loss severity over the entire watershed, it is essential to priorities the areas having high rate of soil erosion. In this context, Table 10.8 shows the priorities areas where high rate of soil erosion estimated were observed. These areas are spatially concentrated in northern part of watershed having agriculture practices in degraded situation and instable slope that are to be given high attention for upstream watershed conservation and also for sustainability of agriculture development in downstream. Based on severity of soil loss, cultivation areas are also to be given priority with optimum agriculture management practices for reducing soil loss. Soil conservation measures are to be adopted on more degraded areas for sustainable watershed management required for sustainable land use planning. The areas of undulating erosional alluvial fan upper piedmont (3c) having

Table 10.8 Prioritization of areas for sustainable land use planning

Soil loss (tons/ha/year)	Class	Prioritization
<100	Very low	Low
100–500	Low	Low
500–1500	Moderate	Moderate
1500–3500	High	High
>3500	V High	V High

soil loss more than 3500 tons/ha/year has to be given highest priority for soil conservation management practices.

10.4 Conclusions

A total of 253.1 million and 27.9 million tons soil were estimated using RKLS and RUSLE annually being lost from the watershed, respectively. Similarly, significant difference was found in the mean annual soil loss estimated by potential (9749 tons/ha) and actual equation (1227 tons/ha) for the study area. In both estimations, soil loss was found highly correlated with the increasing slope of land units. It was evident by the fact that land units such as 3c and 8 having less and more than 20° slope, respectively, were found to be 11 and 64% of potentially and 16 and 21% of actual soil loss indicating natural condition in the watershed. On an average soil loss by physiographic land unit, land unit 8 was found highest, 37,785 tons/ha in potential estimation, whereas land unit 2a, depressional recent alluvial plain lower piedmont (5792 tons/ha) was investigated as highest in actual soil loss estimation. Among the maximum soil loss, land unit 8 was found highest of 1,826,500 and 40,961 tons/ha/year in both potential and actual estimation, respectively, which was characterized as lithic ustorthents as dominant soil type with loamy skeletal as dominant soil texture. Soil erosion rates were found highly correlated with the increasing exposure of land surface. It was supported by the fact that cultivation areas sharing 74.31% of total land use land cover was contributing highest average soil loss in the watershed in natural condition. It was due to adopting unscientific measures of agriculture practices. Undulating erosional alluvial fan upper piedmont (3c) and steeply to very steeply sloping hilly and mountainous terrain (8) having soil loss more than 3500 tons/ha/year have to be given higher priorities for watershed management and conservation planning. Lower percentage of actual to the potential soil loss indicated the fact of contribution of crop management and erosional control practice factor in reducing soil erosion in existing situation.

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Chapter 11
^{137}Cs Tracing Dynamics of Soil Erosion, Organic Carbon, and Total Nitrogen in Terraced Fields and Forestland in the Middle Mountains of Nepal

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Abstract The Middle Mountains is one of the regions of Nepal most vulnerable to water erosion, where fragile geology, steep topography, anomalous climatic conditions, and intensive human activity have resulted in serious soil erosion and enhanced land degradation. Based on the ^{137}Cs tracing method, spatial variations in soil erosion, organic carbon, and total nitrogen (TN) in terraced fields lacking field banks and forestland were determined. Soil samples were collected at approximately 5- and 20-m intervals along terraced field series and forestland transects, respectively. Mean ^{137}Cs inventories of the four soil cores from the reference site were estimated at 574.33 ± 126.22 Bq m^{-2} [1 Bq (i.e., one Becquerel) is equal to 1 disintegration per second (1 dps)]. For each terrace, the ^{137}Cs inventory generally increased from upper to lower slope positions, accompanied by a decrease in the soil erosion rate. Along the entire terraced toposequence, ^{137}Cs data showed that abrupt changes in soil erosion rates could occur between the lower part of the upper terrace and the upper part of the immediate terrace within a small distance. This result indicated that tillage erosion is also a dominant erosion type in the sloping farmland of this area. At the same time, we observed a fluctuant decrease in soil erosion rates for the whole terraced toposequence as well as a net deposition at the toe terrace. Although steep terraces (lacking banks and hedgerows) to some extent

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could act to limit soil sediment accumulation in catchments, soil erosion in the terraced field was determined to be serious. For forestland, with the exception of serious soil erosion that had taken place at the top of slopes due to concentrated flows from a country road situated above the forestland site, spatial variation in soil erosion was similar to the "standard" water erosion model. Soil organic carbon (SOC) and TN inventories showed similar spatial patterns to the ^{137}Cs inventory for both toposequences investigated. However, due to the different dominant erosion processes between the two, we found similar patterns between the <0.002 mm soil particle size fraction (clay sized) and ^{137}Cs inventories in terraced fields, while different patterns could be found between ^{137}Cs inventories and the <0.002 mm soil particle size fraction in the forestland site. Such results confirm that ^{137}Cs can successfully trace soil erosion, SOC, and soil nitrogen dynamics in steep terraced fields and forestland in the Middle Mountains of Nepal.

Keywords Nepal · ^{137}Cs inventory · Soil erosion/deposition · Soil organic carbon · Total nitrogen

11.1 Introduction

Accelerated erosion exacerbated by anthropogenic perturbations depletes soil fertility, degrades soil structure, reduces the effective rooting depth, and in effect destroys the most basic of all natural resources (Lal 2003; Zhang et al. 2006). Accelerated erosion processes that result in soil losses and crop yield reductions in sloping farmlands are the most widespread form of soil degradation (Quine and Zhang 2002; Su et al. 2010). Accordingly, there is growing recognition that more attention should be paid to the adverse impacts of accelerated soil erosion on soil degradation, food security, and water quality/sedimentation in sloping farmland of fragile and sensitive ecosystems (Lal 2001; Li et al. 2004; Oyedele and Aina 2006; Rachman et al. 2003; Zhang et al. 2012).

Nepal is home to one of the most unique regional ecological areas in the world and is the regional "hot spot" of accelerated erosion due to the Himalayan–Tibetan ecosystem (Lal 2003; Nie et al. 2010). Numerous studies have indicated Nepal extremely prone to soil erosion and susceptible to sediment catastrophes due to the fragile geology, steeply sloping rugged mountain topography, anomalous climatic conditions, and intensive anthropogenic activities (Byers 1986; Gabet et al. 2008; Heimsath and MeGlynn 2008; Joshi et al. 1998). Nepal is subdivided into the following five major tectonic zones: the Tibetan–Tethys Zone, the Higher Himalayan Zone, the Lower Himalayan Zone, the Sub-Himalayan Zone, and the Terai Zone, which roughly corresponds to its physiographic zones (i.e., the High Himal Zone, the High Mountain Zone, the Middle Mountains Zone, the Siwaliks Zone, and the Terai Zone) from north to south (LRMP 1986). The geology of Nepal is governed by a complex sequence of historical events that have resulted in the extensive elevation of the Himalaya. Owing to these events, the mountains and hills are young, unconsolidated, and fragile due to tectonic activity in the course of orogenic belt movement (Joshi et al. 1998). Nepal is a classic example of a mountainous nation. Approximately 86% of the area is characterized by steep hills and mountains (Bhandari 2014). Great topographical variety causes diverse climatic conditions in Nepal. Annual precipitation is approximately 1530 mm, with variations from 300 mm in the north to 5000 mm in the central Nepal. Agriculture is the primary source of livelihood for the local population, while population pressure is overloading the production system (Gardner and Gerrard 2003). At the same time, overgrazing, deforestation, fire, and road construction are also major anthropogenic activities that have accelerated erosion and resulted in environmental degradation. It is estimated that as much as 1.63 mm of topsoil is displaced from the total land surface of Nepal each year due to accelerated surface soil erosion induced by anthropogenic activity (Bhandari 2014). Until now, little attention has been paid to the role of soil erosion in the development of within-field spatial variation of surface soil properties and soil degradation. There is therefore an urgent need to study the soil erosion status and the decline of soil quality caused by soil erosion from farmland activity.

Although remote sensing has been widely used to investigate soil erosion in the hilly areas of Nepal (Ghimire et al. 2006; Watanabe 1994), accurately quantifying soil erosion rates on sloping farmland and dense forests is difficult using this approach. Moreover, some previous studies attempted to evaluate the applicability of erosion models (RUSLE model) to assess soil erosion rates in mountainous terrain (Kouli et al. 2009; Vaezi and Sadeghi 2011), but certain model parameters proved difficult to determine due to a lack of long-term field observations (Nie et al. 2010). Under such limitations, the cesium-137 (^{137}Cs) technique could offer an effective means to estimate values related to soil erosion, and it could provide retrospective information on medium-term patterns of soil redistribution for landscapes in which field observational data are largely unavailable (Walling 2005; Wei et al. 2008; Zhang et al. 2012). It is important to note that many countries have utilized the ^{137}Cs technique over the last several decades (Walling et al. 2008; Zhang et al. 2003).

The objectives of this study were to investigate erosion-induced soil redistribution patterns on terraced fields and forestland as well as spatial variation in soil nutrients in relation to soil erosion using the ^{137}Cs technique in the Middle Mountains of Nepal.

11.2 Materials and Methods

11.2.1 Study Area

The study area (27°38′42″ N, 85°34′48″ E) is located in the Kavrepalanchok District, Bagmati Province, Nepal (Fig. 11.1). The Jhikhu Khola watershed, a tributary of Sun Koshi River, is also located within this district. This watershed is also one of the most intensively used watersheds in the Middle Mountains of Nepal. The study area is under the influence of a humid subtropical climate with a mean annual precipitation of 2558 mm and a mean annual temperature of 19 °C. Approximately 80% of total annual precipitation falls during the monsoon season (July through September). The dominant soil type is yellow brown soil with bulk densities of 1.1 to 1.4 g cm^{-3} (Fig. 11.1b), respectively, classified as Eutric Cambisol in the FAO soil taxonomic system (FAO 1988). The area is characterized by mountain ridges, having very sharp crests composed of Precambrian augen and banded gneiss of various grades of metamorphism and mixtures of mica schist, phyllite, and gneiss, mainly oriented east–west (Shrestha 1997). Because of the steepness of sloping farmland in the region, farmers typically till their farmland by the hoeing method, digging soils in a down slope direction to save time and energy. Jhikhu Khola is the main drainage system, fed by numerous tributaries entering the watershed from both sides. The valley is narrow and elongated but widens downstream where rice cultivation prevails. At higher elevations, land cover is mainly forested area that consists of chir pine (*Pinus roxburghii*) and broadleaf tree species (*Schima wallichii,* local name Chilaune). Rain-fed maize and millet are grown in cultivated areas. Secondary forest such as *Shorea robusta* predominates at lower altitudes. Crops include irrigated rice and rain-fed maize and millet.

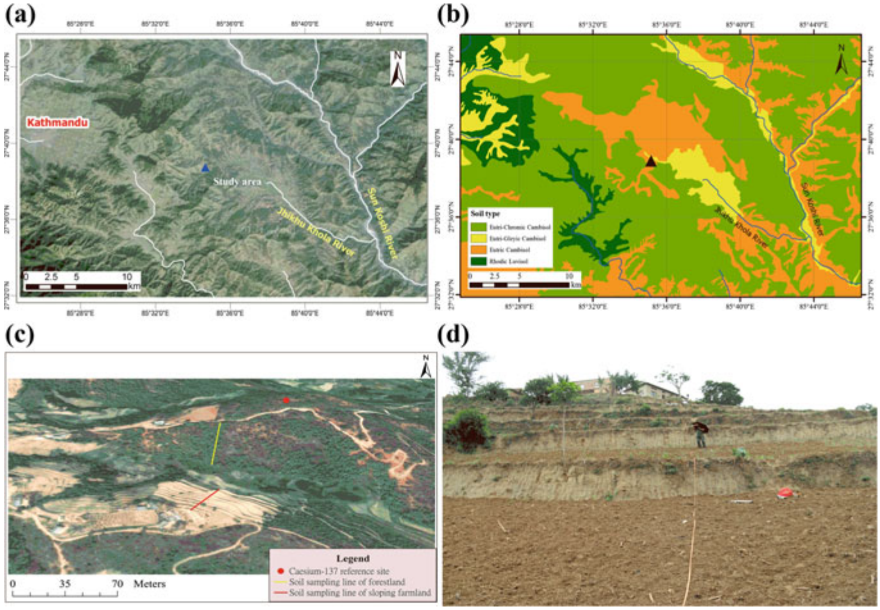


Fig. 11.1 **a** Location map of the study area; **b** soil map of study area; **c** sampling site of the study area; **d** *photo* of terraced fields

11.2.2 Experimental Procedure, Sample Determination, and Data Calculation

Two toposequences, located approximately 100 m apart, were selected to conduct soil sampling (Fig. 11.1c). The first toposequence represents eight terraces with a total horizontal length of 65 m and a mean slope gradient of 35% (Fig. 11.1d and Table 11.1). The second toposequence represents a forested area with a horizontal length of 100 m and a mean slope gradient of 49%. The coordinates of each sampling point as well as their elevations were measured using a DGPS (differential GPS) with a horizontal accuracy of 2 cm. Soil samples for ^{137}Cs and physical and chemical characteristics were collected using a 5.0-cm-diameter hand-operated core sampler. Soil samples were collected approximately at 5- and 20-m intervals along terrace series and forestland transects, respectively. At each sampling point, two cores were collected to a depth down to the bedrock, which were then bulked to make a composite sample. If a subsurface horizon was distinguishable below the plow layer (Ap) in farmland or topsoil (A) of the forestland site, the two horizons were sampled separately. There were 17 and 6 soil sampling points along the forestland and terrace series transects, respectively. At the same time, four soil samples were collected from the reference site adjacent to the study area (200 m from the forestland site) situated on a flat grassland terrain. Each reference core soil sampling depth was at least 35 cm, sectioned at a depth increment of 5 cm. This particular field had not undergone anthropogenic disturbances over the last 60 years. Consequently, soil erosion in this flat grassland was negligible.

Soil samples were then packed into a plastic beaker with 320 cm^3 volume (Zhang et al. 2008). ^{137}Cs activity was subsequently measured using a hyperpure lithium-drifted germanium detector (ORTEC, Oak Ridge, Tennessee, USA) coupled with a Nuclear Data 6700 multichannel gamma-ray spectrophotometer with counting time from 40,000 to 60,000 s. Relative errors of test results were lower than 5%. ^{137}Cs inventories were originally expressed on a unit mass basis (Bq kg^{-1}) and were then converted to an area basis (Bq m^{-2}) using total weight of the bulked core samples and the cross-sectional area of the sampling device.

Physical and chemical characteristics of soil samples were determined using standard methods (Liu 1996). Soil particle size fractions were determined by the pipette method following H_2O_2 treatments to destroy organic matter and subsequent dispersion of soil suspensions by Na-hexametaphosphate. Soil bulk densities were determined using oven-dried weight and sample volumes of standard soil cores used. Soil organic carbon (SOC) was determined using wet oxidation with $K_2Cr_2O_7$, and total nitrogen (TN) analysis followed the micro-Kjeldahl method. The SOC, TN, and soil particle size fractions in the soil profile are given in Table 11.1.

The efficient ^{137}Cs reference inventory is used to eliminate ^{137}Cs surface enrichment impacts derived during periods of nuclear detonation on the assessment of soil losses on cultivated sloping land (Zhang et al. 2003). The efficient ^{137}Cs reference inventory (Ae) is expressed as:

Table 11.1 Sampling site and soil physical and chemical properties in the study area

Sampling site			Farmland	Forestland	Reference site
Main vegetation			Corn	Chir pine	Grass
Average slope (%)			35	49	0
Soil type			Yellow brown soil	Yellow brown soil	Yellow brown soil
^{137}Cs inventory (Bq/m^2)			452.86	549.65	574.33
Soil erosion rate (t/(ha.yr))			70.17	29.63	
Soil physical and chemical properties	A layer	Bulk density (g/cm^3)	1.12	1.25	
		SOC (g/kg)[a]	5.94	4.54	
		TN (g/kg)[b]	1.05	0.86	
		Sand (%)	69.08	69.54	
		Silt (%)	14.09	14.69	
		Clay (%)	16.83	15.77	
	B layer	Bulk density (g/cm^3)	1.32	1.49	
		SOC (g/kg)	7.43	3.81	
		TN (g/kg)	0.84	0.69	
		Sand (%)	54.33	49.92	
		Silt (%)	16.98	16.05	
		Clay (%)	28.69	34.03	

[a] *SOC* soil organic carbon; [b] *TN* total nitrogen

$$Ae = Ao(1 - RI) \tag{11.1}$$

where Ao is the ^{137}Cs reference inventory (Bq m^{-2}) and RI is the runoff index. The efficient ^{137}Cs reference inventory was calculated using a runoff index of 0.27 (Gardner and Gerrard 2003). For an eroding farmland site where total ^{137}Cs inventory A (Bq m^{-2}) is less than the reference inventory Ae (Bq m^{-2}) at year t (years), soil erosion rates can be expressed as follows (Zhang et al. 1998):

$$\gamma = \frac{10\mathrm{d}B}{P}\left[1 - \left(1 - \frac{X}{100}\right)^{1/(t-1963)}\right] \tag{11.2}$$

where γ is the mean annual soil erosion rate (t ha^{-1} yr^{-1}), d the sampling depth (m), B the bulk density of soil (kg m^{-3}), X the percentage reduction in total ^{137}Cs inventory (defined as $(Ae - A)/Ae \times 100$), and P the particle size correction factor.

For the forestland site, soil erosion rates can be expressed as follows (Wen et al. 2000):

$$A = A_0 e^{-\lambda h} \tag{11.3}$$

where λ is the coefficient for ^{137}Cs depth distribution shape (cm^{-1}) and h is depth of soil erosion since 1963.

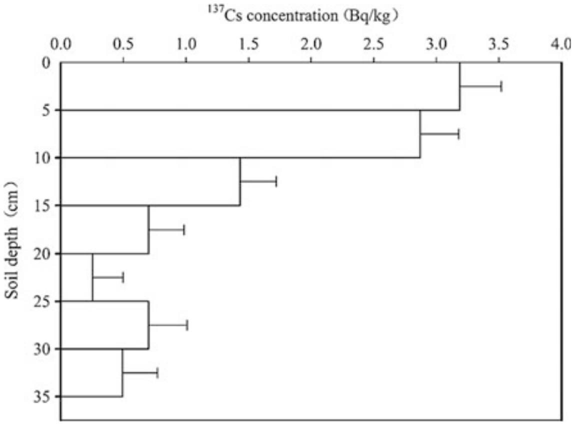
All statistical analyses were conducted using SPSS software (version 11.5). Linear regression analysis was conducted to test correlations between SOC, TN, soil particle size fractions, and the ^{137}Cs inventory.

11.3 Results

11.3.1 ^{137}Cs Reference Inventory

The ^{137}Cs profile of the sectioned core from the undisturbed forested area is provided in Fig. 11.2. ^{137}Cs inventories for the sectioned soil core collected from the Jhikhu Khola watershed reference site was 574.33 ± 126.22 Bq m^{-2} (Table 11.1). Figure 11.2 shows that the ^{137}Cs concentration in the soil profile was mainly distributed to an approximate 15 cm depth. At the same time, an exponential declining trend was observed in the soil profile as soil depth increased, indicating a downward decrement in ^{137}Cs in the soil profile. As a result, the coefficient for ^{137}Cs depth distribution shape is estimated at 0.089 cm^{-1}. A previous study by Wen et al. (2000) reported that the ^{137}Cs reference inventory was 991 Bq m^{-2} in the middle reaches of the Yarlung Zangbo River, Tibet. This value was estimated at 718.56 Bq m^{-2} when it corrected for decay (up to the year 2014) and it was close to the value obtained for the present study area.

Fig. 11.2 Depth distributions of ^{137}Cs reference inventories at the study site



11.3.2 Spatial Variation of ^{137}Cs Inventory and Soil Erosion

Spatial variation of ^{137}Cs inventories and soil erosion rates along the two transects is provided in Figs. 11.3 and 11.4. For terraced fields, a discrete pattern in ^{137}Cs inventories and soil erosion rates was observed in the whole toposequence. Abrupt changes in ^{137}Cs inventories and soil erosion rates were observed between the lower part of the upper terrace and the upper part of the immediate terrace within a limited parameter (Fig. 11.3a). The ^{137}Cs inventory for the lowest sampling point of the 1st terrace (i.e., the top slope of terraced fields) was greater by a factor of 1.81 compared to the adjacent sampling point of the 2nd terrace. Similarly, the ^{137}Cs inventory yielded a result greater than 2.16 in the lowest sampling point of the 6th terrace compared to the highest sampling point of the 7th terrace. However, a gradual increase in ^{137}Cs inventories and a gradual decrease in soil erosion rates were also observed in terraces. Moreover, a fluctuant increase in mean ^{137}Cs inventories was found in the whole toposequence. A fluctuant decrease in soil erosion rates was observed in the whole terraced toposequence, and a net deposition occurred in the 7th and 8th terrace. For the whole toposequence, the soil erosion rate was estimated at 70.17 t ha^{-1} yr^{-1}.

For the forestland site, no trends in gradual changes in ^{137}Cs inventories and soil erosion rates could be determined along the slope transect (Figs. 11.3b and 11.4b). Lower ^{137}Cs inventories were observed at the top of the slope (0–20 m) and at the foot of the slope (80 m) compared to other slope positions, and net soil erosion also occurred at these same slope positions. Conversely, higher ^{137}Cs inventories were

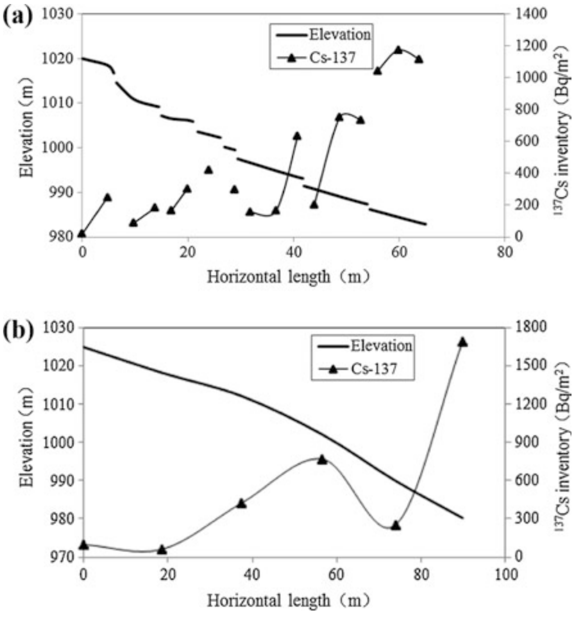
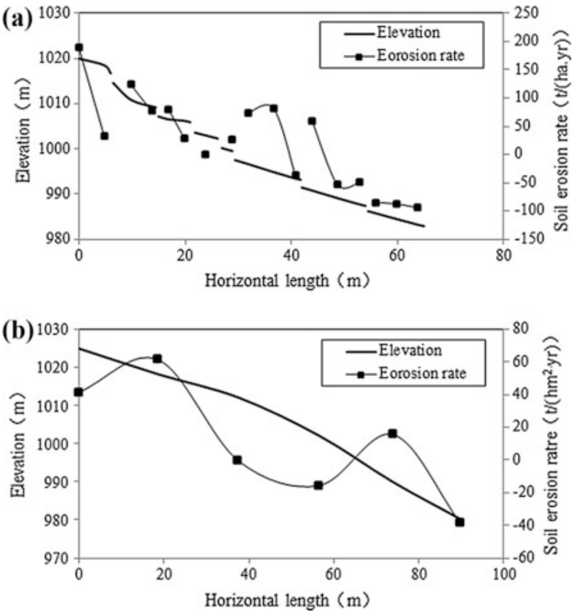


Fig. 11.3 Spatial distribution of ^{137}Cs inventories along transects of terrace series **a** and forestland **b**

Fig. 11.4 Spatial variation in soil erosion rates along transects of terrace series **a** and forestland **b**

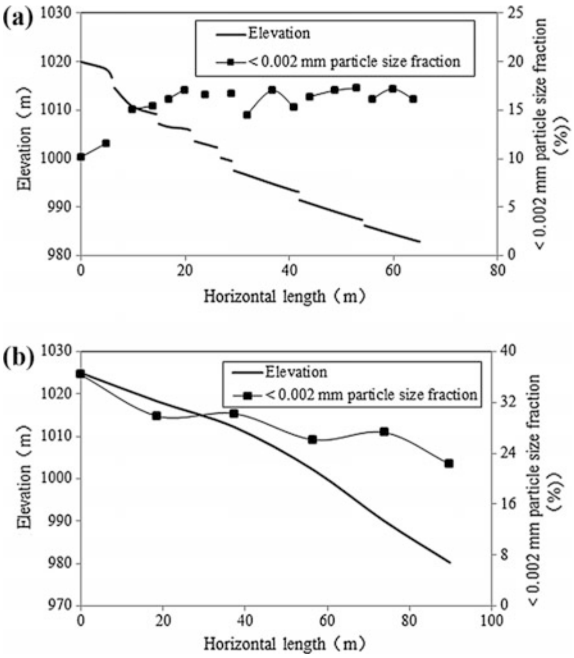


observed at the shoulder slope (40 m), back slope (60 m), and toe slope (100 m) compared to other slope positions, and net soil deposition occurred at these same slope positions. The soil erosion rate was estimated at 29.63 t ha^{-1} yr^{-1} for the forestland site.

11.3.3 Spatial Distribution of Soil Particles, SOC, and TN on Slopes

Spatial variation in soil fine particles (clay sized) along the two transects is shown in Fig. 11.5. Similar to ^{137}Cs inventories, discrete patterns in the soil particle size fraction (<0.002 mm) were observed for terraced fields in the whole toposequence. The <0.002 mm soil particle size fraction of the lowest sampling point in the 3rd terrace was obviously higher than the adjacent sampling point in the 4th terrace. A similar spatial distribution in the <0.002 mm soil particle size fraction between the 7th and 8th terrace was also found. However, a fluctuant increasing trend in the mean <0.002 mm soil particle size fraction was found for the whole toposequence. Additionally, for the 1st, 2nd, 3rd, and 7th terrace, a gradual increasing trend in the <0.002 mm soil particle size fraction was observed in each terrace possessing a short slope length. It should be noted that an abrupt decreasing trend was observed in the <0.002 mm soil particle size fraction at the toe slope position of the 6th and 8th terrace. Conversely, for the forestland toposequence, a fluctuant decreasing

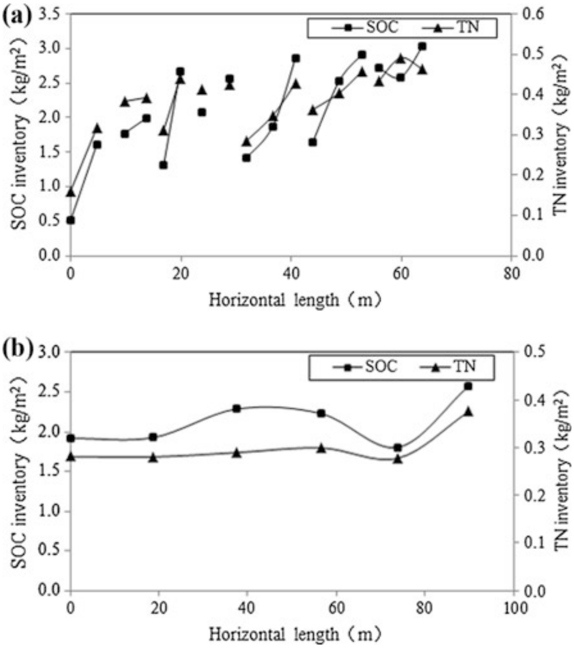
Fig. 11.5 Spatial distribution of the <0.002 mm particle size fraction along transects of terrace series **a** and forestland **b**



trend was observed in the <0.002 mm soil particle size fraction along the transect. The highest content of fine particles was observed at the top of the slope, while the lowest content of fine particles was observed at the toe slope position.

Figure 11.6 shows the spatial distribution of SOC and TN inventories along the two transects. For terraced fields, similar spatial distributions in SOC and TN inventories were found ($r = 0.94$, $P = 0.001$). Moreover, over the terraced toposequence, discrete patterns were obvious in SOC and TN inventories. For each terrace, SOC and TN inventories were low at upper slope positions, while SOC and TN inventories were high at lower slope positions. Spatial patterns showed abrupt changes in SOC and TN inventories between two adjacent sampling locations over short distances either side of terrace boundaries. It should be noted that mean SOC and TN inventories in the 8th terrace were obviously higher compared to almost all other sampling positions. Moreover, mean SOC and TN inventories in the 1st terrace were obviously lower compared to almost all other sampling positions among all terraced series. For the forestland site, a significant correlation was also found between SOC and TN inventories ($r = 0.86$, $P = 0.027$). SOC and TN inventories were low at the top and foot of the slope, while higher SOC and TN inventories were observed at the shoulder slope, back slope, and toe slope. Additionally, the highest SOC and TN inventories were observed at the toe slope.

Fig. 11.6 Spatial distribution of soil organic carbon (SOC) inventories and total nitrogen (TN) inventories along transects of terrace series **a** and forestland **b**



11.4 Discussion

Soil erosion rates of terraced series in the study area were estimated at 70.17 t ha^{-1} yr^{-1}, while for the forestland site, the soil erosion rate was estimated at 29.63 t ha^{-1} yr^{-1}. Such results are consistent with a previous study applying a soil erosion assessment model within the GIS environment in the Likhu Khola Valley, Middle Mountains of Nepal (Shrestha 1997). Results from that study indicated that soil erosion from steep terraced landscapes in the Middle Mountains of Nepal is higher than soil erosion rates from terraced landscapes in the upper reaches of the Yangtze River (37.90 t ha^{-1} yr^{-1}) and Yimeng Mountains (27.00 t ha^{-1} yr^{-1}), China (Zhang et al. 2006, 2014). However, soil erosion rates for forestland in this study were similar to those in the middle reaches of the Yarlung Zangbo River in Tibet (3.41–19.71 t ha^{-1} yr^{-1}). These results also indicated that soil erosion rates in terraced fields are higher than in forestland.

Soil erosion rates derived from ^{137}Cs data showed that there were significantly different soil erosion processes occurring between the two toposequences under different land use types. For terraced series, soil erosion rates generally decreased from upper to lower slope positions for each terrace, indicating that soil material was gradually eroded at the top of the slope and accumulated at the toe slope of each terrace as a result of tillage erosion processes. At the same time, farmers in the study area are accustomed to cultivating sloping farmlands from downslope to upslope positions, and this tillage method would also increase soil loss volume from tillage erosion. Previous studies have reported that soil redistribution rates due to tillage erosion may be more serious than those due to water erosion and sedimentation in short and steep sloping farmland (Govers et al. 1994; Zhang et al. 2004, 2006). This result is also similar to previous studies in purple soil sloping farmland of upper reaches of the Yangtze River, China (Su et al. 2010; Zhang et al. 2008, 2012). At the same time, a fluctuant decreasing trend in soil erosion rates was found throughout the whole toposequence of the terraced land series, suggesting that rainfall and overland flow gradually transported soil material from the upper to the lower terraces and played an important role throughout the whole toposequence. In the study area, local farmers do not construct rock ridges or plant hedgerows between terraces to prevent soil loss from upper to lower terraces. Moreover, overland flow due to intensive rainfall can be accelerated by gravity, moving downward from the upper terrace, and this would increase runoff shear stress and hydropower (Zhang et al. 2014). Downward overland flow transports soil material from the upper terrace and scours the top slope of the lower terrace. This would result in soil loss from the summit slope of each terrace. It should be noted that a net deposition occurred in the lower terrace, suggesting that water erosion could transport soil material from upper to lower terraces while not being able to transport soil material from the whole toposequence. These findings can be expounded upon, i.e., that water erosion is an important soil erosion process throughout the whole toposequence, while tillage erosion plays a dominant role within each terrace. For the forestland site, soil erosion was determined to be serious at the top and foot slope positions. This finding indicated that the distribution of ^{137}Cs inventories did not fit "standard" water erosion patterns due to the serious soil erosion at the top of the slope. The "standard" water erosion model showed that water erosion reached maximal at the lower slope position and was minimal at the top and toe slope positions (Govers et al. 1999). The serious soil erosion that occurred at the top of slope in the forestland site was ascribed to concentrated flow from the country road located above it.

A significant correlation was found between ^{137}Cs and SOC inventories along the two different toposequences (Figs. 11.7 and 11.8; $p \leq 0.01$). Similarly, ^{137}Cs inventories were significantly correlated with TN inventories at two positions ($p = 0.001$). These findings indicated that soil erosion plays an important role in the redistribution of soil nutrients. This result is consistent with previous studies by Zhang (2006, 2012). However, different spatial distributions in the <0.002 mm soil particle size fraction were observed between terraced fields and the forestland site. A discrete pattern in the < 0.002 mm soil particle size fraction was observed for terraced fields throughout the whole toposequence, while a fluctuant decreasing trend was observed in the <0.002 mm soil particle size fraction along the forestland transect. Additionally, the <0.002 mm soil particle size fraction showed similar patterns to ^{137}Cs inventories in terraced fields, while different patterns in the forestland site were found between ^{137}Cs inventories and the <0.002 mm soil particle size fraction. A notable difference in the forestland site was observed at the top of the slope. The highest <0.002 mm soil particle size fraction and the lowest ^{137}Cs inventory at the top of the slope may be the result of soil sediment

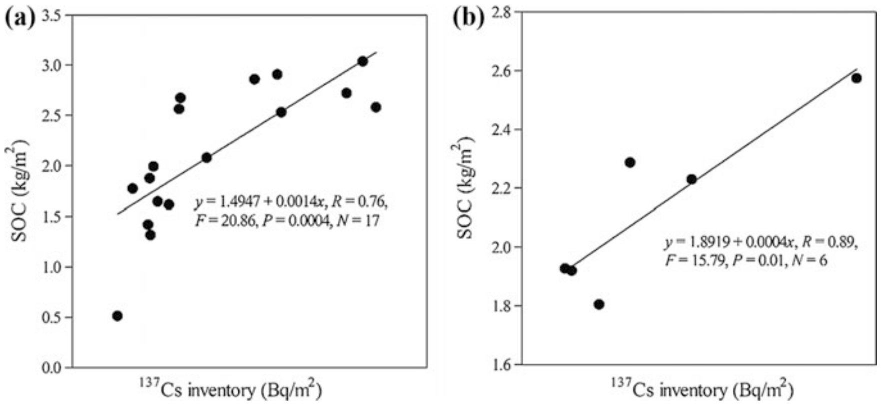


Fig. 11.7 Relationship between ^{137}Cs and SOC inventories along transects of terrace series **a** and forestland **b**

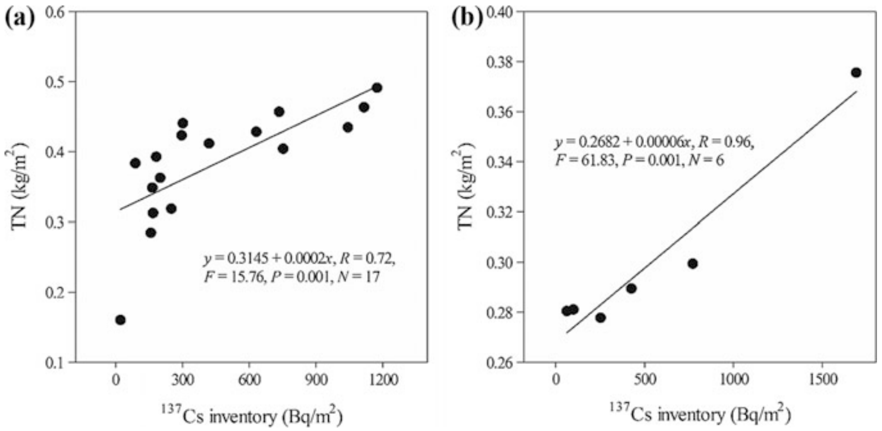


Fig. 11.8 Relationship between ^{137}Cs and TN inventories along transects of terrace series **a** and forestland **b**

accumulation from the country road located above this forestland site. A previous theory concluded that water erosion selectively transported soil material on a slope, while tillage erosion would unselectively transport soil material along a slope (Zhang et al. 2006). In other words, the spatial distribution of <0.002 mm soil particles on the top of the slope in the forestland site should derive from soil material from the country road with a low ^{137}Cs inventory. Similar findings in spatial patterns in the <0.002 mm soil particle size fraction and ^{137}Cs inventories in terraced fields could further validate this theory.

Although different soil erosion processes were determined between the two sites, intense anthropogenic activity could significantly change spatial variations in soil erosion rates. For the terraced field landscape, tillage erosion played an important role in soil loss at the top of each terrace and soil accumulation at the toe slope of each terrace. At the same time, serious soil erosion also occurred at the top of the forestland site due to concentrated flow from the country road.

In the study area, terraces that lack of rock ridges or plant hedgerows are widely used for soil conservation, but little attentions have been focused on the impact of such measures on rates and patterns of tillage erosion. To prevent serious tillage erosion within the sloping farmland of the study area, a series of conservation tillage measures, such as contour tillage, ridge tillage, no tillage, should be conducted in this area. Meanwhile, contour hedgerows have proven to be an effective means for addressing soil erosion and ameliorating soil fertility in the sloping farmland in many countries (Hien et al. 2013; Kovar et al. 2011; Oshunsanya 2013), and this traditional soil conservation measure should be widely applied in the Nepal. However, direct transplantation of foreign experiences to the sloping farmland of Nepal may not generate desired results because it should attune new techniques to fit local geographical and socio-economical conditions. As a result, more attention should be paid to study the soil erosion process and soil conservation measures in the further studies using new and advanced techniques, and then the best integrated control system for soil erosion prevention can be proposed in the Nepal.

11.5 Conclusions

^{137}Cs data showed that both tillage erosion and water erosion are major erosion processes on terraced fields lacking field banks, resulting in serious soil erosion on the upper section of each terrace and soil accumulation at the lower section of each terrace. At the same time, for the entire terraced toposequence, soil erosion was observed to be more severe in higher than in lower terrace positions, and net soil accumulation occurred at the toe terrace. For the forestland site, with the exception of soil erosion at the top of slope, spatial variation in soil erosion was similar to the “standard” water erosion model. The concentrated flow derived from the country road obviously altered soil erosion rates at the top of the forestland slope. It should be noted that significantly higher soil erosion rates were found in terraced fields than the forestland site, indicating that terraces that lack field banks are not effective enough in limiting water erosion and would result in increased tillage erosion rates due to their short slope lengths. In other words, steep terraces without banks or hedgerows would to some extent act to limit soil sediment accumulation in catchments, while soil erosion in each individual terrace would become more serious due to severe tillage erosion rates in short and steep slope terrain. Spatial distributions of SOC and TN inventories followed similar patterns to ^{137}Cs inventories, indicating that SOC and TN inventories increase with decreasing soil erosion rates for both landform types. The <0.002 mm soil particle size fraction exhibited similar patterns to ^{137}Cs inventories in terraced fields, while different patterns could be found between ^{137}Cs inventories and the < 0.002 mm soil particle size fraction in the forestland site. This is ascribed to different dominant erosion processes (i.e., tillage erosion and water erosion occurred in the sloping farmland, while water erosion occurred in the forest land) that take place between the two sites. In conclusion, ^{137}Cs can successfully trace dynamics of soil erosion, SOC, and TN in the Middle Mountains of Nepal and this method can also be used in the other similar area of world.

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Part III
Livelihood and Adaptation

Chapter 12
Responses in Nepal: An Overview Spatial Features of Poverty and Economic-Impoverished Types in Nepal

Jifei Zhang, Chunyan Liu, Wei Deng, Hriday Lal Koirala, Narendra Raj Khanal and Yi Su

Abstract Poverty reduction has been a significant and imperative task in developing countries. Investigating poverty–environment relationship from the perspective of geography provides an ideal way to in-depth understanding of the spatial distribution of poverty and its driving mechanisms. Based on latest district-level data and statistical analysis, this study reveals spatial features of poverty and recognizes the economic-impoverished types of Nepal. Main findings were as below: (1) The poverty incidence (PI) was gradually rising from the Eastern to the Far-Western with geographical differences. The Mid-Western and Far-Western presented higher PI and poverty depth than those of other three regions but with less absolute and relative differences on poverty distribution. By Lorenz curves of poverty distribution, the Central, Western, and Mid-Western Regions were more centralized on poverty population as compared to the whole nation, with the Far-Western Region more evenly distributed on poverty population. (2) A larger proportion of relative high and high poverty but a smaller proportion of low and relative low poverty districts were found in the Mid-Western and the Far-Western Regions. Mountain region was the only region where high poverty districts were observed while hill region held the lowest poverty districts. Tarai region was featured with most moderate and relative poverty districts. (3) All of the 75 districts were divided into three economic-impoverished types: Revealed Poverty Region,

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Hidden Poverty Region, and Specific Low-poverty Region. The stable revenue generated through tourism by the local government is considered a good and sustainable macroeconomic indicator in the Hidden Poverty Region, while local people have fewer opportunities to get involved in tourism development. As for the Specific Low-poverty Region, political struggles, and poor administrative management are identified as the main reasons for both low economic development and high poverty, forcing large number of people to look for better job prospects overseas.

Keywords Poverty · Spatial features · Differentiation · Mountain region · Nepal

12.1 Introduction

Poverty has been a major issue worldwide, especially in developing countries, and has a direct effect on socioeconomic progress (Dhruba Bijaya et al. 2015; Liang and Fang 2011). The scientific cognition on poverty is a deepening process. Previous researchers focused on monetary poverty, quoting it as a status of low-income, insufficient consumption, and lack of food (Noble et al. 2006; Squire et al. 1990). With social evolution, capability poverty and entitlement poverty theory, first put forward by Sen, broadened the view of poverty by defining it as the deprivation of basic amenities and human rights (Amartya 1983, 1976). Pacione (2003a, b) believed that poverty is caused by multiple factors and argued that multiple deprivation (comprehensive poverty) refers to the integrated unfavorable status to individuals, families or whole community, lack of food, clothes and good housing conditions, as well as inaccessibility to education, employment, and social services (Pacione 2003a, b). Comprehensive poverty was analyzed from the perspective of economics and sociology. Since 1990s, the geographic disparities in poverty and development outcomes have drawn increasing attention in the academic world (Hoff and Sen 2010). Spatial poverty has caught the attention of diverse scientific communities and has become a crucial foundation for regional development and poverty alleviation strategies adopted across the world, along with the geographic-related poverty studies (Elwood et al. 2016). Combined with the environmental concerns, spatial poverty mainly focuses on the poverty differences from geographical perspective (Jordan and Roderick 2004). Currently, however, connotation (Alkire and Foster 2011) methods (Payne and Abel 2012; Epprecht et al. 2011) and scale issues (Callander et al. 2012; Madulu 2005; Oliverira and Antunes 2011) are still dominating the poverty study, with spatial poverty less noticed. Studies have shown that poverty presents obvious spatial diversities in regional development and urban rural structure (Ravallion and Jalan 1997; Wang et al. 2012; Broadway and Jesty 1998. Probing poverty–environment relationship from the perspective of geography, such as location and terrain features, provides an ideal way to in-depth understanding of the spatial distribution of poverty and its driving mechanism (Liang and Fang 2011; Wan 2007; Gray and Moseley 2005; Yuan et al. 2016).

Nepal is a mountainous and agricultural country in South Asia, known for its complex and diverse topography, fragile ecosystem, limited natural resources, and ever increasing man–land relationship. Poverty in Nepal is a long-standing issue and requires urgent attention. Since 1976, Nepal has put poverty reduction high on agenda for national development (Nepal 2007). At present, the research in Nepal mainly focuses on the relationship between poverty and income (Joshi and Maharjan 2008), the effects of international and domestic migration and remittances on poverty (Lokshin et al. 2010), the PI and poverty depth (Dhruba Bijaya et al. 2015), the relationship between poverty and political conflicts, violence and wars (Griffin 2015; Do and Iyer 2007, 2010). However, limited research has been carried out in terms of the spatial difference for poverty in Nepal. In the context of complex topography, its features and regional differences of poverty are worthy of further investigation. This study analyzes geography and topography in Nepal from the perspective of spatial poverty theory. A more clear understanding was obtained when poverty population distribution and poverty features differed across its regions by incidence and location quotient of poverty. Based on findings of the study, the aim is to provide reasonable policy recommendations for assisting poverty reduction in Nepal.

12.2 Materials and Methods

12.2.1 Study Area

Nepal is a landlocked country in South Asia occupying an area of 147,181 km^2 (26° 22′N–30° 27′N, 80° 4′E–88° 12′E) (Fig. 12.1), with elevations range from 70 m to above 8000 m. The total population of Nepal has reached around 26.5 million with the annual population growth rate of 1.35% in 2011. Topographically, it is divided into three distinct ecological zones: mountain, hill, and Tarai (flat plains), respectively, inhabited by 6.73, 43.00 and 50.27% of the total population. Administratively, it is divided into five Development Regions: the Eastern Region, the Central Region, the Western Region, the Mid-Western Region, and the Far-Western Region. The country is divided into 14 zones and 75 administrative districts, and the districts are further subdivided into smaller administrative units called Village Development Committee (VDC) and municipalities. The former refers to rural areas and the latter to urban areas. Considering research scale and data accessibility, district was taken as a basic unit for this study.

Nepal shows a compelling case for spatial poverty study due to two reasons. Firstly, it is one of the most under developed country in the world, ranking 145th on the Human Development Index (HDI) in 2014. It struggles and suffers

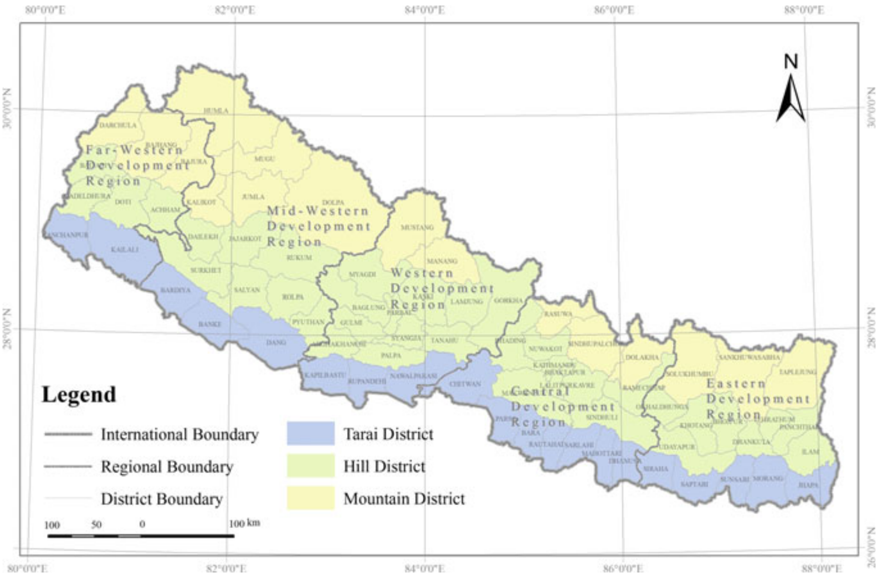


Fig. 12.1 Map of the study area

from high levels of hunger and poverty. Secondly, it is diversified by terrain comprised of distinct belts of ecological zones from the Tarai (accounting for 17% of the total land area) in the southern, rising to higher hills (accounting for 68% of the total land area), and culminating in the high Mountains (accounting for 15% of the total land area) in the north. Every region demonstrates diverse biophysical and socioeconomic features which greatly differ from each other. Along with these features emerges a unique man–land relationship between rural areas and its resources.

12.2.2 Data

Study data includes population, area, the PI, GDP per capita (comparable price), and regional boundary data (.shapefile format). District-level data of Nepal, obtained in 2011, has been used to conduct the analysis. Data regarding population, area, the PI, and GDP per capita for each district were obtained primarily from District and VDC Profile of Nepal (2014/15), 2011 Statistical Year Book and Nepal Human Development Report 2014.

12.2.3 *Methodology*

In order to analyze spatial differences of poverty in Nepal, the paper first applies Location Quotient (LQ) and Lorenz Curve to analyze horizontal comparisons of the position and concentration of poverty among five regions in 2011. Especially, the discrepancies of poverty for different terrains in five Development Regions were compared. In order to further understand the relationship of poverty and economic development, the correlation between GDP per capita and PI was done. According to 3σ criterion of Gaussian distribution (normal distribution), three types of 'economic-impoverished' regions were identified.

12.3 Results and Discussion

12.3.1 *Results*

12.3.1.1 An Overview of Poverty in Nepal

The total poverty population of Nepal was 6.2144 million with PI 27.59% in 2011 (Table 12.1), with poverty gap and poverty gap squared 5.43 and 1.81% in 2010, as well as the range and standard deviation of poverty LQ 2.57 and 0.57, respectively.

From Tables 12.1 and 12.2, it is easy to establish that the Mid-Western and Far-Western Regions are showing higher PI as well as poverty depth than those of the other three regions. However, the range and standard deviation of poverty LQ in the Western and the Central Regions are higher than those of the other three regions and the entire country, indicating that the two regions hold more absolute and relative differences on poverty distribution. Furthermore, the range and standard deviation of poverty LQ in five Development Regions were smaller than those of Nepal, implying that the differences of poverty population are changing to spatial scales adopted.

As shown by Lorenz curves of poverty distribution of the entire country (Fig. 12.2), around 74% poverty population were centered on the 50% territory of the country in 2011. As for the Development Regions described by Fig. 12.3, around 71, 75, 77, 80, and 55% poverty population were centered on 50% territory of the Eastern, the Central, the Western, the Mid-Western, and the Far-Western, respectively. Hence, the Central, Western, and Mid-Western Regions presented

Table 12.1 Poverty of Nepal in 2011

Total poverty population	PI	Poverty gap (2010)	Poverty gap squared (2010)	Poverty LQ	
				Range (u)	Standard deviation (w)
6.2144 million	27.59%	5.43%	1.81%	2.57	0.57

Table 12.2 Poverty in Development Regions of Nepal in 2011

Index	The Eastern	The Central	The Western	The Mid-Western	The Far-Western
PI (in 2010) (%)	21.44	21.69	22.25	31.68	45.61
Poverty gap (in 2010) (%)	3.81	4.96	4.27	7.74	10.74
Poverty gap squared (in 2010) (%)	1.01	1.76	1.38	2.69	3.77
Range (u) of poverty LQ	1.36	1.58	1.85	1.05	0.78
Standard deviation (w) of poverty LQ	0.4	0.46	0.49	0.35	0.23

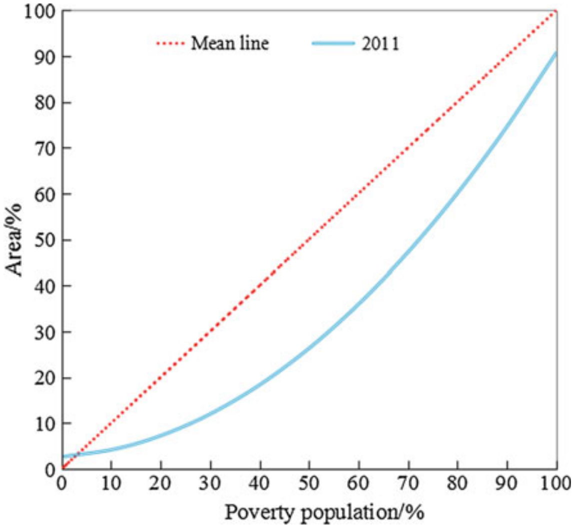


Fig. 12.2 Lorenz curves of poverty distribution of Nepal in 2011

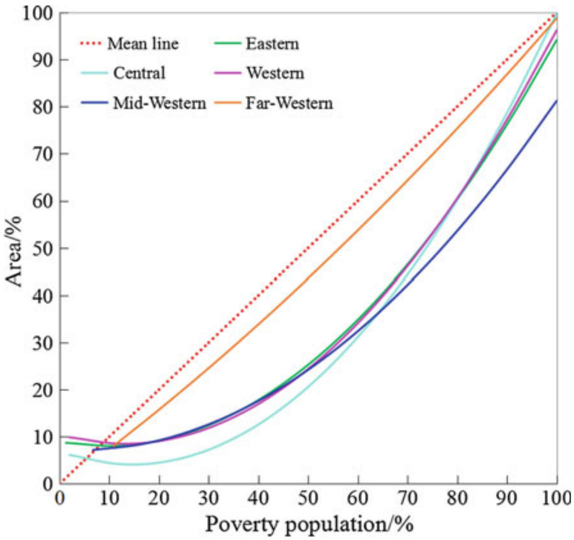
more centralized position on poverty population compared to the entire country, with the Far-Western Region showing even distribution.

12.3.1.2 Spatial Distribution of Regional Poverty

A. Gradual rising of PI from the Eastern to the Far-Western

According to the PI of district-level of Nepal in 2011, 75 districts were divided into five ranks: the low poverty (4–16%), the relative low poverty (6–28%), the moderate poverty (28–40%), the relative high poverty (40–52%), and the high poverty (more than 52%). The PI was gradually rising from Eastern to the Far-Western along with geographical differences (Table 12.3 and Fig. 12.4).

Fig. 12.3 Lorenz curves of poverty distribution of Development Regions in 2011



(1) In the Eastern Region, the whole PI was lower. The low and the relative low district accounted for 68.6% of the two-rank district. Only two districts were moderate, without another two ranks.

(2) In the Central, the low and relative low poverty region accounted for 65.4% of the two-rank district. The other five districts were moderate.

(3) When compared with the Eastern and the Central, there is a proportion of 51.7% of the low and relative low poverty region in West. Five districts were in moderate poverty region, without the relative high and high poverty districts.

(4) In the Mid-Western, the overall PI was rather higher. From Table 12.3, 82.9% of the relative high and high poverty districts were found here. The other 10 districts were ranked into the relative low and the moderate poverty.

(5) The Far-Western demonstrated the highest PI as a whole, where there is low and the relative low poverty districts. All districts were ranked moderate, the relative high and the high poverty, accounting for 10, 57.1, and 60% of those three ranks, respectively.

B. District poverty features changing with Development Regions and geographical conditions

Kruskal Wallis test (KW test) with K sample was done to identify poverty discrepancies among the three districts i.e., Development Regions, terrains, and Development Region-terrains (Table 12.4). Test results showed that P value was less than the significance level of 0.05.

From the perspective of Development Regions (Fig. 12.5), a larger proportion of relative high and high poverty but smaller proportion of low and relative low poverty districts were found in the Mid-Western and Far-Western Regions rather

Table 12.3 Regional poverty ranks in 2011

Poverty rank (PI interval)	Number of districts	Number/proportion of districts in the Eastern (%)	Number/proportion of districts in the Central (%)	Number/proportion of districts in the Western (%)	Number/proportion of districts in the Mid-Western (%)	Number/proportion of districts in the Far-Western (%)
The low (4–16)	15	6/40	5/33.3	4/26.7	0/0	0/0
The relative low (16–28)	28	8/28.6	9/32.1	7/25	4/14.3	0/0
The moderate (28–40)	20	2/10	5/25.0	5/25	6/30	2/10
The relative high (40–52)	7	0/0	0/0	0/0	3/42.9	4/57.1
The high (52–64)	5	0/0	0/0	0/0	2/40	3/60

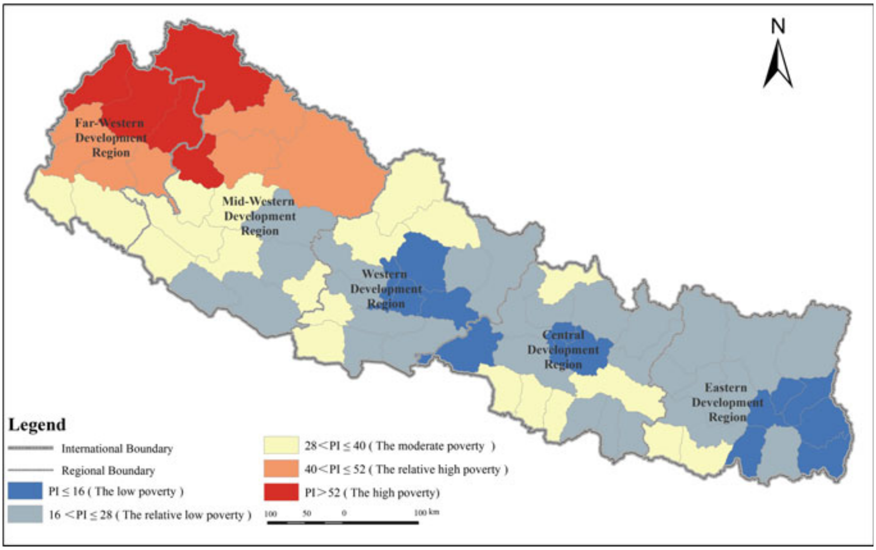


Fig. 12.4 Poverty ranks of districts of Nepal in 2011

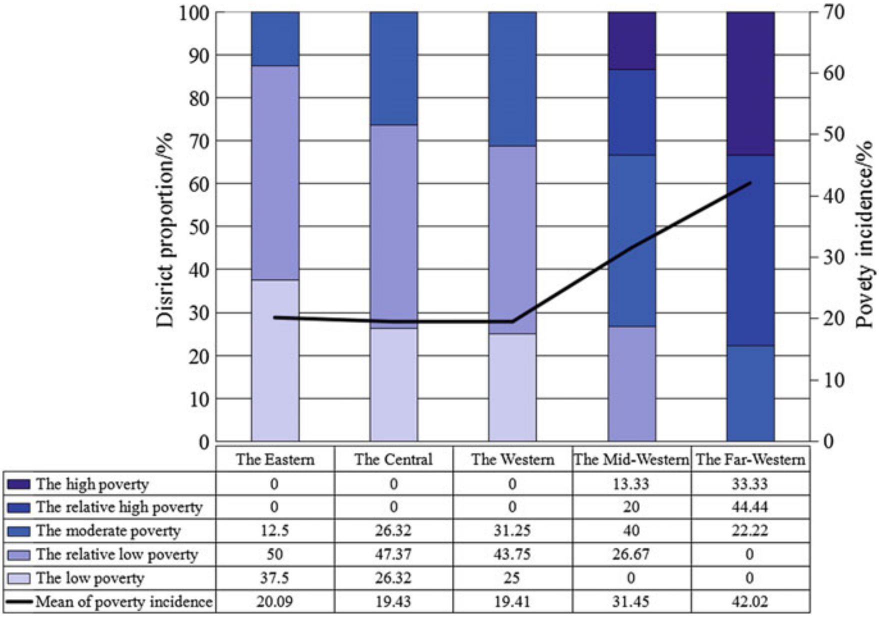
Table 12.4 Statistics for Kruskal Wallis test

Group	Sum of rank	Freedom degree (=K − 1)	Progressive significance (bilateral)
Development Regions	33.473	4	0.000
Terrains	16.035	2	0.000
Development region-terrains	46.58	14	0.000

than in the Eastern, Central, and the Western Regions. The order of PIs from high to low is as under: the Far-Western > the Mid-Western > the Western > the Eastern > the Central.

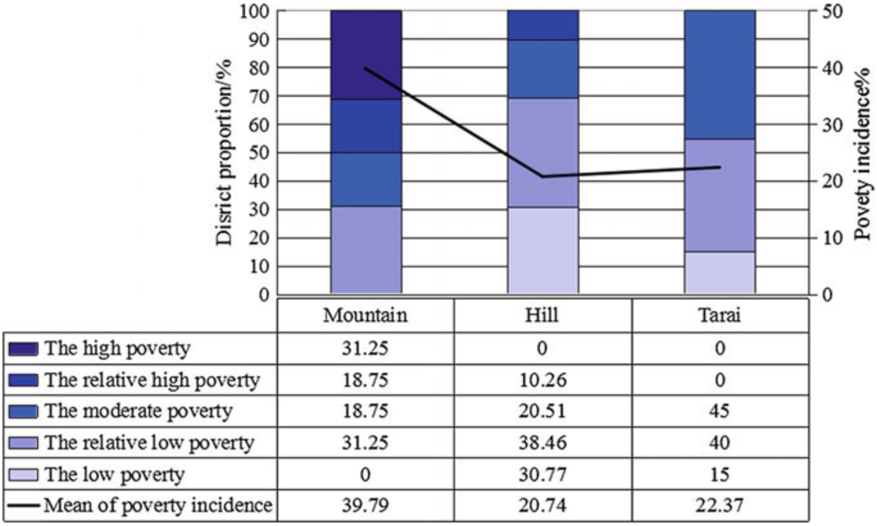
As for the terrains (Fig. 12.6), Mountain region is the only region where high poverty districts were seen, and Hill region held the most relative low poverty districts. Tarai region was featured with most moderate and relative poverty districts. Hence, the order of PI is, Mountain > Tarai > Hill.

Development Region-terrain exhibit, five region-terrain combinations presenting single poverty rank (Fig. 12.6). They are the eastern mountain, western mountain, Far-Western mountain, Far-Western hill, and the Far-Western tarai, respectively, recognized as the relative low poverty region, moderate poverty region, high poverty region, relative high poverty region, and the moderate poverty region. Accordingly, the order of PI is as below: The Far-Western Mountain > the Mid-Western Mountain > the Far-Western Hill > the Western Mountain > the Far-Western Tarai > the Mid-Western hill > the Mid-Western Tarai > the Central



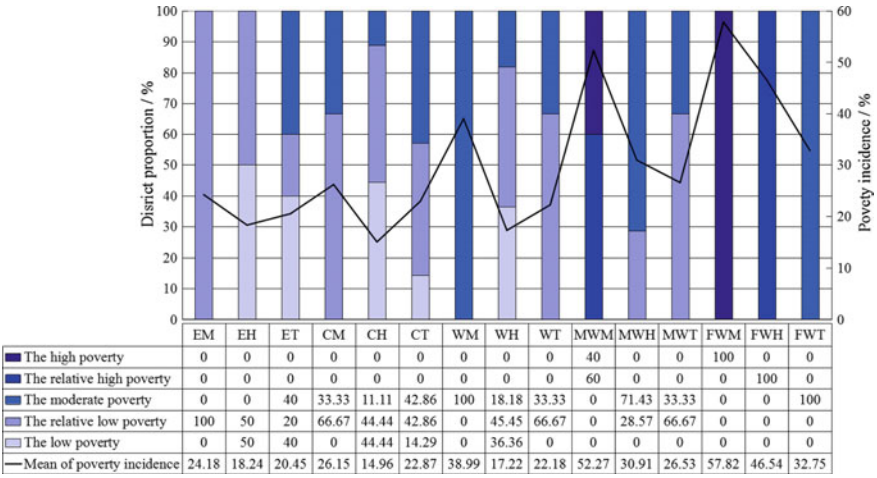
	The Eastern	The Central	The Western	The Mid-Western	The Far-Western
■ The high poverty	0	0	0	13.33	33.33
■ The relative high poverty	0	0	0	20	44.44
■ The moderate poverty	12.5	26.32	31.25	40	22.22
■ The relative low poverty	50	47.37	43.75	26.67	0
□ The low poverty	37.5	26.32	25	0	0
— Mean of poverty incidence	20.09	19.43	19.41	31.45	42.02

Fig. 12.5 PI and ranks for different Development Regions in 2011



	Mountain	Hill	Tarai
■ The high poverty	31.25	0	0
■ The relative high poverty	18.75	10.26	0
■ The moderate poverty	18.75	20.51	45
■ The relative low poverty	31.25	38.46	40
□ The low poverty	0	30.77	15
— Mean of poverty incidence	39.79	20.74	22.37

Fig. 12.6 PI and ranks for different terrain regions in 2011



	EM	EH	ET	CM	CH	CT	WM	WH	WT	MWM	MWH	MWT	FWM	FWH	FWT
■ The high poverty	0	0	0	0	0	0	0	0	0	40	0	0	100	0	0
■ The relative high poverty	0	0	0	0	0	0	0	0	0	60	0	0	0	100	0
■ The moderate poverty	0	0	40	33.33	11.11	42.86	100	18.18	33.33	0	71.43	33.33	0	0	100
■ The relative low poverty	100	50	20	66.67	44.44	42.86	0	45.45	66.67	0	28.57	66.67	0	0	0
□ The low poverty	0	50	40	0	44.44	14.29	0	36.36	0	0	0	0	0	0	0
— Mean of poverty incidence	24.18	18.24	20.45	26.15	14.96	22.87	38.99	17.22	22.18	52.27	30.91	26.53	57.82	46.54	32.75

Fig. 12.7 PI and ranks for different terrain regions in 2011. *Note EM* the Eastern Mountain, *EH* the Eastern Hill, *ET* the Eastern Tarai, *CM* the Central Mountain, *CH* the Central Hill, *CT* the Central Tarai, *WM* the Western Mountain, *WH* the Western Hill, *WT* the Western Tarai, *MWM* the Mid-Western Mountain, *MWH* the Mid-Western Hill, *MWT*- the Mid-Western Tarai, *FWM* the Far-Western Mountain, *FWH* the Far-Western Hill, *FWT* the Far-Western Tarai

Mountain > the Eastern Mountain > the Central Tarai > the Western Tarai > the Eastern Tarai > the Eastern Hill > the Western Hill > the Central Hill (Fig. 12.7).

12.3.1.3 Spatial Relationship Between Economic Development and Poverty

A. Correlation analysis between GDP per capita and PI

In order to analyze the spatial relationship between economic development and poverty, the correlation analysis between GDP per capita and PI of all districts and different types of districts were tested (Table 12.5).

The results showed that a moderate negative correlation (−0.419) was found between GDP per capita and PI of all 75 districts under the significance level of 0.01, while differences could be seen among different types of districts. There was a moderate negative correlation (−0.526) in the central with the significance level of 0.05. A larger correlation (−0.853) existed in the Far-Western with the significance level of 0.01. Now, with the significance level of 0.01, the correlation in hill was −0.704. With the significance level of 0.05, the eastern Tarai demonstrated a positive correlation (0.939) and the central Tarai showed a negative correlation

Table 12.5 Pearson coefficient of PI and GDP per capita for different district types

Type	Analysis unit	Pearson correlation coefficient	Significance (bilateral)	Number
Development Regions	Nation	−0.4191**	0.000	75
	The Eastern	−0.37	0.159	16
	The Central	−0.5268*	0.021	19
	The Western	−0.232	0.405	15
	The Mid-Western	0.353	0.18	16
	The Far-Western	0.853**	0.003	9
Terrains	Mountain	−0.495	0.051	16
	Hill	−0.704**	0.000	39
	Tarai	−0.424	0.062	20
Development Regions + Terrains	Eastern mountain	0.469	0.689	3
	Eastern hill	−0.592	0.122	8
	Eastern Tarai	−0.939*	0.018	5
	Central mountain	0.92	0.256	3
	Central hill	−0.722*	0.028	9
	Central Tarai	−0.139	0.766	7
	Western mountain	−1.000**		2
	Western hill	−0.816**	0.002	11
	Western Tarai	−0.96	0.181	3
	Mid-Western mountain	−0.87	0.055	5
	Mid-Western hill	−0.379	0.402	7
	Mid-Western Tarai	−0.763	0.447	3
	Far-Western mountain	−0.572	0.613	3
	Far-Western hill	−0.126	0.874	4
	Far-Western Tarai	−1.000**		2

Note *means the significance level of 0.05, **means the significance level of 0.01

(−0.722). With the significance level of 0.01, the correlation in the western mountains, western hill and Far-Western Tarai was high, with respective to correlation value −1, −0.816, −1. Other types could not pass the test, displaying no correlation.

B. Division of Economic-impoverished types

To further analyze the particular relationship between 'economy-impoverished,' the GDP per capita was put in order, from high to low, to signify the economic development level of 75 districts in Nepal (expressed by C1 ranging from 1 to 75; higher the value of C1, lower the level of economic development). Meanwhile, the PI was put in order from low to high to signify the poverty condition of 75 districts (expressed by C2 ranging from 1 to 75; higher the value of C2, higher the PI). Then, to calculate D ($D = C1 - C2$), independent sample approach of Kolmogorov–Smirnov (KS) was used to test whether D is submitted to Gaussian distribution.

The research findings showed that Z value of KS was 1.113 and P value 0.168 (>0.05), incapable to deny the original hypothesis, so D can be considered to submit as Gaussian distribution. The average value of D was equal to 0, and the standard deviation σ was 19.96. Applying 3σ rule of statistics, the values of D out of (−19.6, 19.6) were taken as abnormal values, and its corresponding samples were called abnormal samples. The interval meaning of the D values can be comprehended as following:

1. $D \in (-19.96, 19.96)$: These districts are consistent with the entire nation on the relationship of 'economy-impoverished,' coinciding with the economics logic. Those districts are named Revealed Poverty Region, where GDP per capita is high and its PI is exactly contrary.
2. $D < -19.96$: In these districts, the order of economic development level is far less than that of poverty level, which means that the GDP per capita is higher and so is the PI. Those districts are named Hidden Poverty Region.

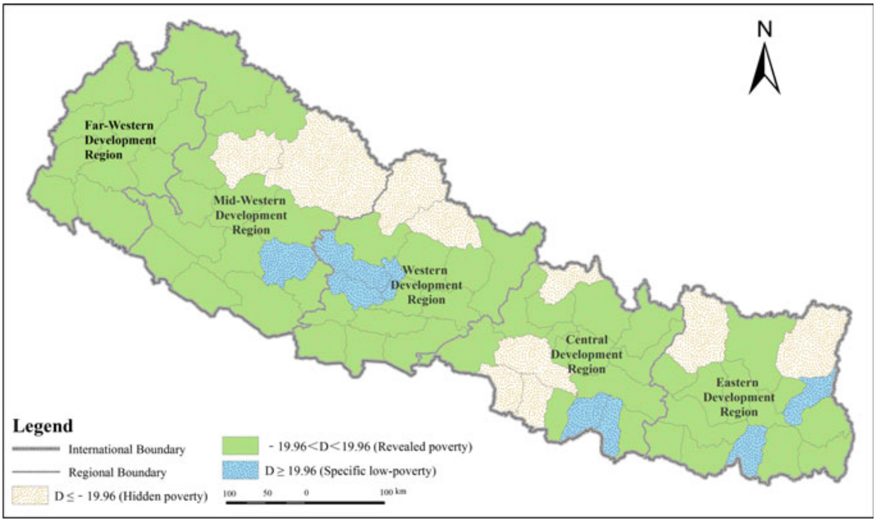


Fig. 12.8 Economic-impoverished type division of Nepal in 2011

3. D > 19.96: In these districts, the order of economic development level is far higher than poverty level with both low GDP per capita and PI. Although their economy falls behind, they do not manifest poverty feature, named Specific Low-poverty Region.

According to the above understanding, the 75 districts of Nepal have been divided into three types as described in Fig. 12.8. A large amount of nationwide districts (76%) belonged to Revealed Poverty Region, showing the inherent relevance and consistency between poverty and economic development. However, the consistency is not suitable for all districts; some districts presented the feature of Hidden Poverty and Specific Low-poverty, respectively, accounting for 13.33 and 10.67% of the total districts.

12.3.2 Discussion

12.3.2.1 The Hidden Poverty Region

The Hidden Poverty Region includes 10 districts, out of which seven districts were found in the Himalaya Mountain regions. These are located in the famous national parks or conservation areas. The former refers to Rara National Park, Shey Phoksundo National Park, Sagarmatha National Park, and Langtang National Park, while the later to Annapurna and Kanchenjunga Conservation Area. For protection and management, these national parks or conservation areas usually charge relatively high fees from the visitors. The revenue generated ultimately contributes to the local and central governments. Thus, it can be ascertained that the macroeconomic of these district is thriving because of the stable revenue dependence on tourism. However, due to extremely low literacy rate, local people do not always get the chance to be fully involved in the tourism business and make money for themselves. For example, there are four out of seven districts with higher adult illiteracy rate than the national level, and three districts holding more than 55% illiterate adults, respectively. This percentage is even higher than the entire mountainous region of the country.

12.3.2.2 The Specific Low-Poverty Region

The Specific Low-poverty Region contains eight districts, in which four districts lie in the West and the Mid-Western. Political struggles have led to the low economic development and high poverty in this area. For instance, Rolpa District was a major flashpoint in the 1996–2006 civil war in Nepal and had been a ‘Maoist Stronghold’ of the Communist Party of Nepal. Additionally, there is a presence of Nepal Army, Nepal Police, and Armed Police Force of Nepal in Baglung District. The district government offices and the police headquarters are located in the town and so is the Nepalese Army base in Gulmi District. Although these districts hold promise of considerable mineral resources and biological resources (such as herbal medicine plants), unstable political situation and lack of effective governmental management have led to the downfall of industry and a blow to economic development since long. As a result, a large number of local people were employed overseas and got jobs in India with preferable salary Baglung District once topped as one of the highest amounts of remittance generated through foreign employment in Nepal. This may explain why Specific Low-Poverty is found there.

Due to lack of availability of data and information about the study area, especially lacking empirical data (such as first-hand survey data), the reasons for 'Hidden Poverty' and 'Specific Low-poverty' require further investigation. However, the preliminary study results present a more detailed picture of spatial features of poverty for 75 districts in Nepal.

12.4 Conclusions

Based on district-level poverty indexes and statistical analysis, this paper presented the disparities of poverty distribution and divided the economic-impoverished types of Nepal in 2011. The following conclusions were drawn from the study:

1. The PI was gradually rising from the Eastern to the Far-Western with geographical differences. The Mid-Western and Far-Western presented higher PI and poverty depth than those of other three regions as well as the nation. However, the two regions held less absolute and relative differences on poverty distribution than the other three regions according to the range and standard deviation of poverty LQ by Lorenz curves of poverty distribution, the Central, Western, and the Mid-Western presented more centralized on poverty population compared to the entire nation, with the Far-Western more evenly distributed on poverty population.
2. By Kruskal Wallis test, poverty discrepancies among Development Regions, terrains, and Development Region-terrains were identified. A larger proportion of relative high and high poverty but smaller proportion of low and relative low poverty districts were found in the Mid-Western and the Far-Western rather than in the Eastern, the Central, and the Western. Mountain region is the only region where high poverty districts were seen and hill region held the most relative low poverty districts. Tarai region was featured with most moderate and relative poverty districts. There were five region-Terrain combinations, respectively, presenting single poverty rank: the eastern mountain, the western mountain, the Far-Western mountain, the Far-Western hill, and the Far-Western Tarai, respectively, recognized as the relative low poverty region, moderate poverty region, high poverty region, relative high poverty region, and the moderate poverty region.

3. The correlation between GDP per capita and PI of all districts along with different types of districts was made, followed by the findings that the central, hill, and central Tarai with a moderate negative correlation, the western mountain, western hill, and Far-Western Tarai with a larger negative correlation, and the Far-Western and eastern Tarai with a positive correlation. Thereafter, 75 districts were divided into three economic-impoverished types: Revealed Poverty Region, Hidden Poverty Region, and Specific Low-poverty Region. The Hidden Poverty Region is mainly located in the Himalaya mountain regions, well known as the national parks or conservation areas. The stable revenue generated by local government from tourism is a good macroeconomic indicator. Nevertheless, local people get few opportunities to earn income through tourism development. In addition, the main reason for both low economic development and low poverty in the Specific Low-poverty Region was attributed to political struggles and management issues, even though abound mineral and biological resources. Consequently, lots of local people were employed overseas (like for example in India) to obtain preferable income.

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Chapter 13
Agricultural Land Use Intensity and Determinants in Different Agroecological Regions in Central Nepal Himalaya

Shanta Paudel Khatiwada, Jifei Zhang, Yi Su, Bikash Paudel and Wei Deng

Abstract Intensification of agricultural land use is the only viable option to achieve food security in countries possessing very limited arable lands such as Nepal. Since sustainable intensification has been policy targets in recent years, understanding agricultural land use intensity and its determinants would provide important support to policy formation toward sustainable agricultural development. However, the status and determinants of agricultural land use intensity in Nepal have been seldom investigated. Based on questionnaire surveys of 453 households, 12 key informant surveys and three focus group discussions, this study assesses cropping frequency, as an indicator of agricultural land use intensity (ALUI), in three agroecological regions in central Nepal. The results show that average cropping frequency in Khet land is 2.9, 2.6 and 1.6 in low-land Terai, mid-hill and high-hill area, respectively, while in Bari land is 2.4, 2.3 and 2.1, respectively. In addition, Terai region has significantly higher ALUI in both Khet and Bari lands than mid- and high-hill areas. Among a total of 18 investigated impacting factors, age and education of household heads, land quality and use of improved seed positively influence ALUI in Khet land, while distances from home to land and vehicle passable roads have negative effects. For the Bari lands, land quality, irrigation facility, tractor availability and improved seeds are positively associated with ALUI, but education of household heads, distances from home to land, home to market center and home to vehicle passable road are negatively influencing factors. This study provides an empirical evidence that agricultural modernization and access to infrastructural facilities are the major pathways to promote agriculture

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intensification in mid and high hills. Intensification of agricultural land use might be a preferable option to reduce poverty and food shortage in Nepal; however, there is a need of effective land management and agricultural policy, along with incentive programs to attract young generations engage in agriculture. More than that, education, training and awareness programs about the importance of maintaining soil fertility under intensified farming are greatly needed in order to achieve a sustainable agricultural in Nepal.

Keywords Agricultural land use intensity · Cropping frequency · Agroecology · Analysis of covariance · Central Nepal

13.1 Introduction

Agricultural land use intensity (ALUI) is a prominent aspect of land use. Higher ALUI is regarded as a viable option to achieve food security in those countries possessing very limited arable lands such as Nepal (Dahal et al. 2008, 2009) where only 16% territory is suitable for agriculture (CBS 2006). As an underdeveloped country, Nepal's economy is dominated by agriculture, of which smallholder subsistence farmers, accounting to 65% of the population, contribute one-third of the total gross domestic product (35.1% in 2011/12) (MoF 2013). Yet, demand for agricultural products in Nepal is continuously rising due to population growth, but available arable lands are gradually decreasing. For example, from 1991/1992 to 2011/2012, average household land holding decreased from 0.96 to 0.68 ha (CBS 2011). This reduction seriously threatens the livelihood security of those depending on farming (CBS 2013; Thapa and Niroula 2008). Poverty and food insecurity are further worst in rural areas due to lack of off-farm employment opportunities and lower crop yields. To overcome those problems, subsistence-based cropping in rural areas has gradually changed to high-value market-oriented products such as vegetables and cash crops (Brown and Kennedy 2005; Brown and Shrestha 2000; Dahal et al. 2009). As a consequence, agriculture land use is intensified in those areas by increasing cropping frequencies and adopting multiple cropping patterns (Brown and Kennedy 2005; Paudel and Thapa 2004; Tiwari et al. 2008a). Although increasing ALUI has positive effects on the wellbeing of farmers, but higher ALUI without sustainable soil and nutrient management practice has accelerated agriculture-driven soil, environment and ecosystem degradation in Nepal (Schreier et al. 1994; Tiwari et al. 2008a). By this means, insight on ALUI is an important aspect of sustainable agricultural development and food security in Nepal.

Nepal is a small mountainous country with enormous climatic and elevational diversity (Chaudhary 2000; Chhetri 2011). It has been divided into different agroecological regions with varying level of resource availability, land use, farming systems, cropping intensities, accessibilities to infrastructures and technologies (Dhakal et al. 2013; Shrestha et al. 2012; Vaidya and Floyd 1997). For instance, the

Terai is a plain area with alluvial fertile soil. Located at an altitude below 500 masl (meter above sea level) under subtropical climate, the sufficient heat and precipitation combined with well-developed irrigation systems enable high land use intensity in this region, which is not comparable in the hills and mountain regions (Maskey et al. 2003).

Rapid change in the degree of ALUI, particularly in the developing countries, has drawn attention of researchers because of its substantial environmental and socioeconomic impacts. Consequently, numerous researchers from both natural and social sciences have studied socioeconomic and environmental impacts of increasing ALUI and provided both positive and negative aspects of it. Higher ALUI is beneficial as it increases productivity, improves food and income security and changes gender roles and division of labor (Dahal et al. 2009; Raut et al. 2010; Tranter et al. 2007). On the contrary, it is detrimental in terms of soil and water degradation, soil erosion and fertility loss, environmental change and biodiversity loss (Brown and Shrestha 2000; Hati et al. 2007; Kehoe et al. 2015; Smith et al. 2008; Thapa 1996; Tilman et al. 2001; Westarp et al. 2004).

Various factors at macro- and micro-levels are expected to influence ALUI. At macro-level, the determinants include geographical location, local climate, population pressure, market demands and accessibility, changes in consumer diets, non-farm employment opportunities, technology development and agricultural policies (Brown and Shrestha 2000; Chhetri 2011; Döös 2002; Gobin et al. 2002; Kastner et al. 2012; Lambin et al. 2000; Saka et al. 2011; van Meijl et al. 2006). Micro-level impact factors are households and socioeconomic conditions such as sex, age, education and training of household head, ethnicity, family size and labor availability, access to credit, land holding size (Aryal and Holden 2011; Gobin et al. 2002; Haiguang and Xiubin 2011; Pan et al. 2004).

Based on the previous studies, it can be concluded that intensification of agricultural land use has positive impacts on socioeconomic aspect of farmer's livelihood, but has negative implication on environment, biodiversity and ecosystem conservation. In order to assess the potential benefits of higher ALUI and to minimize negative environmental impacts, it is essential to understand the current status of ALUI and associated determinants. However, ALUI and its impact factors have been seldom investigated in Nepal. Therefore, a careful assessment of ALUI is required to explore its opportunities, risks and mitigation strategies in Nepal. Concurrently, it is also essential to analyze the factors that influence ALUI in different agroecological regions in Nepal since there are regional variations in the degree of ALUI in different agroecology. Based on the farm households survey data collected from three agroecological regions of Nepal representing different biophysical and socioeconomic levels, this study aims to (1) assess status of ALUI at three agroecological regions of Nepal and compare among the regions, and (2) identify the geo-physical and socioeconomic determinants of ALUI at different agroecological regions. The results will provide insights to develop policy and actions in support of sustainable agriculture in Nepal.

13.2 Methods

13.2.1 Study Area

This study encompasses three VDCs, namely Bachhauli, Ghyalchok and Ghanpokhara from Chitwan, Gorkha and Lamjung districts, respectively, in Gandaki River Basin (GRB) in central Nepal (Fig. 13.1). A Village Development Committee (VDC) is the basic administrative unit of Nepal which is chosen as case study for this study. GRB covers all the agroecological regions in central Nepal (low-land Terai, mid-hill, mountain including trans-Himalaya) (Panthi et al. 2015). Among all, low-land Terai, mid-hill and high hill are the three most important agroecological regions in terms of the agricultural production in Nepal (Vaidya and Floyd 1997). These VDCs are located at different elevation ranges Bachhauli (below 200 masl), Ghyalchok (350–1400 masl) and Ghanpokhara (1500–2700 masl) and represent the three agroecological domains: low-land Terai, mid-hill and high-hill, respectively. These VDCs are characterized with distinct topography, climate and biophysical features that result in different soil types and crop growing conditions and farming system (Chhetri 2011). Details biophysical, socioeconomic, infrastructure characteristics in the study areas are presented in Table 13.1.

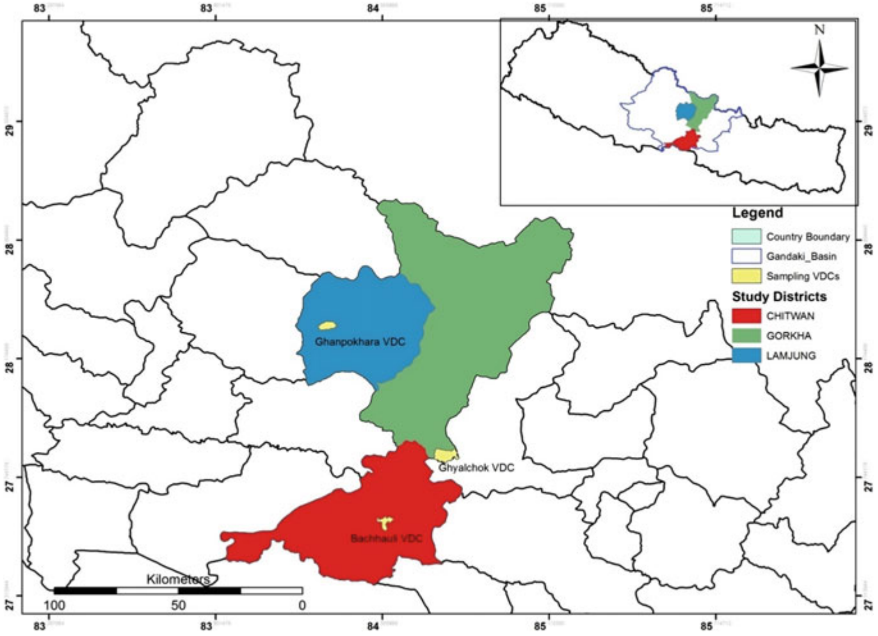

Fig. 13.1 Map of Nepal showing the study area

Table 13.1 Description of study areas with biophysical and socioeconomic characteristics

Characteristics	Bachhauli	Ghyalchok	Ghanpokhara	Data source
District	Chitwan	Gorkha	Lamjung	
Altitude range (masl)	190–200	350–1400	1500–2700	Khatiwada and Ghimire (2009), Shrestha (2007) and Field survey 2015
Agroecology	Low-land Terai	Mid-hill	High hill	Vaidya and Floyd (1997), Shrestha et al. (2012), Dhakal et al. (2013)
Climate	Subtropical climate, rainfall average 2400 mm	Subtropical in valley bottom and warm temperate at the hill top rainfall (1200–1500 mm)	Warm temperate at hill bottom and cool temperate at hill top rainfall (2500–3000 mm)	Khatiwada and Ghimire (2009), Tiwari et al. (2008a, b), Poudel and Shaw (2016)
Land form	Plain	River basin and hill slope	Hill slope	Field survey 2015
Land quality	High (both Khet and Bari land)	High (Khet and Bari land of low valley) medium to low (upland Bari)	Medium in Khet of low land and low in Bari of upland	Field survey 2015
Main source of livelihood	Cereal crop farming, livestock farming, foreign job, business, civil services and tourism	Market-oriented vegetable farming, livestock farming, foreign job, migration to the city or town for job	Subsistence farming, foreign job, migration to the city or town for job, tourism	Field survey 2015
Ethnic group	Tharu-aboriginals, Brahmin, Chhetri, Gurung, Newar, Magar	Brahmin, Chhetri, Gurung, Newar, Kami, Sarki	Gurung, Ghale, Kami	Field survey 2015
Major crops produced	Rice, mustard and wheat	Vegetables, rice, maize and legumes	Rice, maize, potato and millet	Field survey 2015
Infrastructure and agricultural technology available	Access to well-developed irrigation canal, motorable road, close to market center, easy access to agricultural inputs and machines	Lacks access to irrigation canals, motorable road, far from market center, difficult to access agricultural inputs and machines	No irrigation canal, permanent motorable road, far from market center, very hard to access agricultural inputs and no access to machines	Field survey 2015

13.2.2 Data and Sampling

Data for this study were obtained through a household survey conducted during November to December in 2015. By using a structured questionnaire, the survey collected informations on household characteristics, socioeconomic conditions, land and livestock holding, cropping frequencies of the year 2015, cropping patterns, crops produced, access to and use of yield-increasing inputs, irrigation, and land characteristics. The questionnaire was pre-tested in all three VDCs to examine its suitability. Supplementary information were collected through four key informant interviews with village leaders and elder farmers and one focus group discussion with selected representatives in each VDC in order to collect the information on general situation of ALUI and its influencing factors in the village level.

Household survey was administered following multi-stage random sampling. In the first stage, the three districts Chitwan, Gorkha and Lamjung in GRB from central Nepal were selected. Secondly, three VDCs, namely Bachhauli, Ghyalchok and Ghanpokhara from Chitwan, Gorkha and Lamjung, were, respectively, chosen for this study so that the most important three agroecological regions could be included. Each VDC in Nepal contains nine wards. So in the third stage, we randomly selected four wards from Bachhauli, five wards from Ghyalchok and four wards from Ghanpokhara. Finally, around 10% of the total households in each VDC were chosen by assigning a number to each household in each ward and then selecting the computer-generated random numbers. It yielded a total of 453 households, including 217 from Bachhauli, 133 from Ghyalchok and 103 from Ghanpokhara. Among them, ten households were excluded since they neither hold any lands nor involved in agriculture. As a result, a total of 443 households were used for the analysis of ALUI in this study.

13.2.3 Analytical Framework

A combination of descriptive and inferential statistics was used in the analyses. To assess the average ALUI, average cropping frequency was calculated for each VDC, separately for Khet (irrigated low land) and Bari (rainfed upland land). One-way ANOVA was used to compare the regional differences. The significance of difference was determined in post hoc Tukey test.

Analysis of covariance (ANCOVA) was used to examine the relationship between land use intensity and explanatory variables. The model was chosen for this study because the explanatory factors are a mixture of categorical and quantitative variables. ANCOVA is regarded as a robust model that has ability to control the influence of covariates (continuous variables) when examining the influence of factors (nominal variables) (Miller and Chapman 2001; Saka et al. 2011). In the model, cropping frequency was used as dependent variable where continuous variables were set as covariates and other nominal variables were set as fixed factors. Analysis was conducted in SPSS (version 21).

13.2.3.1 Dependent Variables

ALUI refers to how frequently farmland is cultivated (Boserup 1965). Scholars have proposed three ways to measure ALUI: (1) output-oriented measure, i.e., production per unit area per unit time; (2) input-oriented method, i.e., inputs of labor, capital and skills that contribute to agricultural production; and (3) cropping frequency on a given land within a time period (Boserup 1965; Lambin et al. 2000; Shriar 2000; Turner and Doolittle 1978). We used cropping frequencies as the ALUI indicator since the main purpose of this study is to explore the general status and determinants of ALUI and cropping frequency can directly measure how intensely a land is utilized (Boserup 1965; Jiang et al. 2013). The number of crops planted in the year 2015 was considered as the cropping frequency in this study. According to the questionnaire survey, we categorized cropping frequency into four groups, 0 for no plantation, 1 for only one crop, 2 for two crops and 3 for three or more than three crops within a calendar year.

Khet and Bari are the two major land categories cultivated in Nepal (Desbiez et al. 2004). Khet is lowland, generally flat, located nearby streams/rivers and has irrigation facility, and Bari is upland with terraced slopes and usually does not have irrigation systems (Brown and Shrestha 2000; Tiwari et al. 2008a; Westarp et al. 2004). Therefore, it is very likely that Khet land is used more intensely. Raut et al. (2011) explored the determinants of adoption and extent of agricultural intensification in mid-hill watershed only in Khet land. However, Bari land use intensity also plays important role in food and nutritional security and environment management in Nepal as high soil erosion and soil degradation are reported in Bari land (Tiwari et al. 2008a; Westarp et al. 2004; Thapa 1996). This study includes both land categories to examine the actual status of land use intensity and determinants in the three agroecological regions in Nepal.

13.2.3.2 Selection of Explanatory Variables and Expected Impacts on ALUI

Cropping potential is determined by environmental factors like climate and biophysical characteristics (Chhetri 2011; Fischer et al. 2002). However, ALUI is influenced by the interaction of various factors from climatic, biophysical, socioeconomic, infrastructures and technological characteristic (Shriar 2000). Therefore, we selected a total of 18 variables from different categories as the explanatory variables and included in ANCOVA model.

Variables from social/households and heads characteristics include family size, ethnicity, sex, age, education and training. Historically, the Nepalese society has been divided into many ethnic groups based on their castes and used to have distinct professions based on caste. In the ancient time farming used to be the major occupation of the so-called higher caste Brahmin and Chhetri. The previous studies indicated variant influences of ethnicity on cropping intensity in Nepal (Aryal and Holden 2011; Paudel and Thapa 2004; Tiwari et al. 2008b). Therefore, we categorized ethnicity into five groups to examine its effects on cropping intensity.

We hypothesize that age of household heads has negative effects on cropping intensity. Since Nepalese society is patriarchal, male-headed households have better access to resource and technologies (Rana et al. 2007). So, it is hypothesized that male-headed households tend to involve in higher cropping intensity than female-headed households. Education level of the household heads also influences ALUI, because those with higher education have more access to technology, networking, and have more knowledge of yield-increasing inputs (Lu et al. 2012). Therefore, it is supposed that the more years of education the household heads have, the more they are likely to involve in higher cropping intensity. Also household heads with agricultural training are expected to have higher ALUI. There is direct variation in ALUI among different sizes of family (Adikwu 2014). Total number of household members indicates the availability of labor force for agricultural activities, and it is hypothesized that the larger the family size, the higher ALUI.

Occupation, access to non-farm income, total number of livestock and land holding size represent the economic characteristics of household in our study. We expected that household heads whose primary occupation is agriculture are more likely to increase their cropping intensity than others whose primary occupation is not agriculture. The impact of non-farm income on ALUI is dominant (Haiguang and Xiubin 2011). Thus, it is expected that household with non-farm income has lower ALUI. It is also hypothesized that households with larger number of livestock holding have access to more manure to use in the farm land which positively influence the cropping frequency. Previous studies have found that the land holding size of farming households is an important determinant of the ALUI (Lu et al. 2012). Therefore, it is hypothesized that households with bigger size of land holdings are more likely to have higher cropping intensity.

Similarly, we selected irrigation facilities, distance to market and vehicle passable roads representing infrastructural variables. The role of irrigation is prominent for ALUI because irrigation facilities allow farmers to increase cropping frequency (Alauddin and Quiggin 2008). Therefore, it is expected that land with irrigation has higher intensity. Distance to market center and road encourages commercial agriculture (Brown and Shrestha 2000; Nepal and Thapa 2009). It is supposed that households closer to market centers and vehicle passable roads are likely to involve in market-oriented farming, which leads to higher cropping frequencies. Access to modern agricultural technologies, for example, chemical fertilizers, pesticides, improved seeds and tractors, may also influence the degree of ALUI (Saka et al. 2011). It is hypothesized that the higher the access to those inputs, the higher the cropping intensity.

Farm-related factors include land quality and distance to land from home. Farmland that lies nearer to the homestead allows easier supervision by farmers and is hypothesized to be cultivated more intensively. Quality of land has also been reported as a determinant of ALUI (Haiguang and Xiubin 2011; Saka et al. 2011); hence, it is hypothesized that land with better quality is usually managed more intensively. Further, three VDCs from three agroecological regions with different climate and landforms represent biophysical and climatic variables. So it is hypothesized that low-land Terai has the higher ALUI than mid- and high-hill regions.

Finally, the ANCOVA model is specified as:

$$L_i = \alpha + \emptyset_1 Z_1 + \ldots \emptyset_n Z_n + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots \beta_k X_{ik} + \upsilon_i \tag{13.1}$$

where

L_1	Measurement of land use intensity, i.e., cropping frequency
	The Z_s are the nominal variables, while X_{is} the continuous variables.
Z_1	Ethnicity (Dalit = 1, Janajati = 2, Tharu = 3, Brahmin = 4, Chhetri = 5)
Z_2	HH head sex (Male = 0, Female = 1)
Z_3	Main occupation of HH head (Other than agriculture = 0, Agriculture = 1)
Z_4	Improved seed use (No = 0, Yes = 1)
Z_5	Land quality (High = 1, Medium = 2, Low = 3)
Z_6	Irrigation facility (No = 0, Yes = 1)
Z_7	Tractor used (No = 0, Yes = 1)
Z_8	Pesticides used (No = 0, Yes = 1)
Z_9	Agricultural training (No = 0, Yes = 1)
Z_{10}	Non-farm income source (No = 0, Yes = 1)
X_1	Area of Khet/Bari land (ha)
X_2	Home–land distance (km)
X_3	Home–market distance (km)
X_4	Distance to vehicle passable road (km)
X_5	Total household members
X_6	HH age (year)
X_7	HH education (year)
X_8	Total livestock number

13.3 Result

13.3.1 Summary of the Explanatory Variables

The distribution of farming households in the three study sites based on socio-economic characteristics is presented in Tables 13.2, 13.3 and 13.4. The Chi-square values in Table 13.2 showed that main occupation of HH head ($P = 0.05$), ethnicity ($P = 0.001$) and non-farm income source ($P = 0.001$) significantly varied among the three sites. Likewise, one-way ANOVA result in Table 13.3 indicates

Table 13.2 Descriptive statistics for nominal explanatory variables by agroecology

Variables	Response	Bachhauli	Ghyalchok	Ghanpokhara	Total
		N = 208	N = 132	N = 103	N = 443
HH sex	Male	143(68.75)	92(69.70)	61(59.22)	296(66.82)
	Female	65(31.25)	40(30.30)	42(40.78)	147(33.18)
	Chi-square value	3.52			
HH main occupation	Other	96(46)	53(40)	64(62)	213(48)
	Agriculture	112(54)	79(60)	39(38)	230(52)
	Chi-square value	11.79**			
HH agricultural training	No	172(82.69)	91(59.41)	89(86.41)	350(79.46)
	Yes	36(17.31)	41(31.06)	14(13.59)	91(20.54)
	Chi-square value	13.33***			
Ethnicity	Dalit	5(2)	28(21)	30(29)	63(14)
	Janajati	33(16)	40(30)	73(71)	146(33)
	Tharu	79(38)	1(1)	0(0)	80(18)
	Brahmin	83(40)	47(36)	0(0)	130(29)
	Chhetri	8(4)	16(12)	0(0)	24(5)
	Chi-square value	248.26***			
Non-farm income	No	22(11)	38(29)	8(8)	68(15)
	Yes	186(89)	94(71)	95(92)	375(85)
	Chi-square value	26.55***			

The figures in parenthesis are percentage
Significant at ***99%, **95%

that HH head's age and schooling years, total livestock holding, home to market distance and home to vehicle passable road distance significantly differed among three areas ($P = 0.001$).

Table 13.4 shows the average agricultural land holdings and their use in the three VDCs. The overall average landholding area was 0.45 ± 0.48 ha, of which 0.38 ha was used for crop cultivation and 0.07 ha was left fallow. The three study sites were significantly different in their average landholding ($F = 6.209$, $P < 0.05$), average cultivated land areas ($F = 17.215$, $P \leq 0.001$) and average fallow areas ($F = 12.805$, $P \leq 0.001$). Ghyalchok had the highest average area under cultivation (0.52 ha), followed by Bachhauli (0.35 ha) and Ghanpokhara (0.26 ha). The highest fallow land was in Ghanpokhara (0.19 ha). The average size of land holding 0.45 ha is slightly smaller than the national size with 0.68 ha (in 2011/2012) in Nepal (CBS 2011).

House holdings of two different land types, *Khet* and *Bari*, were also significantly different among the three VDCs (Khet: $F = 13.8$, $P \leq 0.001$ and Bari:

Table 13.3 Descriptive statistics for continuous explanatory variables by agroecology

Variables	Bachhauli	Ghyalchok	Ghanpokhara	Total	*F* Value
	N = 208	*N* = 132	*N* = 103	*N* = 443	
HH age year	50.62 ± 13.47	50.61 ± 14	55.34 ± 14.11	51.71 ± 13.89	4.655***
Total house hold member	5.48 ± 2.04	5.67 ± 2.22	5.75 ± 2.46	5.6 ± 2.19	0.614
Total livestock holding	3.19 ± 2.83	8.6 ± 4.83	7.65 ± 25.32	5.84 ± 12.84	8.79***
Home–market distance (km)	4.17 ± 0.91	3.34 ± 2.08	19.22 ± 1.87	7.42 ± 6.7	3767.979***
Home–road distance (km)	0.02 ± 0.06	1.14 ± 1.5	1.32 ± 1.14	0.66 ± 1.16	82.962***
HH education year	4.84 ± 4.81	4.68 ± 4.8	1.99 ± 3.47	4.13 ± 4.67	14.988***

The *F*-statistics were calculated from one-way ANOVA. The results are presented with mean ± standard deviation
Significant at ***99%

Table 13.4 Total land holdings and area of land use for cultivation by agroecology

Land distribution	Bachhauli	Ghyalchok	Ghanpokhara	Total	*F*-statistics
Total land holding (ha)	0.38 ± 0.43	0.57 ± 0.44	0.44 ± 0.59	0.45 ± 0.48	6.209**
Total cultivated area (ha)	0.35 ± 0.39	0.52 ± 0.39	0.26 ± 0.22	0.38 ± 0.37	17.215***
Area left fallow (ha)	0.03 ± 0.13	0.04 ± 0.11	0.19 ± 0.52	0.07 ± 0.28	12.805***
Total Khet (ha)	0.32 ± 0.38	0.12 ± 0.16	0.29 ± 0.46	0.26 ± 0.36	13.893***
Total Bari area (ha)	0.06 ± 0.12	0.44 ± 0.36	0.15 ± 0.2	0.19 ± 0.29	113.771***

The *F*-statistics were calculated from one-way ANOVA. The results are presented with mean ± standard deviation
Significant at ***99%, **95%

$F = 113.7$, $P \leq 0.001$). Bachhauli, located in plain area, is dominated by Khet lands, had highest average Khet-holding size (0.32 ha) followed by Ghyalchok (0.12 ha) and Ghanpokhara (0.29 ha). The highest Bari holding was in Ghyalchok (0.44 ha), followed by Ghanpokhara (0.15 ha) and Bachhauli (0.06 ha).

The distribution of farming households and their adoption of modern agricultural inputs in Khet and Bari lands by agroecological regions is presented in Table 13.5. Overall, the majority of households had used modern agricultural technologies in Khet land. About 60, 84, 73 and 83% households have used tractor, fertilizers, pesticides and improved seed, respectively, though it significantly varied among study areas ($P = 0.001$). Similarly, the utilization of modern agriculture technologies in Bari land also significantly varied among the study sites ($P = 0.001$) (Table 13.5).

Table 13.5 Use of modern agricultural input by agroecology

Agriculture input	Bachhauli	Ghyalchok	Ghanpokhara	Total	Chi-square value
Khet land	$N = 198$	$N = 76$	$N = 94$	$N = 368$	
Tractor used					
No	0(0)	54(71)	94(100)	148(40)	
Yes	198(100)	22(36)	0	220(60)	302.99***
Chemical fertilizer used					
No	0	0	58(62)	58(16)	
Yes	198(100)	76(100)	36(38)	310(84)	200.69***
Pesticides used					
No	0	12(16)	86(91)	98(27)	
Yes	198(100)	64(84)	8(9)	270(73)	278.82***
Improved seed used					
No	0	8(11)	55(58)	63(17)	
Yes	198(100)	68(89)	39(42)	305(83)	156.72***
Bari land	$N = 26$	$N = 128$	$N = 50$	$N = 204$	
Tractor used					
No	4(15)	72(56)	50(100)	126(62)	
Yes	22(85)	56(44)	0	78(38)	56.28***
Fertilizer used					
No	4(15)	21(16)	41(82)	66(32)	
Yes	22(85)	107(84)	9(18)	138(68)	74.604***
Pesticides used					
No	4(15)	37(29)	36(66)	74(36)	
Yes	22(85)	91(71)	17(34%)	130(64)	27.03***
Improved seed used					
No	6(23)	40(31)	23(46)	69(34)	
Yes	20(77)	88(69)	27(54)	135(66)	5.03*

The figures in parenthesis are percentage
Significant at ***99%, **95% and * 90%

13.3.2 Comparison of ALUI in the Three Agroecological Regions

Our result showed average cropping frequencies in Khet land were 2.9, 2.6 and 1.6 per year in low-land Terai, mid-hill and high hill VDCs, respectively. Similarly, in Bari lands, we calculated cropping intensity per year to be 2.4, 2.3 and 2.1 in the respective areas (Fig. 13.2). Analysis of one-way ANOVA shows that average cropping intensity is significantly different among the three agroecological zones in both Khet land ($H = 219.24$, $df = 2$, $P \leq 0.001$) and Bari land ($H = 6.21$, $df = 2$, $P = 0.049$). Pair-wise multiple comparisons show that study area in low-land Terai has the highest cropping intensity in Khet lands followed by mid-hills and high hills (Fig. 13.2a). However, the average cropping intensity in Bari land differs only between mid-hills and high hills (Fig. 13.2b).

13.3.3 Major Crops and Cropping Pattern in the Three Agroecological Regions

Shrestha and Aryal (2011) indicated three cropping seasons in Nepal, i.e., dry season (March–June), rainy season (July–September) and winter season (October–February). We analyzed major crop rotation pattern in these three seasons separately for Khet land and Bari lands in order to assess the major crops produced and commonly followed crop rotation pattern in the three agroecological regions. Our result indicated that most of the Khet lands are possible to grow three crops per

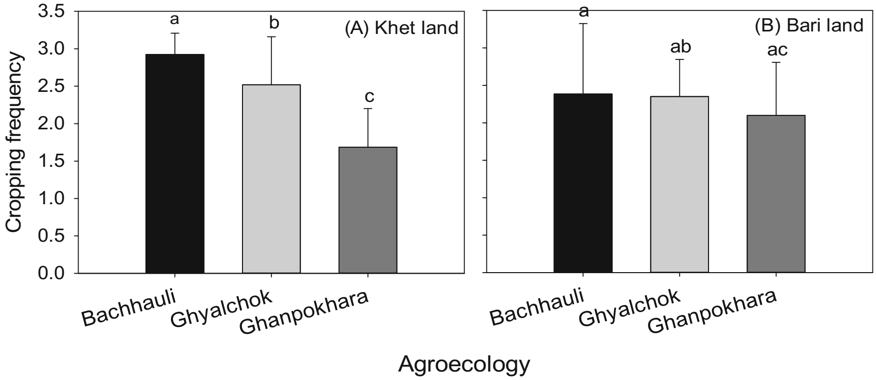

Fig. 13.2 Difference of cropping frequency in agroecological region **a** Khet land and **b** Bari land. The different letters in bar indicate significant difference. The letters are derived from one-way ANOVA with post hoc Tukey test

year. The majority of the households in Bachhauli (53%) adopted a three-crop rotation of rice–rice–mustard in Khet land for dry–rainy–winter cropping season. Similarly, 58% households in Ghyalchok followed vegetables–rice–vegetables pattern and 53% households in Ghanpokhara were with maize–rice–fallow pattern (Table 13.6).

The three cropping seasons are also possible in some Bari lands but depend on rainfall pattern and availability of irrigation. In Bachhauli, most of the households (47%) followed maize–rice–mustard/lentil three cropping patterns in Bari land. In Ghyalchok, a large number of them (38%) practiced double cropping includes maize/vegetable–vegetable/legume–fallow rotation. Similarly, the majority (66%) of households in Ghanpokhara adopted double cropping comprised of maize–millet/legume–fallow rotation model.

Table 13.6 Crop combination/rotation pattern in three agroecology

	Crop rotation pattern	Percentage	Crop rotation pattern	Percentage
	Khet use		Bari use	
Bachhauli	Rice–rice–mustard	53	Maize–rice–mustard/lentil	46.92
	Rice–rice–mustard/lentil	41	Maize–rice–wheat/lentil/potato	22.31
	Maize–rice–wheat	4	Banana garden	15.38
	Fallow–rice–mustard/lentil	2	Fallow–legume–fallow	15.38
Ghyalchok	vegetable–rice–vegetable	58.23	Maize/vegetable–vegetable/legume–fallow	38.35
	Maize–rice–fallow	16.8	Rice/vegetable–vegetable/legume–vegetable	21.80
	Vegetable–rice–fallow	10.6	Maize/vegetable–legume–wheat/vegetable	19.55
	Vegetable–vegetable–vegetable	8	Maize–millet/legume–fallow	12.03
	Maize/–rice–wheat	6.37	Rice/maize–legume/sesame–fallow	8.27
Ghanpokhara	Maize–rice–fallow	52.50	Maize–millet/legume–fallow	65.63
	Fallow–rice/millet–fallow	30.12	Maize–millet–fallow	15.63
	Maize–rice/millet–fallow	11.21	Maize/legume–mustard/potato–fallow	9.38
	Maize–rice/legume–fallow	4.05	Tea garden	6.25
	Maize–rice–potato/wheat	2.12	Maize–legume–vegetable	3.13

13.3.4 Determinants of Khet and Bari Land ALUI in Different Agroecological Region

The result of ANCOVA model for Khet land shows that five categorical variables and six co-variants are retained on the best ANCOVA model explaining about 80.7% of the total variation (Table 13.7). The ALUI of Khet land is significantly

Table 13.7 Results of ANOCOVA models showing the determinants of cropping intensity

Variables		Khet cropping intensity	Bari cropping intensity
Fixed factors		Coefficient (Std. Error)	Coefficient (Std. Error)
Intercept		3.754(0.519)***	3.072(0.247)***
Ethnicity	Dalit	0.264(0.166)	0.073(0.127)
	Janajati	0.288(0.155)*	0.041(0.12)
	Tharu	0.17(0.146)	−0.259(0.218)
	Brahmin	0.257(0.148)*	−0.16(0.127)
	Chhetri	0[a]	0[a]
Quality of land	High	1.036(0.433)**	0.478(0.114)***
	Medium	0.121(0.203)	0.205(0.086)**
	Low	0[a]	0[a]
Irrigation	No	–	−0.219(0.085)**
	Yes	–	0[a]
Tractor used	No	–	−0.219(0.096)**
	Yes	–	0[a]
Improved seed used	No	−0.18(0.093)**	−0.292(0.07)***
	Yes	0[a]	0[a]
Agricultural training	No	–	−0.14(0.094)
	Yes	–	0[a]
NF income source	No	0.195(0.127)	0.04(0.073)
	Yes	0[a]	0[a]
HH sex	Male	0.069(0.077)	0.01(0.081)
	Female	0[a]	0[a]
Covariates			
HH age (years)		0.005(0.003)*	−0.001(0.003)
HH education (years)		0.017(0.008)**	−0.017(0.008)**
Total Khet holding (ha)		−0.344(0.105)**	−0.117(0.095)
Home–market distance (km)		–	−0.019(0.006)***
Home–vehicle passable road (km)		−0.332(0.106)**	−0.099(0.028)***
Home–land distance (km)		−0.287(0.073)***	−0.666(0.094)***
Livestock holding		−0.008(0.01)	0.005(0.006)
Adjusted *R* square		0.807	0.586
Levene's test of homogeneity *F*(*P*)		1.208(0.297)	0.51(0.999)

[a] This parameter is set to zero because it is redundant
Significant at ***99%, **95% and * 90%

influenced by ethnicity, adoption of improved seed and quality of land. Similarly, ALUI of Khet land is positively associated with age and HH heads' education. In contrast, the ALUI of Khet land is negatively associated with 'total Khet holding,' 'home-to-road distance' and 'home-to-land distance.'

The result of ANCOVA model for Bari land shows that eight categorical variables and seven co-factors are retained on the best ANCOVA model which explained about 58.6% of the variation (Table 13.7). The results further indicate that 'quality of land,' 'availability of irrigation,' 'use of tractor' and 'adoption of improved seeds' significantly influence the ALUI in this type of land.

13.4 Discussion

Consistence with the national cropping intensity trend as shown by CBS (2011), this study indicates a gradual decline in cropping intensities with increasing elevation. The result shows that low-land Terai village has the highest average ALUI, which is reasonable considering its favorable land form, soil and climatic condition for intensive farming (Maskey et al. 2003). In addition, our focus group discussion and field observation found that there is access to irrigation facilities, modern agricultural inputs and market in Bachhauli. Mid-hill study area has second highest ALUI for both land categories. The main reason is increasing market-oriented vegetable farming in the recent years. Our discussion with villagers also found that increasing trend of growing unseasonal vegetable even in Bari land through developing piping water from local stream for irrigation has increased cropping frequency of the low land area. Moreover, located in an accessible distance from three main cities of Nepal, Kathmandu, Pokhara and Narayangadh, Ghyalchok has an easy access to market centers, which could have accelerated the intensive vegetable farming. As hypothesized, the lowest mean cropping frequency in both land types are observed in the high-hill study site, i.e., Ghanpokhara VDC. Since the VDC is located in steep mountain slope, topographical difficulties, and low quality of land, cold climate and lack of infrastructure might be the bottlenecks for higher cropping intensity in this VDC. Our discussion with farmers in Ghanpokhara revealed that there is increasing trend of out-migration of young generation which is creating a labor shortage which caused a gradual decline in ALUI. In addition, it was noted that Khet lands are very far away (down the hills) from farmers' home, which could be another reason for low cropping intensity in Ghanpokhara.

13.4.1 Determinants of ALUI

Based on the findings of the ANCOVA, the ALUI determinants (both categorical and quantitative) can be grouped into three groups: (a) significant determinants irrespective of land type, (b) ALUI determinants for Khet land only and (c) ALUI determinants for Bari land only.

13.4.1.1 ALUI Determinants for Both Khet and Bari Lands

It has been proven fact that farmers cultivate better quality of land more intensively because of potential higher benefits (Haiguang and Xiubin 2011). In this study also, high-quality lands are likely to have higher ALUI than low-quality land in both Khet land and Bari land, which is reasonable since farmers would prefer to grow more frequently in more productive land. An application of yield-increasing modern inputs such as improved seed, chemical fertilizers and pesticides increases ALUI (Lu et al. 2012; Raut et al. 2011; Saka et al. 2011). This study also found farmers who have adopted improved seeds are likely to have higher ALUI than who do not have access to such resources. Thus, Khet and Bari lands' cropping intensities share two categorical variables as determinants, i.e., 'quality of land' and 'adoption of improved seeds.'

In addition, farm-related factors and access to facilities such as distance of farmland from farmers home, road and market center impact ALUI (Mottet et al. 2006; Saka et al. 2011). This study showed that 'home-to-land distance' is negatively associated with ALUI in both Khet and Bari lands. The result indicates that farmers who have farmlands nearby their houses tend to have higher ALUI and it is understandable because longer distance from home to farm means more difficult to manage the land and protect crops from disturbance by wild and domestic animals. Similarly, the variable 'home-to-road distance' represents the access to transportation facilities which also has negative association with ALUI in both Khet and Bari lands in this study. The negative association of the ALUI with home-to-road distance is reasonable since higher distance from home to road is likely to increase the cost of production and transportation and reduce the farm gate price for surplus, making the frequent crop production less profitable, which discourages farmers to increase cropping intensity.

It is found that more educated household heads have higher access to technology, networking and have more knowledge on yield-increasing inputs which lead to intensive farming (Lu et al. 2012). Interestingly, we found the 'years of education of HH head' is positively associated with Khet ALUI but negatively with Bari ALUI. Higher level of education, on the one hand, improves the farmers' ability to grow more profitable crops, which may lead to higher cropping intensity; on the other hand, it also increases their access to alternative livelihood sources, which would reduce cropping intensity of the household. Here, the positive influence of education to Khet ALUI might be due to two simultaneous reasons, (a) higher educated farmers are more likely to adopt commercial agriculture, and (b) Khet land is more suitable for commercial agriculture than Bari land. Therefore, it seems that educated farmers prefer to intense cropping in Khet land even though they have to reduce cropping in Bari land. From the point of view of sustainable food security, this could be disturbing, because it shows a further shrinkage in agriculture lands and additional pressure on quality lands.

13.4.1.2 ALUI Determinants for Khet Land Solely

Three explanatory variables, ‘ethnicity,’ ‘age of HH head’ and ‘land holding size’ significantly influence only the Khet land ALUI. In Nepalese society, ethnicity used to play a deterministic role in livelihood preference, for example, Dalits for iron work, sewing and leather works, Chhetri for farming and warriors, and Brahmins for farming, priests (Aryal and Holden 2011). Their reminiscence of such traditions is still there, for example, the majority of Dalits still live on their traditional roles though some have changed to more business-oriented jobs and the Brahmins and Chhetri are engaged in farming. Regarding the influence of ethnicity on ALUI, our result slightly differs with the previous conclusion by Aryal and Holden (2011) which concluded that low castes tend to involve in higher cropping intensity, while our result showed that Brahmin and Janajati tend to adopt higher ALUI than the Tharu and Chhetri. It might be due to Dalit and Janajati have lower Khet holding than the Brahmin, Chhetri and Tharu communities. With less land area available, there is no alternative rather to increase cropping intensity.

Following the finding of Haiguang and Xiubin (2011), our result showed that ALUI of Khet land is positively associated with ‘age of HH head.’ It might be because older HH in Nepal generally are less educated and they have less access to non-farm employment comparing to younger HH. Thus, they spend more time on farming. In contrast, younger HHs are expected to be more educated who have more opportunities to involve in alternative sources of income such as migration, business and salaried works. In addition, less and less young people want to continually live on agriculture in Nepal but to find other jobs in national and international markets. The ALUI of Khet land is found to be negatively associated with ‘total land holding,’ suggesting that farmers who have smaller Khet holding are likely to grow crops more frequently than those who hold large lands. This could be because subsistence farmers have to grow the food required for the households from limited land areas, where the smaller the land size, farmers have to grow more crops to meet family needs. This result contradicts with the findings of Raut et al. (2011) who concluded that households with larger land holding size are more likely to adopt agricultural intensification.

13.4.1.3 ALUI Determinants for Bari Land Solely

For Bari lands, the effect of land quality, availability of irrigation, use of tractor and adoption of improved seeds on ALUI are significantly positive, whereas the effects of schooling years of household head, distances from home to land, home to market and home to motorable roads have negative effects. Labor input is important in subsistence farming system particularly in mid- and high-hill areas in Nepal because almost all agricultural activities (such as plowing, hoeing, planting and harvesting) are performed manually. However, shortage of agricultural labor force caused by increasing out-migration of rural youths has compelled farmers to prioritize their farming on the land with better quality. Therefore, the impact of labor reduction is obvious on low-quality Bari lands in mid- and high-hill study area. When farmers have access to tractor, they can cope with labor shortage. For this reason, 'use of tractor' is a major determinant to Bari land ALUI. The results from this study are aligned with the findings of Nepal and Thapa (2009) who also reported that agricultural mechanization facilitates the commercialization of agriculture with more intensive land use. The role of irrigation is vital in crop farming as it enables farmers to improve productivity and grow high-value crops (Alauddin and Quiggin 2008; Cassman and Pingali 1995). The result of this study has shown that farmers who have access to irrigation facility are likely to have higher Bari land ALUI than those who lack irrigation. It is logical because Bari land farming in the mid- and high-hill regions in Nepal mainly depends on rainfed irrigation in which two crops per year can be harvested at most. Therefore, irrigation is particularly important for Bari land to have higher cropping intensity. Finally, 'home-to-market' distance is also negatively associated with Bari land ALUI, which signifies that home-to-market distance is a proxy of marketing potentials of both outputs and inputs. Market demands and proximity to highway have facilitated market-oriented cash crops in mid-hill of Nepal (Brown and Shrestha 2000). Commercialization is easier in those areas closer to market centers, and a higher distance from home to market will increase the cost of products and transportation and reduce farm gate price.

13.4.2 Farming System and Risk to Soil Fertility

Soil fertility sustainability is essential for agriculture and land conservation. Among agricultural management practices, proper crop rotation and multiple cropping systems are major solutions to maintain soil fertility (Havlin et al. 1990) such as including nitrogen fixing crops like legume in the annual crop rotation (Yu et al. 2014). Though our result shows that multiple cropping with high diversities of crops and mixed cropping system are common in the study area, except some Bari lands in Ghyalchok, there is a lack of legumes planting. It indicates that Khet lands in low-land Terai and low land of mid-hills are at potential risks of soil nutrient depletion. Also, upland Bari in mid- and high hills is subject to soil erosion from frequent tillage under intensive cropping.

It has been proven that higher cropping intensity with excessive inorganic inputs and machineries would significantly increases crop yields and ecosystem productivity (Pretty et al. 2012; Tscharntke et al. 2012) but can be detrimental to soil fertility and agricultural ecosystem in the long run if sustainable strategies for water, tillage, nutrient, crop and soil management are not adopted (Reidsma et al. 2006; Schreier et al. 1994; Tiwari et al. 2008a; Westarp et al. 2004). This study has shown that low-land Terai VDC is experiencing high cropping intensity with high modern agricultural inputs (tractors, chemical fertilizers, pesticides and improved seeds), so as the mid-hill region (i.e., Ghyalchok). Such farming practices may create problems to the long-term sustainability of agricultural production, soil fertility and agricultural ecosystems in those areas and other areas with similar farming practices. Since this study found the lowest cropping intensity but highest average fallow land in high-hill VDC which indicates that there is increasing trend of agricultural land abandonment. This trend, further, may not be good for agricultural country like Nepal from both sustainable food production and land management perspectives.

13.5 Policy Implication

The results of this study have significant policy implications for sustainable agricultural land use in the study area and in other areas under similar biophysical and agroecological conditions. Considering the per capita land holding and crop yield, Nepal is already among the lowest in the world (World Bank 2016) and increasing cropping frequencies is the only pathway to improve food and income security in this country (Dahal et al. 2009). The findings of this study suggest that access to transportation, machineries, improved seeds, market and irrigation influence the cropping intensity. Although 20-year Agricultural Perspectives Plan (APP 1995–2015) of Nepal had emphasized for enhancing agricultural productivity through intensive use of farm land by developing irrigation, rural road, agricultural market and technical support in the remote areas (APP 1995). However, due to limited efforts for planning and implementation, it has been proven not very effective to achieve the objectives (Pyakuryal 2012). Therefore, government should come up with a solid policy that accomplishes planning into action for the development of targeted interventions that encourage higher cropping intensity.

This study further suggests that low land Terai has better access to irrigation, fertilizers, pesticides, seeds, markets and technologies and thus has intensive farming. Now the government policy should prioritize mid- and high-hill areas with more efforts and investment to improve such facilities wherever feasible. Extension of these facilities in mid- and high hill would encourage farmers to commercialize their products that could establish agriculture as a profitable occupation and can improve economic situation of farming households.

The lowest cropping intensity with highest average fallow land in high-hill area in the study indicates a low level of agriculture development in spite of long efforts of government such as APP Nepal. Recently endorsed Agriculture Development Strategy (ADS) 2015 also has addressed the same vision of APP focusing on productivity and profitable commercialization (MOAD 2015) which could be feasible for Terai and low lands of mid-hills which are closer to highway and market center but may not be effective for the high-hill area like Ghanpokhara. Considering the topographical difficulties to develop infrastructure, high production cost of cereal crops and increasing labor constraints, the government should focus on common crops or high-value crops that are appropriate to the landform and micro-climatic conditions with a solid land use plans in the high-hill area.

The existing models of agricultural land use that emphasize on higher farming frequency and commercialization of agriculture are clearly unsustainable because it not only demands higher external inputs but also makes soil more vulnerable to erosion following increased tillage operations. This study also suggests that farmlands in low land of Terai and mid-hills are more vulnerable to soil degradation due to higher cropping frequency with intensive tillage and use of chemical fertilizers, pesticides and lack of proper crop rotation. While current land use model focuses on intensification, sustainability also should be addressed, such as promoting conservation of agriculture production systems (i.e., integrated tillage management, residue/cover crop management, crop rotation and organic farming) in order to maintain sustainability of soil in those areas. Technologies such as sloping land management, micro-irrigation, agro-forestry and orchards plantation should be adapted for sustainable agriculture development in mid- and high-hill slope.

It is regarded that educated and trained farmers are more likely to adopt new agricultural and soil conservation technologies (Lu et al. 2012; Tiwari et al. 2008b), but this study found less educated, untrained and older farmers involved in higher cropping intensity. Therefore, government should recognize this issue and provide trainings to these farmers to increase awareness on soil and land management for agricultural sustainability in Nepal. Furthermore, effective agricultural policy and incentive programs attractive to young generations in farming occupation also should be developed.

13.6 Conclusion

This study has assessed the situation, variation and determinants of ALUI in three agroecological regions in Nepal. The results show great spatial variation of cropping intensity in the three regions with highest cropping frequencies in low-land Terai which owns better quality of land, access to infrastructures and technologies in compare with mid- and high hills. This study provides empirical evidence that land-specific factors, household and head's characteristics, infrastructure condition and agricultural technologies are the determining factors of ALUI in Nepal. Therefore, cropping frequencies can be increased even in mid- and high hills by developing infrastructures and technologies in the geographically feasible areas. Although intensification of agricultural land use can be a better option for Nepal to mitigate poverty and food insecurity, current trend of land use intensity and farming system portray challenges for sustainable agricultural production, soil fertility and agricultural ecosystem in the study areas and other areas with similar biophysical and agroecological condition in Nepal. Therefore, a carefully constructed agricultural policy with region-specific land management plan is essential for the sustainable agriculture land use in Nepal. Moreover, priority should be given to the programmes related to farmer education, trainings to create awareness on soil and land management practices such as annual crop rotation and other for the sustainable agricultural growth in Nepal. Further, effective agricultural policy and programs with new incentives (such as agricultural subsidies and insurances) that can attract young generation in farming occupation should be developed.

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Chapter 14
Livelihood and Land Use Pattern of Melamchi Basin in the Mountainous Areas of Central Development Region in Nepal

Yi Su, Wei Deng, Jifei Zhang, Shanta Paudel Khatiwada and Hriday Lal Koirala

Abstract Changes in household livelihood strategies have provided a new research perspective for land utilization changes. This research uses questionnaire surveys, semi-structured interviews, mathematical statistics and other research methods to conduct a systematic investigation of the households and land plots of four typical villages located in the Melamchi basin of the central mountainous areas in Nepal. The study also analyses the different types of households' livelihood strategies and land use patterns. The results show agriculture-dependent type and non-farming-dependent type are more efficient and livelihood diversity index is higher, so as a result there are relatively lower livelihood risks. Households' land area, cultivating land structure, labor input and land yield-increasing input are all different. Since different types of households' perceptions and strategies for livelihood improvement are present, their influences on land use are varied. Non-agricultural livelihood activities will not only reduce the vulnerability and risks of livelihood, but will also reduce the household's dependency degree and land reclamation ratio, which will promote a change of land ownership and land redistribution and improve agricultural production rate. Given the environmental features in the mountainous areas of Nepal and unfavorable factors hindering the improvement in households' livelihood, this paper comes up with feasible strategies for improving households' livelihood and promoting the sustainable utilization of land at both household and regional levels.

Keyword Land use · Rural areas · Households types · Mountainous areas · Nepal

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14.1 Introduction

In recent years, the households' livelihood issue has obtained considerable attention from the developing countries and respective regions (Block and Webb 2001; Bouahom et al. 2004). The relationship between households' livelihood strategies as well as their land utilization changes have also become a research focus (Barrow and Hicham 2000; Ellis and Mode 2003; Holden et al. 2004; Soini 2005; Gina and George 2005; McCusker and Carr 2006; Bradstock 2006). Moreover, the evolution of livelihood mode has gradually gained a fresh perspective for exploring land utilization at a microscale (Yan et al. 2005). As the most basic microeconomic unit of the rural areas, the household is acting as a decisive factor in the human–land micro-mechanism in rural areas (Lu 2006; Li 2009). And the households' production decisions will impact directly land utilization (Zhang et al. 2008). In other words, their improper land utilization mode is actually the major cause and direct cause for land degradation (Shuhao et al. 2001). For the vast number of developing countries that are under the dual stress of population expansion and economic poverty, households have to make their living by expanding farmland scale. Therefore, a large scale of forest lands is cultivated into farmland, which causes environmental degradation. As a consequence, the vicious circle theory is being generated, namely "population expansion-poverty-farmland expansion-land degradation-poverty" (Pender 1999; Shriar 2002). Livelihood diversity will drive and influence land utilization (Tittonell et al. 2010). Besides, non-agriculture livelihood activities will reduce poverty. Moreover, proper non-agricultural part-time jobs will help enhance land production (Xiang and Han 2005). All of the above methods will further reduce harmful land utilization such as deforestation and land reclamation and promote forest recovery (Walker et al. 2002; Read et al. 2003; Rudel et al. 2005; Hecht et al. 2006). These theories can be reflected and similar research can be done in other regions such as the Amazon basin, Indonesia, Cameroon Honduras and Tibet region of China (Evans et al. 2001; Ketterings et al. 1999; Mertens et al. 2000; Liu et al. 2008). However, certain scholars perceive that non-agriculture will lower down the human interference with the forest ecological system, which will have an adverse effect on maintaining environmental diversity and will probably hinder the forest recovery (Arroyo-Mora et al. 2005; Jacob et al. 2008). Besides, excessively increased non-agricultural part-time behaviors will reduce the land input, resulting in land fallow or extensive cultivation and decreasing of land utilization efficiency (Shuhao et al. 2001; Cai 2005). As indicated by McCusker et al., livelihood and land utilization are different reflections of the same social course. The latter authors have discussed the symbiotic relationship as well as the analysis framework between livelihood and land utilization changes. They have also expounded the relationship between livelihood and land utilization changes from the perspective development interference (McCusker and Carr 2006). Households' livelihood strategy changes have offered a new research perspective on land utilization changes. Future research should consider the relationship mentioned above along with the development of rural areas. Moreover, researchers should explore how to adjust households' livelihood strategy and how to properly utilize natural resources in order to achieve sustainable development of rural areas (Wang and Yang 2012).

Nepal is a typical agricultural country, which seated at the south slope of Himalaya. With complicated landforms, fragile ecological environment as well as limited environmental carrying capacity, Nepal also ranks as one of the most typical regions with contradictions between human and land. As a result, it is an excellent sample region for studying human–land relationship. Due to lower urbanization and industrialization, human interference with the ecological environment here is manifested mainly through households' land utilization behaviors. For the past 20 years, diversified livelihood and rising non-agricultural income have become an essential feature of the social–economic changes in the mountainous areas of Nepal (Blaikie and Coppard 1998). Given the transformation from agricultural labor to non-agricultural labor, there will be an inevitable impact on the amount of labor and working time as well as respective structural changes, land utilization types and cultivating modes (Thapa and Paudel 2002; Raut et al. 2010). Currently, most of the research on livelihood and land utilization conditions in the south-facing Himalayan slope region has focused on the influences of certain types of livelihood activities on land utilization. However, researchers have overlooked the variations in land utilization modes resulted from different combinations of livelihoods and livelihood strategies. Thus, for the ecologically fragile mountainous areas, this becomes a key issue as for how to optimize households' livelihood strategy in order to achieve proper land utilization and enhance sustainable development. Therefore, this paper provides a classification of the households based on their income combinations. Furthermore, it analyzes the livelihood strategies and land utilization mode for different types of households. The paper also explores their influences on land utilization through comparing their recognition and strategies for improving livelihood status. Based on the above, this research will suggest different options for properly utilizing land resources and improving households' livelihood abilities. The research will not only provide references for policy making regarding the sustainable development of the rural areas of Hindu Kush–Himalaya, but also will lay down the foundation for comparative study of households' livelihood and land utilization mode changes of both the south and north slopes of the Himalaya.

14.2 Research Area

Melamchi basin is located in the Sindhupalchok district of Bagmati zone, in the Central Development Region of Nepal (Fig. 14.1). Its southernmost point is 30 km away from the capital Kathmandu, at 27° 48′–28° 09′N and 85° 26′–85° 37′E. Originated from Jugal Himal Mountain, Melamchi river is composed of 14 branches with the highest altitude of 5875 m, total length of 41 km and drainage area of around 330 km^2, occupying the most important part of Koshi river. Melamchi basin spatial scope includes eight village development committees (VDC) from Sindhupalchok

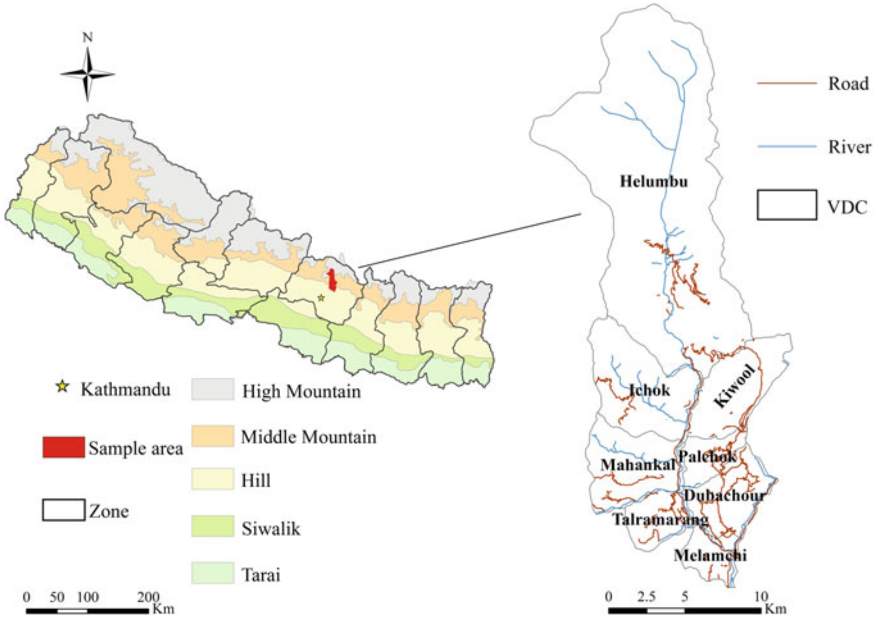


Fig. 14.1 Location of study area

district with population density of 165 people per km^2 (Khadka and Khanal 2008). This basin covers three types of mountain landforms (hill, middle mountain and high mountain) with distinct vertical differences and diversified ecosystems.

14.3 Data and Method

14.3.1 Investigation on Households

According to the landform features, this research selects four typical villages from the Melamchi basin as sample areas (Table 14.1), namely Melamchi, Dubachaur, Ichowk and Helambu. Using a random sampling method, it will abstract a certain number of households. The investigation is primarily based on participatory rural appraisal method with specific PRA tools including a questionnaire survey method, an observation method, a small scale of colloquia, an insider interview method etc. In addition, based on the preliminary research conducted in October 2014, field research was carried out in November 2014 with a total duration of 14 days and 2–3 h for each interview. A total number of 210 copies of questionnaires are distributed with 204 of them as valid. The efficiency rate is 97.14%. Among these, there are 50 copies for Melamchi, 51 copies for Dubachaur, 51 copies for Ichowk and 52 copies for Helambu.

Table 14.1 Topographic characteristics of sample villages

Sample villages	Altitude (m)	Relief amplitude (m)	Geomorphic
Melamchi	853	219	Valley area
Dubachaur	1550	237	Low mountain
Ichowk	2032	285	Middle mountain
Helambu	2561	361	High mountain

14.3.2 Classification of the Household Types

According to the agricultural degree and the variation of peasants' livelihood diversity, this paper has divided households' livelihood types into four groups based on input direction of family labor and family primary income ratio. These four groups are pure-agriculture, agriculture-dependent, non-agriculture-dependent and non-agriculture (Zhang et al. 2008; Yan et al. 2010). The main ideas of the detailed classification method are as follows: Firstly, based on whether there are non-agriculture activities in households' livelihood activities, households are divided into pure-agriculture households, part-time households and non-agriculture households. Secondly, according to the non-agriculture income ratio per total family income, households with ratio less than 60% are defined as agriculture-dependent households, those with ratio larger than 60% but less than 95% are defined as non-agriculture-dependent households and those with ratio larger than 95% are defined as non-agriculture households.

14.4 Result and Analysis

14.4.1 Types and Features of Households' Livelihood

As reflected in Fig. 14.2, agriculture-dependent and non-agriculture-dependent households are taking up the majority of the households among the research area. The non-agriculture-dependent type of households presents the highest ratio in Melamchi at the river valley and Helambu in the high mountainous areas. This is due to the fact that terrains in the valley are relatively flat, which facilitates transportation conditions in general and provides more non-agriculture employment opportunities. Thus, households here tend to belong to non-agriculture-dependent and non-agriculture types. On the other hand, high mountainous areas are limited in land resources, and therefore, households in these areas have to resort to non-agriculture activities. By contrast, Dubachaur and Ichowk take up primarily agricultural activities and households from the latter belong mainly to agriculture-dependent type accordingly.

The following observations are based on the features of different types of households (Table 14.2, Fig. 14.3). For the pure-agriculture type, educational level

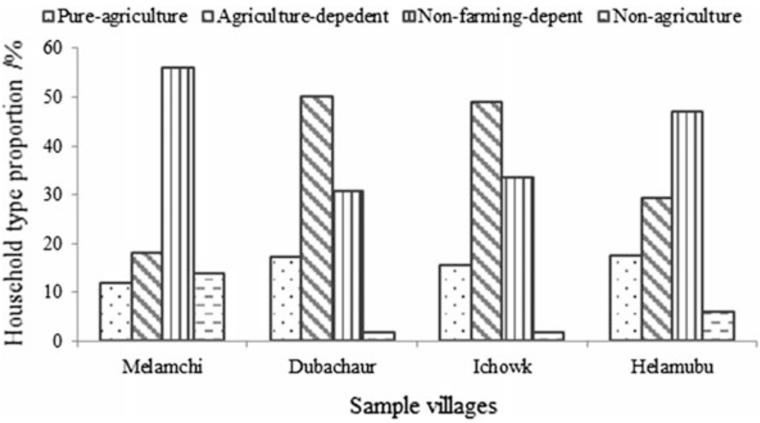


Fig. 14.2 Household types of sample villages in study area

is lower, illiteracy rate is higher and male labor source ratio is the lowest. Family scale is larger and age structure is younger for agriculture-dependent and non-agriculture-dependent types. Lastly, for non-agriculture type, their family scale is small with higher ratio of male labor and higher educational level.

14.4.2 Different Types of Households' Livelihood Strategies

14.4.2.1 Livelihood Combination Mode

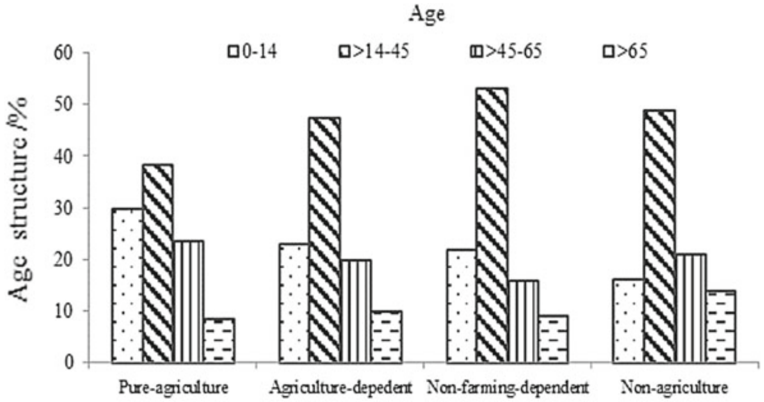
Livelihood strategies adopted by different types of households also vary from each other. This is strongly dependent on the combination ratio of agriculture activities and non-agriculture activities.

1. Pure-agriculture type. Households engage only in agricultural activities. The common livelihood combination mode is planting–breeding, and the major income source comes from selling crops and livestock. In recent years, since some public land resources and marginal land have gradually turned into forests, there are fewer and fewer land resources to breed livestock, which causes a drop in livestock production. To sum up, the livelihood strategy for this type of households is single and their living conditions are subject to multiple external factors and internal limitations. Hence, their livelihood risk is relatively higher. Factors like droughts and floods, livestock diseases and declining agricultural product prices will all increase the livelihood risks for this type of households.
2. Agriculture-dependent and non-farming-dependent types. Households are involved in both agricultural and non-agricultural activities. Agriculture-dependent type, on the one hand, is represented by agricultural helpers occupations and family sideline businesses as well as other activities

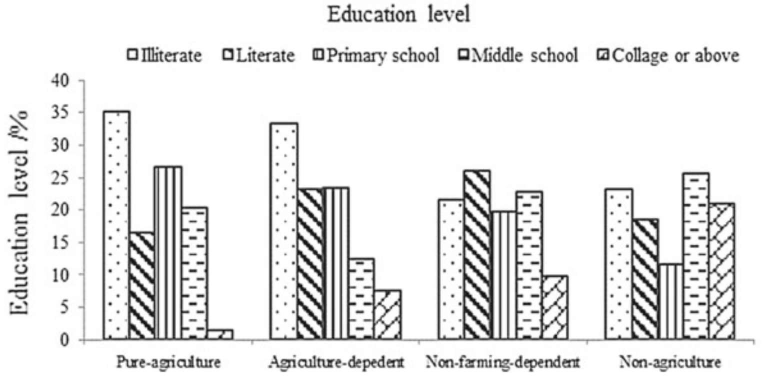
Table 14.2 Different households' composition and labor division

Type	People every household	Labor division							Sex proportion (%)	
		Farming	Out working	Trading	Salary working	Sideline	Student	Others	Male	Female
Pure-agriculture	4.00	2.09	0.00	0.00	0.00	0.00	1.25	0.66	46.09	53.91
Agriculture-dependent	4.73	2.43	0.19	0.11	0.20	0.08	1.12	0.60	48.47	51.53
Non-farming-dependent	4.32	1.59	0.22	0.54	0.12	0.05	1.26	0.54	49.73	50.27
Non-agriculture	3.33	0.58	0.17	1.08	0.25	0.00	0.83	0.42	52.17	47.83

Note Compared with out working, salary working only indicates working in government department (e.g., village administration, school and post office) with formal position and stable wage income; others include the elderly and young children



a. Age structure



b. Education level

Fig. 14.3 Different households' age structure and education level, **a** age structure, **b** education level

which require lower skills and no capital input. On the other hand, non-agriculture-dependent type is more diversified and people make their living mostly through house rentals and tourism related and other businesses. For these two types of households, in addition to the agricultural income there is also a non-agriculture income as a supplement. Thus, livelihood risks are relatively lower.

3. Non-agricultural type. Households never or seldom pick up agricultural activities. They are mainly engaged in non-agriculture activities such as operating a business or working in the tourism sector. Their income is usually higher than that of other types of households. However, subject to the impact of national political conditions and market fluctuations, they also face certain livelihood risks and uncertainty for the future.

Table 14.3 Different households' livelihoods diversity index of sample villages

Sample villages	Pure-agriculture	Agriculture-dependent	Non-farming-dependent	Non-agriculture	Average
Melamchi	1.83	3.58	3.49	1.58	3.04
Dubachaur	2.00	3.27	3.22	2.00	3.01
Ichowk	2.00	3.36	2.94	2.00	2.98
Helambu	1.56	3.40	2.88	2.00	2.75

14.4.2.2 Livelihood Diversity

Livelihood diversity acts as an essential method for reducing livelihood risks and for resolving poverty (Blaikie and Coppard 1998). This paper looks at the livelihood activity types of each household family as the diversity index. Namely, it assigns each type of livelihood activity of the households as "1." Then, it further generates the livelihoods diversity index for different altitudes and different types of households (Table 14.3). Hereby, agriculture-dependent type households of the Melamchi from the river valley regions have the highest livelihoods diversity index with an average value of 3.58; whereas, pure-agriculture type households of Helambu in the high mountainous areas possess the lowest livelihoods diversity index, an average of 1.56. As far as the households are concerned, the livelihood diversity index is the largest for the agriculture-dependent households, followed by the non-farming-dependent type, the pure-agriculture type and the non-agriculture type has the lowest value. Moreover, the households' livelihood diversity index shows a descending tendency with the increase in altitude. Due to the constraints from external restriction and internal limitations, the livelihoods diversity index for pure-agriculture and non-agriculture types is relatively lower and as a result, livelihood risks are higher.

14.4.3 Land Utilization Mode for Households Under Different Livelihood Types

14.4.3.1 Land Ownership and Renting Conditions

With land as the important resource for households' livelihood, land utilization structure acts as an essential indicator for reflecting both the households' livelihood strategy and the income level (Blaikie and Coppard 1998). As presented in Table 14.4, land resources in the river valley regions are relatively abundant, with cultivation land coverage per capita and per family all higher than that of the other three villages. However, lands are scattered and mostly rented to households living in the middle and high mountainous areas. As a result, tenants have to cross long distances to the rented land, which has increased the cultivating radius. Based on

Table 14.4 Different households' land allocation and land tenancy of sample villages

Sample villages	Type	Number of parcels	Area of farming land (hm^2)		Area of rented land (hm^2)		Area of abandonment (hm^2)
			Average area of household	Average area of farmer	Rented in	Rented out	
Melamchi	Pure-agriculture	2.67	0.66	0.15	0	0.17	0.08
	Agriculture-dependent	3.33	0.77	0.12	0.01	0.16	0.04
	Non-farming-dependent	2.54	0.51	0.11	0.01	0.16	0.03
	Non-agriculture	0.29	0.04	0.01	0	0.08	0
Dubachaur	Pure-agriculture	2.00	0.47	0.10	0.05	0.06	0
	Agriculture-dependent	2.27	0.68	0.14	0.12	0.01	0
	Non-farming-dependent	2.24	0.42	0.09	0.07	0.17	0
	Non-agriculture	0	0	0	0	0	0
Ichowk	Pure-agriculture	2.38	0.43	0.10	0.14	0	0
	Agriculture-dependent	2.60	0.63	0.13	0.07	0.05	0.01
	Non-farming-dependent	2.47	0.41	0.09	0.04	0.04	0.03
	Non-agriculture	0	0	0	0	0.20	0
Helambu	Pure-agriculture	2.44	0.35	0.12	0.06	0.14	0.04
	Agriculture-dependent	2.08	0.47	0.12	0.05	0.03	0.09
	Non-farming-dependent	2.07	0.33	0.07	0.02	0.25	0.10
	Non-agriculture	1.00	0.08	0.03	0	0.05	0.07

the household types, land coverage per capita and per family can be basically ranked as agriculture-dependent, pure-agriculture, non-farming-dependent and non-agriculture. Hereby, agriculture-dependent households rent the largest area of land. Due to the larger number of family members and less non-agricultural income, these households have to resort to an increasing planting income in order to maintain their standard of living. On the other hand, non-agriculture households have higher income but lack sufficient labor force and, thus, choose to rent their lands out.

14.4.3.2 Land Utilization Structure

In terms of the land utilization structure, cereal crops planted in the research areas are represented mainly by rice, wheat, maize, millet, buckwheat and barley with rice, wheat and maize being the primary cereal crops. In addition to non-agriculture households, all the other three types of households occupy a high percentage of cereal crops planting. Among these, the pure-agriculture households possess the highest cereal crops diversity index; and the agriculture-dependent households occupy the largest planting coverage. On the other hand, cash crops in the research area include fruit, vegetables, beans, cardamom and coffee. As reflected in Table 14.5, the proportion of households, diversity index and coverage for planting economic crops are relatively low. Based on the household types, agriculture-dependent households present higher percentage and the largest planting coverage by comparison. However, cash crops diversity index of agriculture-dependent households is lower than that of the pure-agriculture type households. This is because agriculture-dependent households have a larger land coverage with sufficient labor force, and they are able to plant a large scale of cash crops for sale purposes. By contrast, pure-agriculture households' cash crops coverage is smaller and is mostly for personal use.

Table 14.5 Different households' land use structure

Household types	Proportion of farmers (%)		Diversity index		Cultivated area (hm^2)	
	Cereal food	Cash crop	Cereal food	Cash crop	Cereal food	Cash crop
Pure-agriculture	100.00	51.74	3.98	0.83	0.40	0.08
Agriculture-dependent	100.00	53.18	3.92	0.79	0.49	0.15
Non-farming-dependent	97.64	36.76	3.22	0.44	0.35	0.06
Non-agriculture	36.90	7.14	0.52	0.07	0.03	0.001

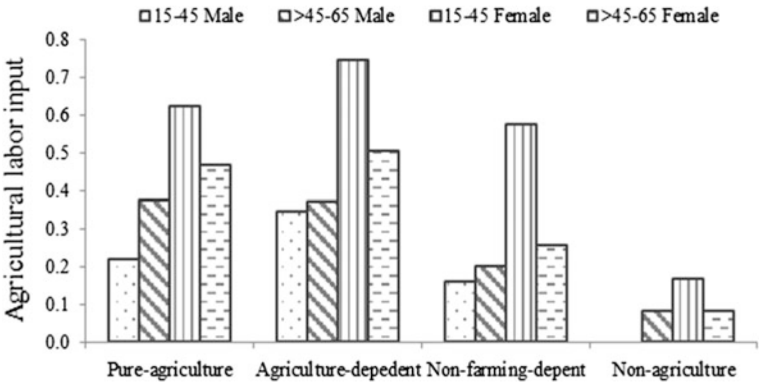


Fig. 14.4 Different households' labor input for different gender and different age groups

14.4.3.3 Labor Input Arrangement

Regarding agricultural labor input (Fig. 14.4), women and old people are the major participants in agricultural activities; whereas, young male laborers with higher educational level are mostly involved in non-agricultural activities in order to obtain a more significant compensation. Among them, labor input for pure-agriculture and agriculture-dependent type are with a higher male ratio. There are less laborers for the non-farming-dependent and non-agriculture labor input, and most of laborers are female. Moreover, for non-agriculture households, there are no young male laborers involved in agricultural activities.

14.4.3.4 Land Yield-Increasing Input

For different types of households in different regions, the fertilizers and land yield-increasing input (seedlings and fertilizer applied) also vary from each other (Table 14.6). Spatially, households from the river valley areas are using a higher percentage of fertilizers, and this percentage declines with the rise of altitude. The percentage of households using fertilizers in the Helambu village of high mountainous areas is distributed among the different types of households as follows, starting from highest to lowest: non-farming-dependent type > pure-agriculture type > agriculture-dependent type; while that of the other three sample villages show a different sequence: agriculture-dependent type > pure-agriculture-dependent type > non-farming-dependent type. Such phenomenon can be explained with the poorer land quality and limited resources in high mountainous areas, thus non-agriculture households rely on applying higher amounts of fertilizers in order to increase crops yield. With regard to the land yield-increasing input for unit area of land, non-farming-dependent households' input occupies the largest percentage. This is because non-farming-dependent households' income level is

Table 14.6 Different households' fertilizer and yield-increasing input

Household types	Proportion of households using fertilizer (%)				Yield-increasing input (NPR/hm^2)
	Melamchi	Dubachaur	Ichowk	Helambu	
Pure-agriculture	71.43	33.33	37.50	22.22	30,123
Agriculture-dependent	90.00	42.31	40.00	20.00	29,680
Non-farming-dependent	57.14	31.25	29.41	25.00	37,731
Non-agriculture	0	0	0	0	10,778

Note % is proportion of households; NPR is monetary unit of Nepal, 1 dollar ≈ 100 NPR

relatively higher and they do not have sufficient laborers to engage in agricultural activities. Therefore, they attempt to increase crops yield through increasing agricultural input. In addition, as perceived from interviews with the farmers, due to the declining amount of livestock in recent years, the amount of farmyard manure is decreasing as well, which causes a rising trend in the fertilizer usage.

14.4.4 Livelihood Improvement Strategies Adopted by Different Types of Households

Different livelihood improvement strategies adopted by different types of households (Table 14.7) influence land in various ways. Specifically speaking, (1) pure-agriculture and agriculture-dependent types of households have a relatively low educational degree, lack in specific skills and techniques, are at an older age and have insufficient capital to take up on non-agricultural activities. As a result, most of them expect to increase their income by planting crops with high economic value and by raising livestock. Land is still the most essential livelihood capital. However, cash crops will not only increase households' income level, reduce livelihood risks but will also increase land utilization diversity, optimize planting structure and enhance land utilization rate. In addition, the rising number of livestock will provide large amount of farmyard manure. Thus, it could replace the chemical fertilizers and reduce the capital input to some extent, which will effectively decrease land degradation and improve land quality. (2) Non-farming-dependent and non-agriculture types of households: On the one hand, they expect to increase their livelihood income by planting crops with high economic value; on the other hand, they hope to enhance their non-agricultural income through expanding their business scale and working in a field different from agriculture. Moreover, there is a small number of non-agriculture households who prefer to purchase land in order to reduce their insecurity resulted from lack of land. Non-agriculture activities are the main focus with the planting and breeding industry being the supplementary form of income. This mode will achieve a virtuous circle internally within the family. As indicated by the farmers during the interview process, agricultural income is exerting smaller influences on the

Table 14.7 Different households' strategies of livelihood improvement

Household types	Livelihood pressure		Strategies of livelihood improvement		Helps needed of livelihood improvement	
	Type	Proportion of households (%)	Type	Proportion of households (%)	Type	Proportion of households (%)
Pure-agriculture	Lack of capital	88	Improve farming technology	47	Construct irrigation facilities	100
	Poor irrigation conditions	100	Plant cash crops	41	Provide technical guidance on planting and breeding	66
	No culture and technology	91	Develop livestock breeding	25	Provide local employment	44
	–	–	Find a part-time job	19	Provide skills training	59
	–	–	–	–	Build new roads	33
Agriculture-dependent	Poor irrigation conditions	100	Improve farming technology	65	Construct irrigation facilities	93
	Low returns on agriculture	45	Plant cash crops	53	Provide technical guidance on planting and breeding	67
	Low wages	14	Develop livestock breeding	7	Provide local employment	50
	No culture and technology	76	Find a part-time job	20	Provide skills training	78
	Lack of employment opportunities	45	–	–	Build new roads	35

(continued)

Table 14.7 (continued)

Household types	Livelihood pressure		Strategies of livelihood improvement		Helps needed of livelihood improvement	
	Type	Proportion of households (%)	Type	Proportion of households (%)	Type	Proportion of households (%)
Non-farming-dependent	No convenient traffic	74	Plant cash crops	12	Provide local employment	41
	High interest on loans	60	Find a part-time job	38	Provide discount or low-interest loans	23
	Lack of employment opportunities	69	Expand business	34	Provide skills training	29
	–	–	Operate sideline production	26	Build new roads	65
Non-agriculture	Lack of land	42	Buy land	25	Provide local employment	58
	High interest on loans	58	Find a part-time job	42	Provide discounts or low-interest loans	33
	Lack of employment opportunities	67	Expand business	58	Provide skills training	42

livelihood and its degree of reliance on land is declining as well. With the non-agriculture support, households will not only buy livestock to replace labor input, but can also purchase seedlings and fertilizers to increase the yield input, in order to improve the planting structure. The most urgent assistance farmers need includes: constructing irrigation facilities, increasing agricultural yield-increasing input, providing guidance on breeding technology, offering technical training, increasing local employment opportunities, providing interest subsidy or land with lower interest, and building up roads and additional infrastructure by the government. This means that farmers are more inclined to increase land output through increasing agriculture technology, which will reduce the land cultivation rate to a certain degree.

14.5 Discussions and Conclusions

14.5.1 Discussion

Non-agriculture activities have become a crucial component for the households' livelihood strategy. The increase in non-agriculture income has not only reduced the livelihood frangibility and livelihood risks, but has also brought down households' dependency on land and lowered down the land cultivation rate. Besides, the author has discovered during the investigation that marginal lands are transferring into forests. Meanwhile, the increase in non-agriculture income has also accelerated land ownership changes. Nepal implements a policy of private land ownership and the majority of the lands are concentrated in the hands of a small group of landlords. Even though the government of Nepal has conducted a series of reformations in the past decades, the phenomenon of highly centralized land has not altered in essence (Joshi and Mason 2007). In recent years, since non-agricultural activities' income has far exceeded that of the agricultural income and agricultural income lacks stability, many landowners have sold their land to farmers in need. 5.4% of the farmers who have been investigated do not have their own land. Therefore, non-agricultural income has promoted the reassignment of land to some extent, which has also shrunk the classic differences and narrowed the wealth gap. Moreover, since the land ownership belongs to the farmers themselves, their production initiatives will be considerably enhanced and this will enable the planting structure optimization accordingly. Furthermore, some of the farmers who have been interviewed have noted that their land yield-increasing input is gradually going up, and this is especially valid for non-agriculture households.

It is worth mentioning that during the labor transformation to non-agriculture employment, women and old people in the research area represent the core labor force. The lack of sufficient labor force has directly caused the increase in fertilizer input. The well-cultivated mode has gradually fainted, which has intensified land quality degradation and environmental pollution risks in the fragile mountainous areas.

Given the natural resources and environmental features in the mountainous areas of Nepal and the negative factors impacting households' livelihood status, this paper comes up with the following suggestions regarding livelihood optimization and sustainable utilization of land resources: (1) As far as the households are concerned, pure-agriculture and agriculture-dependent peasants should adjust their land utilization type and planting structure according to the market demand and land resources in the mountainous areas. They should improve planting technologies and land centralization degree. To achieve this, they may plant crops with higher economic value and greater market demand such as fruit, vegetables, coffee beans and cardamom. In addition, they should develop the combined agricultural mode of economic crops in order to increase agriculture diversity. Non-agriculture-dependent and non-agriculture households should expand income sources and channels in order to reduce their livelihood risks. (2) On a regional level, respective regions should deepen land policy reformation, accelerate land circulation and encourage households' initiatives. Besides, they should also improve households' educational attainment, properly adjust planting structure and enhance techniques based on the marketing demand. Furthermore, these regions should increase irrigation facilities, add agriculture productivity input and improve land production rate. They should also improve the local infrastructure, such as roads, provide loans with lower or no interests, increase non-agriculture employment opportunities and guide the surplus laborers to transfer to non-agriculture positions in a reasonable and orderly way, so as to reduce land pressure.

14.5.2 Conclusions

As indicated by this research focusing on typical villages in the Melamchi river basin in the mountainous areas of Central Development Region in Nepal, different types of households have manifested different features in terms of family scale, family members, labor allocation, age structure and educational level. Agriculture-dependent and non-farming-dependent households possess better livelihood strategy combinations, and their livelihood diversity indexes are higher with lower livelihood risks. In addition, various types of households also show distinct variances in terms of land ownership and renting, land utilization structure, labor input arrangement and land yield-increasing input. Moreover, different recognition and livelihood strategies adopted by households will also exert different impact on the land. The most desired types of assistance required for households include building up irrigation facilities, increasing agriculture land yield-increasing input, providing breeding technology, offering skills training and employment opportunities, providing interest subsidy or loans with lower interest and building roads. As a result, this could turn into an essential resolution for reducing the cultivating rate of this region. Non-agriculture livelihood activities have not only reduced livelihood fragility and livelihood risks, but also have reduced cultivation rate and households' dependency on the land. Hence, these livelihood activities have promoted a land ownership alteration and reallocation and have enhanced the production rate. At the same time, as a downside, such activities will intensify land quality degradation and increase pollution and environmental risks in the given areas.

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Chapter 15
Livelihood Diversification Amidst Shocks and Stresses in the Mountains in Nepal: Experiences from Villages of Mustang

Bhim Prasad Subedi

Abstract People's livelihoods in the villages of the mountain region of Nepal are based on agro-pastoral system, and such livelihoods are stressful. Most studies carried out on livelihoods in Nepal have analyzed the status of capital assets, but they have grossly overlooked the equally important aspect of shocks and stress on sustainable livelihoods. This paper highlights the diversification in the livelihoods of mountain people in the midst of consistent stresses and shocks that result from both natural and social factors plus familial incidents. The study is based on case material from two settlements namely Phalyak and Dhakarjong of Kagbeni VDC of Mustang district. Necessary socioeconomic data were collected from 50 households of the settlements. Apart from household surveys, information has been collected from key informant interviews, informal discussions and field observation carried out several times between 2013 and 2015. Findings suggest that households in these settlements amidst shocks and stresses have diversified their livelihood options from being primarily dominated by agriculture and livestock raising in the past to apple farming (cash income), vegetable farming, external migration and tourism based activities. Despite isolation in the past, people are now becoming more linked with external world through their changing economic efforts. As a result, their current livelihood pattern shows that they are not only aware of external world but that they are trying to strike a balance between continuation of customary livelihood and cashing the new opportunities generated by recent development adventures in the area.

Keywords Livelihood diversification · Shocks and stresses · Mustang · Mountain · Nepal · Bi-locality and multi-locality

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15.1 Contextualizing Social Landscape of the Study

Let me begin this chapter with recollection of my own childhood days in the remote hill village of far eastern Nepal. How the mountain people are perceived/received by the ordinary rural households of hills of Nepal is described by the two statements that follow.

The first statement:

"*Ghar nacchadnu. chakchak nagari basnu. natra Bhote aayera thulo jholama haalera laijala. Bhoteharu lek tirabata aaunchhan. Uniharu sanga thulo jhola lukai rakheko hunchha nee bakkhu bhitra*" (Do not leave home [while we are away in the field]. Be good or don't roam around unnecessarily. Otherwise *Bhot*e (the scary mountain man) will come and put you in his big bag and take you far away. He comes [is] from mountains (lek) and travels with his big bag which he hides inside his warm dress (known as *Bakkhu*).

This statement is a common cautionary note of parents (guardians) to their children while they go away to the distantly located farmland leaving their children at home. The statement was particularly of more relevance when the days were cloudy and visibility to the surrounding was poor due to fogs and that sounds of cicada (*jhyaun kiree*) prevailed from the jungle nearby. Adding fear to the children left behind, jackals entered the household premises for hunting domestic fowls in such weather conditions occasionally. Once in a while rumors would surface in the village that "this many" children had disappeared lately but no one would answer who those children were. I am one of the witnesses of this situation during my childhood days in my village in the far eastern hills of Nepal during early 1960s. Whether or not it was (is) a good or bad practice is a different story but for ordinary parents of farm households in the hills of Nepal this was (is) more of compulsion than anything else when specific farm activities needed to be carried out within particular days or weeks of the season. Furthermore, there arose a situation where every single able-bodied member of the household had to be involved in farm work and every hour counted.

The second statement:

"*Kasto bhotejasto! nuhaunu pardaina?, sapha sugghar hunu pardaina? paani chhuna katti gaharo lageko hera?*" (How dirty *like* a *Bhote*! Don't you need to take a bath? Don't you need to be neat and clean? What a shame! How scared are you of touching (using) water even if for your personal hygiene?)

These phrases are commonly used by parents and guardians at home and by teachers in the schools of the hills of Nepal when they find their children dirty and filthy and want them to pay attention to their personal hygiene. Here, the term *Bhote* is characterized as a person who does not regularly take bath and thus is dirty and smelly.

Both these above characterization may have provided negative image to the subject, perhaps unknowingly, failing to realize the compulsion of living in the freezing cold in the mountain and that taking bath is not as easy as in the hills where they have normal water. But for the young people in the hills, these statements are enough to give a special impression about mountain people and that they are different from the people in the hills. I had repeatedly heard these expressions during my childhood days in the village. These expressions are not uncommon in the rural hill villages today but also in many of the towns and cities in Nepal.

In my late childhood, when I began understanding things about the world outside my village by witnessing visitors and relatives, these expressions came true when mountain people visited our village as part of their voyage and the business. *Bhote*—generic term used for mountain people in the hills, used to come to the hill villages during winter to avoid severe cold in the mountain villages. They were seen to wear warm woolen blanket like cloths that looked dirty and a typical odor used to come from their dress and the body while encountered closely. They would have big bags or backpacks with them from where they would take out items of sale such as traditional herbal medicines, such as *pakhan ved* (*Berginia ciliate*), bikhamba (*Arisaema speciosum*), ordinary pins, safety pins, buttons, beads, sandalwood pieces, laha (glue sticks) and many other tiny but necessary items of household use. They used to sell such items by visiting village to village normally in cash but also in kind at times.

On the hindsight, I find these two sets of expression (to which I had been quite attached) very fascinating and relevant although not very reverent. These vernacular Nepali expressions provide enough background about mountain as *ecumene*, partial story of livelihoods there and more importantly, how mountain people have been perceived by the people in their neighboring regions. The overall environment has changed over time, and from contemporary perspective, those expressions may be attributed to poor understanding of the situation or else reflections of regional bias but with due respect to all those, this is still the common understanding of mountain and mountain people in the hills of Nepal. It is in this context that this paper examines the livelihood diversification in Mustang—a Trans-Himalayan area of Nepal, placing diversification as an ongoing part of life despite constant stresses and shocks and also reflect on the resilience in the livelihood pattern of mountain people.

15.2 Perspectives on Mountains

15.2.1 Mountains in the National Context

Nepal is popularly described as a mountainous country with three-fourth of its territory comprising of highland commonly referred as *pahad* (including hills and valleys) and *himal* (including high mountains and Trans-Himalayan valleys/areas). Nearly one-fourth of its territory is lowland commonly referred as the Tarai. The highlands are broadly categorized into two categories: the mountain with their elevation roughly above 3000 masl and the hills with their elevation less than 3000 masl. Even the hills of Nepal may be considered as mountain in the European context considering their high elevation. Politico-administratively Nepal is divided into 75 districts, and among them 16 districts belong to mountain, 39 to the hills and 20 districts to the Tarai. Nepal is a highland country in terms of its terrain condition, and it also used to be demographically dominated by people living in the highland until lately. However, the recent census figure has shown a slim numerical edge of lowland population over the highland population (CBS 2012). By 2011, of the total population, i.e., 26,494,504, the 55 highland districts shared 49.7% and 20 lowland (Tarai) districts shared 50.3%. In terms of territory, the highland districts share 77% of the nation's territory and in particular 16 mountain districts share 35%. Moreover, historical documents suggest that the highland areas especially the hills are the oldest settled areas in the country and thus many settlements in the hills fall among the oldest settled areas in South Asia (Poffenberger 1980). On the other hand, most of the lowland areas commonly known as Tarai/Madhesh are newly populated areas of the country.

15.2.2 Theoretical Perspectives

Discussion on mountain livelihood entails clarity on two theoretical and/or conceptual aspect. The first one is about mountain as such and its people, and the second one is about analytical framework of livelihood. Much is written about mountain, and there are a number of national and international organizations and institutions looking into various aspects of mountain ranging from physical, climatological, glaciological to integrated mountain development (e.g., ICIMOD). However, there is more to be known on what constitutes mountain and how mountains and mountain people are understood in the local and regional context. In most cases, understanding about mountain and mountain people is poor and incomplete. Mountain, especially the Himalayan mountain in Nepal, is generally understood as congregation of highly elevated landscape constituting snow covered ranges and peaks that function as barrier between Indo-Gangetic plain and the Tibetan plateau. In the text books of geography in Nepal, Himalayan ranges are interpreted as barriers to moisture laden summer winds blowing from Bay of Bengal resulting into monsoon rainfall in Nepal (e.g., Shrestha 1961).

Two dominant perspectives on mountains prevail in the development discourse in Nepal. One perspective is that of *mountains as physical barriers* and thus *obstacles to development*. In the early discourse of development, mountains are usually portrayed as impediment to the development because of difficult terrain conditions for inhabitation and accessibility. "*Pahad*" as it is the vernacular Nepali term for mountain in general (for high Mountain with snow cover, the term Himal is used), is also being used to mean something difficult to surmount in the local conversation when stated emphatically. One local saying common in Kathmandu valley goes as *Chandragiri nachadeko mancche ra bachha napayeko mahila* (man who has not climbed Chandragiri hill and woman who has not undergone labor pain meaning not given birth to a child). The reference to Chandragiri hill implies "difficulty in overcoming." Likewise, of all the pains in the life of a woman the labor pain is taken as the most intense. This way in the social landscape of Nepal the term mountain embodies something difficult. Specifying the characteristics of Nepalese mountain peaks in general and the Himalaya in particular (Gurung 1989) states excessive altitude, steep gradient, low air pressure, high isolation, poor soil, sparse population and immense diversity as elements of Nepalese mountains. Articles published in *the Himalayan Review* (annual publication of Nepal Geographical Society since 1968) on geographic foundations, landscape patterns and physical aspect of geography of Nepal discuss the altitudinal diversity in the country and terrain conditions in the mountain areas (Burathokey 1968; Gurung 1968, 1971). Directly or indirectly the message conveyed is that mountains are difficult places to live, move and develop. These publications were meant to introduce geographic setting (rather physical geographic) of the country than initiating any debates on development or else. The country situation until the second half of twentieth century was such that farming or agriculture was the main economic activity and thus an issue of discussion in planning, development and academia. Consequently, mountain areas or the highlands were less favored for agriculture and from point of view of subsistence agriculture-based livelihood, mountain (and the hills) obtained negative scores than the lowlands.

The other perspective considers mountains as opportunities. This perspective takes the view that mountain areas have enormous potentials and that such areas should be considered positively in the development discourse. Undoubtedly, mountain areas are in relative isolation and are inaccessible but they have comparative advantage for mountaineering, trekking and wilderness adventure (see also Sharma 1998; Sharma 1995; Banskota and Sharma 1998). Mountain areas represent physiographic as well as cultural diversities, and one can and should take advantage for the overall development of the region and the country. This perspective has its link with development of tourism and hydropower as an important and emerging sector of economy in the country. Since mountain areas in Nepal ranging from Mahabharat *lekh* to the Himalayan ranges and peaks have potentials for attracting international as well as domestic tourists, providing services and facilities to them at the local level becomes imperative. This entails employment opportunities at the local level especially with respect to accommodation and services they require. It is true that mountain-specific potentials were there in Nepal all along but what is also true is that the overall country environment was not conducive earlier to realize or internalize these potentials. It is to be noted that it is only in 1955 (the coronation year of late King Mahendra) that tourist visas were issued and for the first time, hotel was opened. In addition, it was only in 1962 that counting of tourists was done recording a total of 6179 tourists that year (Stevens 1993).

These two perspectives may appear as mutually exclusive at the cursory level, but they are not. In reality, they deal with two aspects of mountain realities and reflect better understandings on various aspects of mountain and life in the mountains. In this context, this chapter argues that Nepalese mountain areas are relatively isolated but they are not totally uninhabited. Settlements have been developed in scattered pockets of suitable areas in the Nepalese mountains. People have lived in the mountains of Nepal for centuries. These people are resilient, and despite hardships of the terrain conditions and overall living environment, they have continued their livelihoods there in the mountain. Portrayal of mountains both as impediment to the development and as opportunities only is incomplete understandings. The case of Mustang reflects both the realities.

15.3 Data and Methods

15.3.1 *The Study Area*

Kagbeni village development committee (VDC) has been taken as case study VDC. Kagbeni is a strategic location in the Nepal Himalaya and is known as gateway to the north, especially Tibet, the Autonomous Region of China. This place is also notable for Hindu pilgrimage where pilgrims perform ritual in the name of deceased parents and ancestors with a belief that the deceased would go to heaven. In the meantime, the performers would also earn merit (*punya*). Administratively this place belongs to Mustang district, and Mustang is one of the 16 mountain districts of Nepal. Politico-administratively Nepal has 75 districts, and geographically there are three ecological zones—mountain, hill and Tarai. Generally, 20 districts in the south are considered as part of Tarai ecological zone that stretches east–west. Likewise 39 districts in the middle are considered as hill districts, and remaining 16 districts constitute part of mountain ecological zone. Mustang enjoys its advantage as one of the most popular mountain district consisting of Thak khola area—a popular trade post on the way to Tibet during salt trade era. Mustang has also obtained its reputation due to the location of Muktinath temple, one of the most revered deity of Hindus. In addition, Mustang in general and the study VDC in particular is now part of popular Annapurna Circuit Trek and is modestly accessible compared with many other mountain districts in the mid-west and far-west Nepal.

Figure 15.1 shows the location of study area. In particular, information for this study has been collected from two villages of Kagbeni VDC, namely Dhakarjong and Phalyak. These two are the main settlements of the VDC, and politico-administratively they form four out of nine wards of Kagbeni VDC. Dhakarjong belongs to wards 2 and 3 and Phalyak to wards 4 and 5. According to National Population and Housing Census 2011, there were 274 households and population of 937 in Kagbeni VDC (CBS 2012). Among total population, female constituted 50.8% and male 49.2%. According to the same source, Dhakarjong had 42 households and 126 population, and Phalyak had 54 households and 185 population. In total, these two villages represented 33.2% of the total VDC population. As the terrain conditions in the mountains are mostly uninhabitable, settlements in general in mountain areas such as these represent selected pocket areas amidst vast uninhabitable areas of the district. These two settlements are located at an elevation between 3000 and 3225 masl. They are located within a walking distance of about

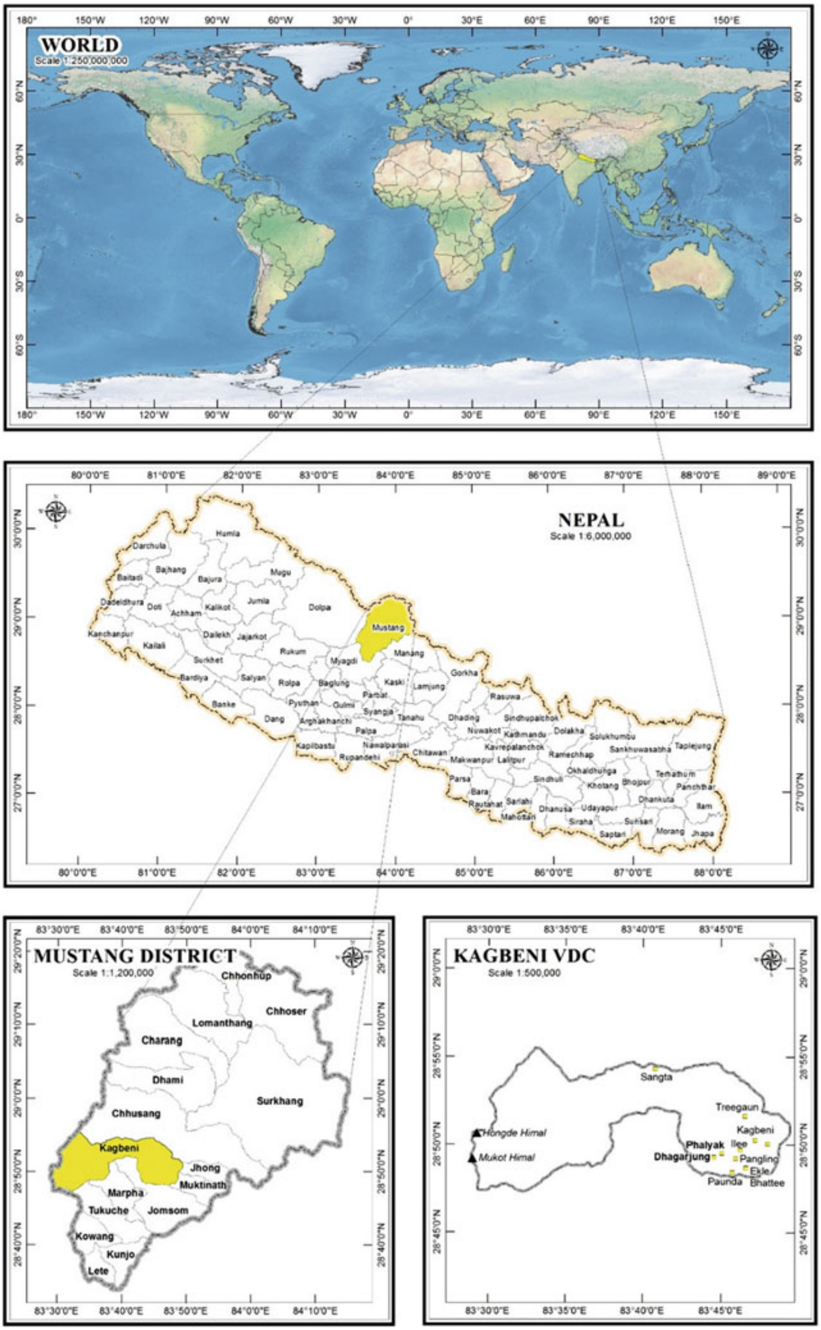

Fig. 15.1 Situating Kagbeni (study area) in the map of district, the country and the world

an hour from each other. The residents belong to same ethnicity, i.e., Gurung. Notwithstanding the settlement identity, these two villages share common socioeconomic and cultural characteristics and a canal for irrigation of their cultivated land. As a result, these two settlements can be considered together as single unit for analytical purposes.

15.3.2 Sources of Data

Four main sources of data used in this study are: (i) household survey, (ii) key informant interviews, (iii) field observations, and (iv) informal discussions with the local residents. Household survey was carried out with a total of 50 households in these two settlements. Among them, 30 households were from Dhakarjong and 20 from Phalyak.[1] This figure represents 52.1% of the total households in two villages. Much of the household selection for survey depended upon availability of household head and/or informed member in the household given the high mobility household members and the seasonality of stay of other members in the villages. The household survey form included information on demographic, socioeconomic and migration status of the household. It also collected information on engagement of household members in farming and nonfarming activities, changes in cultivation pattern, farm inputs, labor availability, and introduction of new crops and irrigation practices.

The key informant interviews focused on their perceptions of stresses and shocks, their views on changing livelihood patterns and the diversification among members of the household and in the villages. A total of six key informants including local elderly persons and former *Mukhiya,* i.e., the Headman were interviewed in the villages. In addition, the VDC official (Secretary) and the school teacher were interviewed separately in the village, while at Jomsom—the District headquarters, the Local Development Officer (LDO) and his assistants were interviewed about their knowledge of study villages and their people.

The household survey was carried out in 2014 while other field activities were carried out during several visits of the study area and its vicinity between 2013 and 2015. The field observations proved helpful especially in understanding the changing cropping pattern, multi-local residence and labor management support system in the households. The informal discussions took place in the mornings and evenings while taking meals, tea and light snacks. Such informal discussions also

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[1] Household survey information used in this study was collected as part of a broader study of climate change under Mountain EVO Project where many other field instruments were used to collect information on various other aspects in the district. I am thankful to the Project team and in particular to Mr. Jagat K. Bhusal, Chairperson of SOHAM and his Colleagues in Nepal and to Dr. Prem Sagar Chapagain for allowing me to use household survey information and some photographs. The author was also associated with the Project as one of the members of the Advisory Team.

took place when the study team was joined by local household members in the observation of farms and irrigation regulatory arrangements.

15.3.2.1 Data Analysis

Household survey data have been analyzed primarily focusing on two aspects, namely socio-demographics and livelihood aspects. The data obtained from key informants and informal interviews have been recorded during the field survey. Field notes were kept to the extent possible to record field observations, key statements of informants related to study themes. Observations, supported by some photographs, key statements during informal talks have been summarized for their essence and meanings to understanding livelihood aspect in the villages. During analysis and interpretation, such information has been drawn from the field notes, either in the form of excerpts or as short statements, to establish the facts and/or to substantiate findings from household surveys and other sources.

It has been a common practice to use sustainable livelihood framework (see, Chambers and Conway 1991) while analyzing any livelihood-related issue in Nepal. Subsequently there is a common tendency to emphasize the importance of household capital assets in the analysis. However, the vulnerability context as examined through stresses and shocks has been rather overlooked in most of the livelihood analyses in Nepal (Subedi et al. 2007; Suwal 2016). This chapter recognizes the components of sustainable livelihood frameworks, but given the neglect of vulnerability context in the earlier analyses, it attempts to pay a little more attention on this vulnerable aspect of mountain people in the following analysis.

15.4 Livelihoods in the Mountain Areas of Mustang

15.4.1 Mustang in the Map of Nepal

Mustang occupies an area of 3573 km^2 which constitutes 2.4% of total territory of Nepal. It is the fifth largest district of the country with respect to territorial size. On the contrary, with a total district population of 13,452 in 2011 and the population density of 4 persons/km^2, it ranked 74th in both the indicators. Its elevation ranges from 2000 to 8168 masl. The entire area lies on the rain shadow of Annapurna, Dhaulagiri and Nilgiri range of the main Himalaya and thus forms part of Trans-Himalayan zone in Nepal. It is bordered with China (Tibet) on the north and is drained by Kali Gandaki River and its tributaries. Mustang also enjoys its popularity as having world's deepest gorge over Kali Gandaki River between Annapurna and Dhaulagiri range. Popularly known as An-Dha gorge, it is located close to Dana village.

Mustang area is culturally divided into four divisions, namely (from north to south)—*Lho chhyo dhuin, Baragaon, Panchgaon,* and *Thak satsae khola*. The people of Lho chyyo dhuin area are known as Loba. Lho-manthan, probably the only surviving walled city like settlement in the Nepal Himalaya is part of Lho chhyo dhuin. The second division, i.e., Baragaon literally translates as 12 settlements and/or villages. Currently there are 18 settlements in Baragaon and politically they are organized into 4 VDCs and Kagbeni, the present study area, is one of them. Lho chhyo dhuin and Baragaon are very close culturally. Although southern hill residents referring them as Loba or "Bhote" (a generic term for all high altitude residents), they are found to use three surnames—Bista, Gurung, and Thakuri. Among Kagbeni residents, Gurung is the most common surname used in official documents. Kagbeni, Dhakarjong, Phalyak, Pakling, and Tiri are main settlements of Kagbeni VDC. Kagbeni is considered as gateway to upper Mustang and Tibet. Muktinath temple, one of the four main pilgrimage sites of Hindus, is located in Baragaon area. The temple and its associated structures including *akhanda jyoti* (uninterrupted eternal flame) attract both the Hindus and Buddhist pilgrims. The third division is *Panchgaon,* and it literally translates as five villages. Jomsom and Marpha are part of Panchgaon, and Thakali is the dominant ethnic group in this area. *Thak satsae*, i.e., the fourth section, refers to traditionally known Thak khola area of 700 residents. This area functioned a *break of bulk point* for traders from south and the north (including Tibetan autonomous region) to exchange their items during salt trade era. Overall, the whole area of Mustang has remained culturally linked with Tibet (China) from its known history.

15.4.2 Land Use Pattern of the Study Area

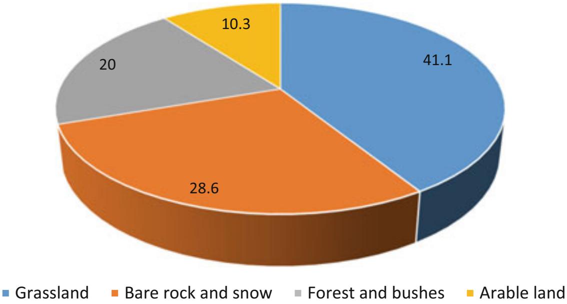
Figure 15.2 provides a glimpse of general landscape pattern of the study area. The landscape pattern is dominated by undulating terrains including mountain with bare rocks and snow, and plateau like sloppy terraces with human inhabitation and cultivation. Terraces with human inhabitation are primarily located on the southeast facing slopes of the mountain. This study area forms part of the Lumbuk khola watershed and is a sub-watershed of greater Kali Gandaki watershed area. This is a small watershed area and comprises a total area of 17.5 km^2.

The main land use/cover categories in this area include grassland, bare rock and snow, alpine forest and bushes and arable land. Of all the land cover/use categories, grass land occupies the largest proportion. Of the total area, it covers 41.1% (Fig. 15.3). Bare rock with occasional snow cover comprises the second largest category. A large part of land in this category is covered by snow during winter except steep slope. Alpine forest and bushes come out as the third important category. Arable land comprises only 10.3% of total area.

Of all the land categories, the arable land deserves special attention. *Bari* and *khet* are the common arable land classifications. *Bari* refers to nonirrigated upland and the area that is adjacent to the homestead. Likewise, *khet* refers to all terraced

Fig. 15.2 View of Dhakarjong village and its landscape pattern

Fig. 15.3 Land use/Cover pattern in the study area (in percent) (*Source* Satellite Image, 2014)



irrigated land. Normally khet is located at a distance from the residential area. As per the utilization of land by the households, there are three types of arable land—*bari*, *khet,* and *banjho* (fallow and/or abandoned land). In the case of Kagbeni, most of the current *bajho* land was part of cultivated land in the past. Of the total arable land, i.e., 1800 ha 51% was *bari*, 28% was *khet* and 21% was *banjho*. There are a few notable land use issues with respect to arable land in this area. First, all households have some amount of cultivated land and all of them are owner cultivator. Second, no tendency of horizontal expansion of cultivated land was noticed and thus, for many years the cultivated land had remained almost stable. Third, farmers reported a tendency of drying up of original water sources due to limited snowfall in recent decades. This has resulted in limited availability of water for irrigation. This meant a sizeable amount of *khet* had remained either fallow leading toward abandonment. The fact that 21% of arable had remained fallow or abandoned clearly justifies this. Fourth, many farmers were heading toward multiyear crops and crops that would need limited irrigation. Their motivation toward apple farming is one example.

15.4.3 Demographic and Socioeconomic Characteristics of Study Households

As noted above, the household survey covered 50 households from two settlements, namely Phalyak and Dhakarjong. The total population in the surveyed households was 290. The sex ratio was 110 males per 100 females. This is similar to the district situation with sex ratio of 111 but contrary to the national scenario of 94. The household size was 5.8 persons. This household size is larger than the national average of 4.9 persons and the district average of 4 persons according to 2011 population census of Nepal.

15.4.3.1 Age–Sex Distribution

Table 15.1 presents the population distribution by broad age groups. Of the total population, young population below 15 years of age constitute 14.2% only. In particular, children aged 0–4 years constitute 7.2% only. The sex ratio of young population is 141 boys per 100 girls. This means the young population is numerically male dominated. The proportion of economically active age population is 74.1%, and it is also highly male dominated. Likewise, the proportion of elderly population aged 60 years of age and over is about 12% and contrary to earlier groups, this group is numerically dominated by female. This proportion of aged population is quite high by national average where only 8% of population belonged to this age group at the national level. The overall dependency ratio is 35% which is far lower than the national average of 75%.

Demographically, this represents a special case of population in the mountain area. First, this is a mature population given that the proportion of young population is far lower and that of elderly population far higher by national standard. Second, this represents a situation of a far higher level of demographic dividend. Having almost three out of four populations in the economically active age group is a very positive situation for the development of a country if the state is able to utilize its enormous potentials. Third, this is a situation where the state can invest more on improving the quality of its population than investing on programs of reducing

Table 15.1 Population distribution by broad age groups

Age group		Both sexes	Male	Female	Sex ratio
Less than 15 years		14.2	8.3	5.9	141
15–59 years		74.1	39.3	34.8	113
60 years and above		11.7	4.8	6.9	70
Total	Percent	100	52.4	47.6	110
	Number	290	152	138	

Source Household Survey, 2014

fertility and mortality. Fourth, the proportion of children is exceptionally low by any demographic standard and that this represents a situation of negative population growth rate.

15.4.3.2 Literacy and Educational Attainment Status

Of the total population, 92.8% (269) was 6 years of age and over. Among them, males constituted 52.4% and females 47.6%. Overall, 29% population was illiterate and 71% literate. As elsewhere in the country, the illiteracy rate was far higher among females than males. For example, female illiteracy was as high as 36%. Gender gap in literacy was still high. Whereas only 64% females were literate, male literacy was 78%. This literacy rate in itself may not be considered satisfactory. However, these values are higher than the national averages (66%) for both male (75.2%) and female (57.4%) according to census results of Nepal 2011.

Table 15.2 shows the status of literacy and educational attainment among the study population. Among literates, one out of every five had not attended any formal educational institutions in their life course and most of them constituted senior and elderly population. A sizeable proportion (7%) had obtained *Lama* (Buddhism based learnings) education from *Gumba*. Largest proportion of literate population, i.e., about 37%, had formal education up to primary level. Likewise 20% had secondary level education, and those having SLC and higher education comprised 17%. In particular, the proportion having Bachelor and above education was nearly 7%. This proportion is far greater than the national average. At the national level, among literate population only 2.6% were graduates and post graduate (CBS 2012).

Gender dimension of educational attainment is interesting. Lama education was highly gendered. Among 14 adults in this category, 13 were males and one female. Of the rest, the distribution pattern of educational attainment was similar by levels and by sex. The male–female ratio was equal for those attaining up to primary levels. Among others, this ratio was marginally in favor of male, and there was no clear gap. An exception was those with SLC level where male–female ratio was as high as 3:1. This could be simply understood as the local elderly stated "*padheko*

Table 15.2 Status of literacy and educational attainment (6 years of age and over)

Description		Both sexes	Male	Female	M:F Ratio
Literacy status					
Illiterate		28.6	22.0	35.9	0.7:1
Literate		71.4	78.0	64.1	1.3:1
Total	Percent	100	100	100	NA
	Number	269	141	128	1.1:1
Educational attainment					
Literate only		19.3	20.0	18.3	1.5:1
Up to primary level		36.5	31.8	42.7	1.0:1
Secondary level		19.8	19.1	20.7	1.2:1
SLC only		2.1	2.7	1.2	3.0:1
Intermediate (10^{+2} Level)		7.8	7.3	8.5	1.1:1
Bachelor level		6.8	6.4	7.3	1.2:1
Master level		0.5	0.9	0.0	NA
Lama (religious)		7.3	11.8	1.2	13.0:1
Total	Percent	100	100	100	NA
	Number	192	110	82	1.3:1

Source Household Survey, 2014

ketiharu kina baschha ra gaonma" (translates as why would the educated girls stay in the village?), referring most girls who complete SLC either go out for work or go for higher education but hardly stay in the village. It is likely that there is status concern among educated girls to engage in farm work and the statement of elderly reflects this social reality of the village.

15.4.3.3 Occupation

Among those who stay there permanently, agriculture was the main occupation and all household heads reported it as their primary occupation. However, in their responses, two important dimensions were inherent. First, agriculture is the translation of Nepali term *khetipati* and it includes both the crop farming and livestock rearing. This meaning holds true in the hills of Nepal too, but the difference lies in the preeminence of the component. In the hills, crop farming overshadows livestock rearing but in the mountain areas such as in Mustang it is the other way around and either the share of crop farming and livestock rearing is equal or livestock rearing surpasses crop farming. Nevertheless, the commonly reared livestock in Kagbeni are goat/sheep, *jhopa* and cattle. Numerically, goat/sheep dominate. The average number of goat/sheep per household was reported to be between 30 and 35. Likewise, all households had one *jhopa* on an average. A few households reported to have domesticated cows. Second, majority households had their members engaged in nonagricultural activities. The per capita income from occupations other than agriculture was higher than regular income from agriculture. As one elderly lady (household head, aged 70 from Dhakarjong) noted "*when our people get employment outside the country they earn more but the tasks are difficult and there is no permanency of job.*"

Table 15.3 presents main occupation of the household members in Kagbeni (Dhakarjong and Phalyak). Almost three out of five household heads reported multiple occupations of their members. Apart from agriculture, other occupations included foreign employment, local wage labor employment, and trade/business. Before the fall of salt trade, some of them were engaged in this business and used to move between home and Tibet. After the end of salt trade in 1959, the pathway changed and instead, going to India and Southeast Asia became common with new items of petty trade and to new locations.

On the other hand, only 44% households reported they were dependent entirely on agriculture. Whereas many of them would leave the village for employment, there were also cases of outsiders working in the village as wage workers. Migrant workers are employed especially during harvesting time.

15.4.4 Livelihood Patterns with Stresses and Shocks

The overall livelihood pattern in the mountain areas is based on agro-pastoral system. Despite the reality of low production and food insufficiency for more than 6 months for an average households, mountain people report agriculture as their main occupation and thus the main livelihood option. As reported by the household heads, the average landholding size per household was between 16 and 18 *ropani.*[2] Largest proportion of households had less than 10 *ropani,* whereas about one-third of the household had more than 20 *ropani* of land. Wheat, naked barley, buckwheat, potato, oilseed (mustard) are the main crops. Maize is also grown, but its production as well as yield is very low. Vegetables including legumes are also grown in recent years. Apart from crop farming, Kagbeni people have long been engaged in livestock rearing, long distance trade, seasonal (winter) movement, and local petty business. Overall, compared with hill and the Tarai while crop yields and productions are limited here due to physical limitations, the livelihood options are also limited by the same token.

Viewed from the perspective of agro-based subsistence economy, living in the mountain areas is more challenging and stressful. Mountain people having agro-pastoral-based livelihoods are continuously under stresses. The stresses are more serious in comparison with hill people with similar livelihood pattern because agro-based options for the mountain people are more limited. However, most mountain people acknowledge the main stresses as routine features of living there. "*Hamro thaun yestai chha—bhiralo chha, kheti jamin thorai chha, kaile ali*

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[2] One *ropani* roughly equals 0.05 ha.

Table 15.3 Occupation of the household head

Type of occupation	Households engaged	
	Number	Percent
Agriculture only	22	44
Agriculture and employment outside the country	21	42
Agriculture and wage labor inside the country	4	8
Agriculture and business/trade	3	6
Total	50	100

Source Household Survey, 2014

phalchha kaile phaldaina, chiso chha ani hiun parchha, subidha chhaina" (this is the reality of our place—the terrain is sloppy, there is limited cultivated land, there is uncertainty of harvest, sometimes it [harvest] is ok other times it is not, it is cold and there is snowfall as well plus there are no "facilities") says the former *Mukiya* of the settlement (Field note, January 2014).

Figure 15.4 presents some of the main stresses and shocks that people of Mustang routinely face. As part of Himalayan country with subsistence economy and poor infrastructural development, most part of the mountain (including hill areas) have poor access to other areas. As a result, Mustang remained largely isolated territory until lately. The road (fair weather) link to Jomsom (the district headquarters) from Beni (Headquarters of adjacent district to the South) is as recent as less than 7 years. More importantly, fair weather road to Muktinath that passes through left bank of Kali Gandaki River is as recent as one year.

The harsh climatic condition is a common feature of high mountain areas, and the study villages in Mustang are no exceptions. It is always stressful to adapt to the cold weather especially when one has to carry out season-specific farm activities outside home. The snowfall, occasional windstorms and the threat of avalanche are always there to which one has to be prepared for several months of a year. While basic infrastructural and utility facilities are limited as a result of isolation, the existing facilities are also constrained by the severity of weather and climatic conditions. The risk of crops being damaged by frost and snow during spring and autumn exists. From the point of productivity, most of the land area used for farming is marginal. Soil depth is low, and the fertility is not good given that the parent materials are nutrient poor granite or gneiss. The high altitude and cold condition mean that planted crops take long duration to grow, mature and provide yield.

There is limited land suitable for cultivation in the study villages although the villages are located on relative level land from the perspective of mountain landscape in general. Terracing, fencing and terrace maintenance take long hours and more labor force compared with equal size of field in the hills. Due to cold climate, the growth rates of crops are slow and thus, chances of growing more crops in the same field in an annual cycle are limited. This also means that for farm households, the choices of crops for planting are very limited. For any crop planted, either farmers have to be convinced that it is resistant to the climatic adversities or it has to

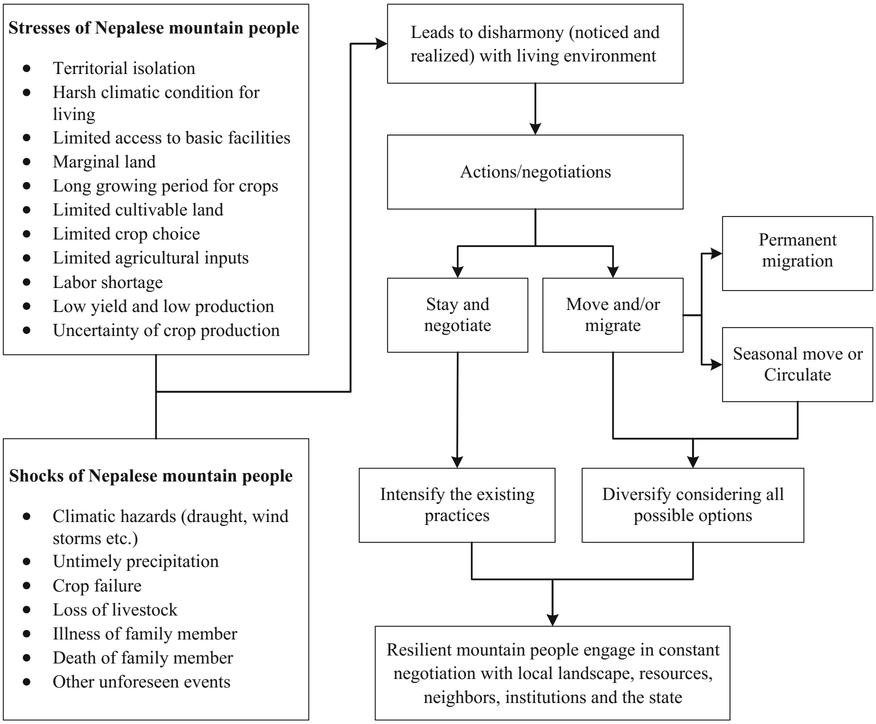

Fig. 15.4 Stresses and shocks among mountain people and their actions as resilient inhabitants

have long historical precedence. Farmers' tendency, as informed during field survey (2014–15), is that they tend to avert risk and not to take chance. "*Naya bali falena bhane kasle khana dinchha ra?*" (Who pays or who feeds us if the new crop fails) states one senior lady (aged 72) from Dhakarjong who has a family of eight persons. This has implications for livelihood security especially in case crop failure.

Because of the relative remoteness, agricultural markets are not always accessible and that necessary items (inputs) are not available on time. In addition, accessing to the agricultural inputs that are in short supply at the headquarters is also not easy. Labor shortages are becoming as perennial issue. Once Lhomanthang was linked with China (Tibet) through an extension of Chinese road inside Nepal about a decade ago, hardly any laborers come from northern Mustang for wage work there. This labor shortage was frequently reported by most of surveyed households in Phalyak and Dhakarjong who had sizeable amount of cultivable land. In this context, former Headman *(Mukhiya)* from Dhakarjong (January 27, 2014) remarks

> Getting agricultural laborers is very difficult now a days. Wage workers used to come from upper Mustang and Dolpa in early days. They do not come here for such works these days. With roads from Tibet (China) linking some of the interior part of mountain district, they

> carry out petty business and transportation of goods in the border areas. Now a days, we get limited number of wage workers from Myagdi and Dhading. For people from south it is not easy to come and stay in Mustang.

While uncertainty of crop production is always there, the low yield and low production mean further stress in maintaining livelihood security in the households. More worrisome is that most of these stresses are inherent part of the terrain conditions and high altitude for which there are very limited options at present except diversifying their livelihood pattern. Livelihood diversification is like compulsions in the mountain. Reflecting this Gurung (1989), although in a different context, wrote "mountains everywhere are marginal areas for human occupance. The mountain-dweller must remain mobile to survive: with livestock according to season for pastorage, travel where trade opportunity lies and engages in smuggling if on the border (p. 31)."

The shocks are even more worrisome, and mountain people are not prepared for coping with shocks. Occasionally villages suffer from climatic hazards such as draught, windstorms and associated damages. This is despite a common saying *Jomsom mathi asina aaudaina* (there is no hailstorm to the north of Jomsom). The untimely precipitation widely reported by almost all household heads in recent years comes as shock as the households are unprepared to respond or utilize it for their crop farming and livelihood maintenance purpose. For various mismatches in the production cycle, the households face unexpected crop failure, and this comes as shock in managing livelihood pattern.

Mountain people suffer from shocks from within the family as elsewhere. Family members get sick for days, and this illness brings not only loss of family labor but also cost for treatment plus compromise on supporting member's work efficiency. If the illness ends up with death, it leads to further worsening the household economy. As usual no family or household envisages immediate death of its member, and thus, no one is prepared for it, but it happens. All these shocks are not unique to mountain people, but the important distinction is that their impacts are far greater in that it takes a long duration to mitigate these household level impacts in the mountain environment.

The outcome of all these stresses and shocks means it creates a situation of disharmony of households with the living environment. Some of these disharmonies or tensions are perceived clearly and realized, but others are taken for granted. When such disharmonies are realized by the households or in other words, the stresses and shocks are such that the household feels the need of readjustment in their usual pattern of living, its members begin to negotiate over the existing and possible options. This negotiation process takes place under two fronts. First, they opt for searching ways from within available resources in the households and in the neighborhood. Making provisions of irrigation, application of modern fertilizers, introduction of new and/or high value crops, and use of modern agricultural implements are some of the ways and means of intensifying existing farming practices. Second option for them is to move out of the village for short term or for longer-term migration. This normally happens when the household members see a poor or no prospect from the local options. The short-term mobility which is often termed as *ghumphir* is one instrument of negotiation while remaining integral part of the village but permanent migration often referred as *basai sarai* in the hills of Nepal, does not come easy among mountain residents (see Subedi 1993 for details of these two concepts). Overall, negotiations focused on staying amidst these stresses and shocks are clear reflections of mountain people's resilience while migrating permanently may be seen as an "escape" from the realities of mountain life. More and more households at present appear to participate in *ghumphir* while keeping foothold in the village through regular visits and remittances to the household.

15.4.5 Livelihood Diversifications: Avenues and Drivers

From the perspective of livelihood diversification of the households in the mountain areas, two demographic observations are notable. First, the household size is almost 6 persons which is far greater than the national average of 4.9 persons as per census 2011. Second, three out of every four population belongs to the economically active age group. As a result, household economy among mountain people comprises multiple occupations of their household members. This is more so when households consisting of economically active members of two or more generations live together and when largest proportion of households are headed by person aged 60 years and above.

15.4.5.1 Household Heads by Age–Sex and Generation Living Together

Table 15.4 presents the age group of household heads and their sex with number of generations living together. Nearly one-fourth households were headed by women, and this is fairly comparable with the national level in 2011 but higher than the average for mountain region (22.9%). The distribution of household heads by age group clearly shows that this is a mature population. Among five age groups of household heads those aged 50–59 years comprised the largest proportion. However, the proportions of those aged 40–49 years, 60–69 and 70 and over were fairly close. In the survey, there was only one household head whose age was less than 40 years. It was a case of 3 member household headed by 24-year-old person living with his spouse and a three-year-old son.

Majority households had two generations, and single generation households were limited. With respect to single generation, there was also a case of three mature sisters living together in a household. More than one-third of the households had three generations. Likewise there were also households with four generations living together. The case of Mr. Gurung clearly exemplifies this.

Table 15.4 Household head's age group, sex and generations living together

Age group of the household head	Sex of the household head			Households with number of generations living together			
	Male	Female	Total	I	II	III	IV
70 years of age and over	6	4	10	–	2	8	–
Aged 60–69 years	9	2	11	1	4	5	1
Aged 50–59 years	12	3	15	2	13	–	–
Aged 40–49 years	10	3	12	2	8	3	–
Less than 40 years of age	1	–	1	–	1	–	–
Total	38	12	50	5	28	16	1

Source Household Survey, 2014

> Mr. A. Gurung (aged 67), heads a family of 9 persons in Dhakarjong. His mother, D. Gurung is 93 years old and lives with him. His wife is older than him by 4 years. They have two daughters and one son. Both the daughters, though older than son are not married. Their son is married and has two children - one boy and one girl. Mr Gurung, his wife and daughter in law are engaged in agriculture. His son works at telecommunication office. His second daughter has gone to USA recently and is employed there but he considers her as integral part of the family as she is unmarried. All of them belonging to four generations live under the same roof.

15.4.5.2 Avenues of Livelihood Diversification

Household survey revealed two avenues of livelihood diversification in Kagbeni, Mustang. These are: (i) from within existing local resources and (ii) search and/or adopting for new avenue. The two avenues are most often complimentary and generally follow a sequence beginning with local and followed by nonlocal avenues. Box 15.1 lists the avenues and activities under each of the avenues of livelihood diversification.

Searching for and carrying out activities that improve livelihood status of households is a normal phenomenon and this takes place with collective efforts of the household members. Because two or three generations of economically active population live together in these mountain areas, the collective efforts are more evident there than perhaps in other regions of Nepal. Activities to diversify livelihoods first begin with improving and intensifying cropping pattern with increased agricultural inputs. The field observation clearly showed that farmers were keen on preparing their fields with intense care through draught power first, followed by further levelling of field by human labor and showing seeds in an uniform manner plus adding manure based on soil quality (Figs. 15.5 and 15.6).

In addition to naked barley, buckwheat, wheat, mustard seed, and potato, they gradually began to grow maize although its production is limited. Local sources suggest that even potato is not a traditional crop but introduced a few generations ago. Beans, pumpkins, and lentils are intercropped with maize or are grown

Fig. 15.5 Farm households preparing field for wheat plantation in the study area

separately. Over the last 30 years, they have begun to use chemical fertilizers (urea) by mixing with goat manure. Households with sizeable number of economically active members have now focused on increasing and improving not only the quantity of compost manure, but also they are paying attention to improving its quality. The existing irrigation canal from Lumbuk khola has been rehabilitated, and its water has been regulated for irrigation. These days Phalyak gets canal water for 3 days, and Dhakarjong gets for two days in turn. This regulation had to be done for two main reasons. First, the amount of water from other sources in both the villages, i.e., Syang khola for Dhakarjong and Shyamathangpka (snow-fed pond) for Phalyak had dried up. Second, the farm households have begun multiple cropping practice which meant need for more water. No specific time line can be drawn on when exactly the study villages begun multiple cropping practices but the version of Dhakarjong *Mukhiya* suggests that it is their generation that they practiced to grow more than one crops in their land. Thus, the need for regulation of water and upgrading the existing canal became imperative.

Apple farming was introduced about 35 years ago according to an informant from Dhakarjong who also runs a hotel at Eklebhatti, Kagbeni. According to him, its introduction and spread were facilitated by various factors. First, it does not need regular irrigation like wheat and barley and thus, it is climate resistant. Second, overall climatic condition has been favorable now than about 40–45 years ago because of low amount and shorter duration of snowfall in recent years and farmers

Fig. 15.6 View of farm land ready for plantation in Phalyak with settlement at the far end

now consider this crop as one of the feasible one. Third, it is less labor intensive since it is a multiyear crop compared with cereal crops produced there and that it is more favorable when households are facing labor shortage in recent years. Fourth, with improved transport, wholesale traders from south book and/or pay in advance the amount for all apple tress before the fruits are ripe. The owner does not need to look for labor to harvest and take them to the market (Fig. 15.7). Fifth, seedling is available from agriculture office within the district and apple farming in the south, i.e., Ghasa area has faced degradation in quality and quantity due to temperature increase there. It has now been shifting toward north and the higher altitude. All these meant a situation conducive to apple farming in this area.

Vegetable gardening is a recent phenomenon. It is over the last 15–20 years that households started growing green vegetables for household consumption and for sale. The main vegetables included mustard cabbage, cabbage, garlic, onion, tomato, and carrot. Beans were grown there for some generations and that black bean from this area (and its neighborhood) has become almost like an indigenous produce. In recent years, it has been quite popular among visitors. Similarly, demand for wheat has increased as dishes made from its flour have become preferred items among visitors.

Fig. 15.7 Farmer from the study area harvests apple and packs for handing over to the market agent

Box 15.1: Avenues and activities of livelihood diversification in Kagbeni, Mustang From within existing local resources

- Intercropping and multiple cropping with increased inputs
- Introduction of climate resistant high value crops
- Vegetable gardening
- Intensify indigenous varieties of cereals & beans having demand from outsider

Search and/or adapting for new avenue

- Adoption of alternative occupation (tourism related)
- Employment in civil and security services
- Seasonal movement and remittance
- Bi-local/Multi-local living

The second avenue of livelihood diversification is the search and/or adoption of options outside household agriculture and the village. A few households were engaged in running hotels and selling some local woolen products. For example, one of the hotels on the way to Muktinath *(Eklebhatti*) was run by Dhakarjong resident. Some households had members engaged in preparing woolen wears such as sweaters, mufflers, and caps. Such products were sold in the district headquarters, and outsiders and tourists would buy them as one of the souvenirs of Mustang. Employment in civil service within the country and as security personnel in foreign countries was other livelihood options adopted by many households. Although employment in civil service was limited with only one working as technician in telecom, some of the foreign labor migrants were reported to be working as sentry. Employment and migration are integral part of livelihood diversification in these villages. Almost all households reported one or more members employed, i.e., “doing service.” Twenty-three out of 50 households had absentee member abroad. The total absentee abroad constituted 13% of the total population. This proportion is much higher than the corresponding national average of 7.3% according to census 2011. The proportion of female among absentee was 29% which is more than twice the proportion at the national level. Figure 15.8 shows the number of households reporting their members outside the country with total absentee abroad by sex. For unknown reason, largest absentee had gone to USA followed by India. The category “other countries” includes Germany, Malaysia, and China (Hong Kong) where a total of three persons (one person each) were reported to have gone there for service.

Mountain people were also engaged in internal migration as a part of employment and business. This short-term or seasonal move implied alternate livelihood strategy to subsidize household economy since this form of movement involved earning income from business and/or remittance through various kinds of employment at destination. Fifteen households and 21 persons were on internal move in the study area, and many households had both internal and external migrants.

15.4.5.3 Residential Pattern and Livelihood Diversification

An important part of livelihood diversification was physically staying at different places as mover (or migrant) for work or business without abandoning household membership and keeping all household obligations in the village. As mentioned above, migration of a longer duration, i.e., more than a season or a year, is not uncommon among mountain people in this area. This arrangement is part of livelihood diversification since most of the moves especially to Kathmandu and abroad involved engagement in service (including wage work). It can also be considered as strategies of engaging in multiple livelihood options among household members—a strategy that may be called “staying away but remaining integral to the village household.” It is this strategy of the household members that places them in a living pattern that is normally known as bi-locality and/or multi-locality.[3] This residential pattern has emerged dominant in the study area. Table 15.5 shows the distribution of households by their residential arrangements. Three types of

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[3] Bi-locality in this case refers to members of households living in two locations with Kagbeni as the hearth and the other as extension of primary home. Likewise, multi-locality refers to extended living of household members in more than two locations with Kagbeni as the primary home and the others as extensions or secondary home. In both the cases, members remain integral part of primary home and the head of the household considers all of them as members of his residential household.

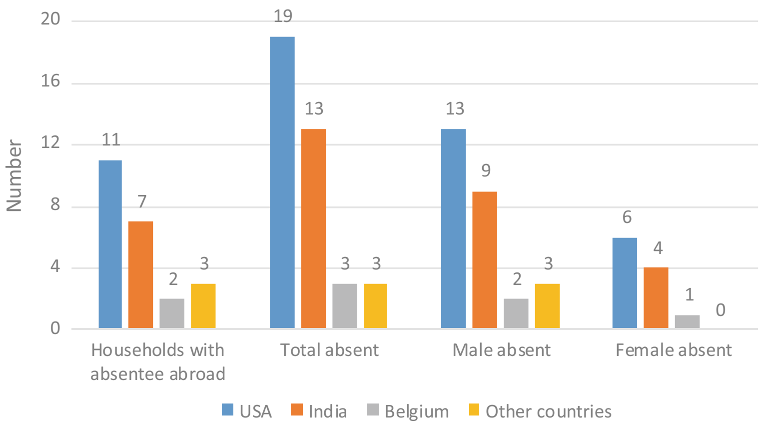

Fig. 15.8 Households with absentee abroad and absentee population by sex in the study area

arrangements have been noted namely single, bi-local, and multi-local. Among 50 households, 27 households had this bi-local or multi-local residential pattern. Among those with bi- or multi-local living arrangements, bi-locality or bi-local living was most common. For example, two-third had bi-local residential arrangement and one-third the multi-local residence. Of the two settlements, Dhakarjong demonstrated wider incidence of bi-local and multi-local residence.

At the cursory level, searching and adapting new avenues outside agriculture may appear easy for the new generation, especially to those who have obtained higher education but it does not come easy for all. On one hand, there are cultural and ritual practices in the household and in the village that are closely tied up with farm, farm produce, particular seasons and local livestock and livestock products. One way or the other some of these products, persons, relations, and places are necessary to perform life-cycle rituals. This entails the need for continuation of traditional occupation in situ or with modern innovations. Equally important is the parental generation's inner desire to not abandon village ties, customs and farm practices. On the other hand, with modern education, exposure to outside world, realization of physical constraints of mountains to continue traditional lifestyles and increased linkage with the south and the external world through transport and communication, the new generation is more tempted by the external world and livelihood options outside traditional agriculture. Moreover, increased uncertainties due to apparent change in the climatic conditions over the last 20–25 years further reinforce the dilemma of whether to continue and remain there or change and leave the village among new generation. An excerpt (transcribed version) of local elderly (octogenarian) from Phalyak (P. Gurung) who served the village as head for several years is relevant in this context.

> I perceive a clear dilemma among our young generations. They are educated and have visited many places outside the village and the country. They have knowledge of various other ways of livelihood than this mountain farming. They have first-hand experience of

Table 15.5 Bi-local and multi-local arrangements of living

Villages/settlements	Members of the household engaged in			Total
	Single locality	Bi-locality	Multi-locality	
Phalyak	15	5	–	20
Dhakarjong	8	13	9	30
Total	23	18	9	50

Source Household Survey, 2014

> hardship of the mountain village and that of mountain agriculture. We, the older generation keep telling them to continue our cultural practices and not to abandon us and the village. But I see them not interested in farming (esp. plowing and transporting manure). They have also observed the drying up of local water sources and the uncertainty of snowfall and rainfall in recent years. They may also not get "good" job in the country since it is competitive. In this difficult situation, our young generations have responded differently - some have stayed and helped their parents in traditional agriculture while others have left. But even those who have left, do come at the time of annual festivals and family life-cycle performances. Nonetheless, all our young men have continued to maintain share in their household obligations in the village such as maintenance of irrigation canal, local water supply, trail maintenance and more (Field note, January 2014).

The multi-local residential arrangements especially where sons together with their immediate family members live abroad for "service" are also an indicative of ambivalence among young generations on whether to continue to remain abroad or to come back to the village and remain active in the village.

15.4.5.4 Households, Generational Transitions in Livelihood and Education

Livelihood diversification, number of generations living in the households, and education are closely linked. As noted above, this population is characterized by joint and extended families than nuclear families. When two or more generations originally based on agro-pastoralism live together in the same household and when the succeeding generation gets education, engagement of household members in different types of occupations becomes obvious. As a result, the households demonstrate diversified livelihood patterns. Education also plays an important role in diversification, and a clear transition in literacy and education pattern by the generations is observed in Kagbeni.

Table 15.6 shows the generations living in the households, occupations of each of the generations and highest education obtained by the member of the generation. Generations have been defined as grandparent, parent, and children because the way they are addressed in the household. Alternatively, they may also be referred as first generation, second generation, and third generation, respectively. This table includes only those surveyed households that have had heads aged 60 years and over. This is in order to capture the actual situations of as many generations as possible. The household size ranged from four to 13 members and generations mostly three. All female headed households had three generations. The main occupation or livelihood option for the first generation was agro-pastoralism. This is the grand parental generation. Among ten households, only one household had member(s) eligible for employment and this person was engaged in short-term employment in USA. The parental or the second generations have adopted various occupations outside agriculture. Notable among them are wage employment in foreign country (which they refer as service), wage work outside the village, and Lamaism. According to the household heads, even the second generations who were engaged outside farming had their share in agriculture in the households. Moreover, the prevalent cultural practice of inheritance meant the succeeding generations are automatically entitled for their share of parental property.

A clear progressive sequence in educational attainment was observed by generation. Most of the grand parental generations were illiterate, and literate ones were like exceptions. The second generations had range of educational attainments obtaining as high as up to graduate level. To be literate only was like an exception. It is also important to note that these mountain people are no exception in the nationwide trend among better-offs and middle class households of enrolling children in nursery and private boarding schools. Likewise, Kagbeni people have also a long tradition of participation in *Gumba*-based education. This form of education is part of Buddhist religious tradition, and the product is *lama*. This tradition has also strengthened the educational situation of mountain people in this area. After all, it is this relatively better educational attainment that has facilitated them to adopt occupations outside agriculture and diversify their livelihoods.

15.4.5.5 Drivers of Livelihood Diversification

In the case of mountain people, the drivers of livelihood diversification can be grouped into two sets: negative drivers and positive drivers. There are a number of factors within these sets (Box 15.2). They have lived with the reality of rough, rugged and limited pockets of suitable terrains for agriculture and the marginal productions for generations. Built upon this reality, the uncertainty of crop production due to climatic variability has been one of the main negative drivers. Likewise, the inadequacy of irrigation water for customary farming has been another driver for reorienting the new generations beyond agriculture. The water supply from existing irrigation canal from Lumbuk River has been grossly inadequate. The water regulation established as 3 days for Phalyak and two days for Dhakarjong, and reservoir (pond) constructed in each village for storage of water during night time has definitely facilitated farm irrigation, but it is still inadequate. There were also cases of land abandonment in both the villages. The plots located at the lower end of the villages and at distance from the water regulating pond of each of the village were abandoned in recent years. Climate change-induced conflicts had also surfaced in this area (see, Bhusal and Subedi 2014). This was primarily due to inadequacy of water for irrigating these plots.

Table 15.6 Household transitions in occupation and education by generation

Household head aand age in years	Sex	Household size and number of generations (GN)		Occupation of generations I–grandparent II–parent III–children			Highest education of I–grandparent II–parent III–children		
		Size	GN	I	II	III	I	II	III
NG–81 year	F	13	3	Agro-pastoralism	Agro-pastoralism, foreign employment (USA)	Employment in US	None	Literate	10 plus 2
KG–70 year	M	10	3	Agro-pastoralism	Agriculture and Service (US and India), Lama	NA	None	IA	Nursery
KoG–63 year	M	8	2	Agro-pastoralism	Agriculture and Lama	NA	Literate	Grade VIII, Lama	NA
CRG–64 year	M	10	3	Agro-pastoralism	Agriculture, business (KTM), foreign employment, Lama (US)	NA	Literate	BA	NA (infant)
SOG–64 year	M	12	2	Agro-pastoralism	Agriculture, foreign employment (US, Germany)	NA	None	Grade V	NA
MG–89 year	F	4	3	Agro-pastoralism	Foreign employment (US), agriculture	NA	None	Literate	Grade VII
BG–67 year	M	9	3	Agro-pastoralism	Agriculture, foreign employment (US), service (technician)	NA	None	IA	Grade I
TT–78 year	M	5	2	Agro-pastoralism	Agriculture, foreign employment (US),	NA	None	Grade V	NA
UG–72 year	F	8	3	Agro-pastoralism	Agriculture, foreign employment, and Lama (US)	NA	None	Grade VI	Nursery
PGG–62 year	M	7	3	Agro-pastoralism	Agriculture, foreign employment (Belgium, US)	NA	Literate	Grade VII	Infant

Note The names of household heads (acronyms) in the first column are pseudo-names. M and F in the second column refer to male and female, respectively
Source Household Survey, 2014

There are a number of positive set of drivers that have singly as well as collectively led to livelihood diversification. The headquarters of Mustang district was shifted to Jomsom from Dana (farther south) in 1968. This relocation or shift meant need for government investment on establishing district administrative structure at Jomsom which is far closer for Kagbeni people than Dana. Two infrastructures, namely air travel and road transport, have played important role in diversifying the livelihood options of these mountain people. As early as 1970s, Jomsom was linked with south through air transport. Declaration of Jomsom as district headquarters and location of Muktinath temple about 6 hours walking distance from Jomsom were the main impetus for development of airport there. Muktinath is visited by thousands of Hindu pilgrims from within Nepal and from India annually. Considering the undulating terrain and the poor condition of trail up until lately it was convenient to use air service to Jomsom for middleclass Indians who come to Muktinath for pilgrimage. From Jomsom, the pilgrims would walk or take a horse ride in case of high altitude sickness. Within the last five years, the trail leading to Muktinath has been improved to fair weather road and there is bus service available from Jomsom to Muktinath at present. On their way to Muktinath, many Hindu pilgrims from Nepal and India visit Kagbeni (confluence of river originating from 108 sprouts at Muktinath and the Gandaki coming from the northwest) to perform annual rituals (*shraddha*) in memory of their deceased ancestors. This pilgrimage tourism has also provided market for local products from Phalyak and Dhakarjong.

Box 15.2: Drivers of livelihood diversification Negative drivers

- Uncertainty of crop production due to climatic variability
- Inadequacy of irrigation water for customary farming

Positive drivers

- Infrastructure development
- Increased link with south
- People's perceived benefit from options other than customary agriculture
- Conservation area declaration and subsequent popularity of Annapurna Trekking Circuit
- Demands for new products from tourists/visitors
- Improvement in social (educational) capital
- Conducive environment for external migration

Related to infrastructure development was the increased link with the south. With the end of salt trade and recent infrastructure development, the prominence of Thak khola as strategic location for exchanging items from the mountain (the North) and the middle hill and Tarai (the South) faded away. Now, there was no longer a need to have break of bulk point between Pokhara Baglung and Mustang area for goods from the south and the north. This meant link with the south was direct, short and relatively easy. This transition took a few decades but ultimately relative ease to south for the Mustang people meant their enriched exposure to outside world both physically and livelihood option wise. With general education and increased exposure to outside world, the succeeding generation began to look for livelihood options other than agriculture. For some unknown reason, the formal education system in Nepal detracted human resource from customary agriculture and a perception that “in the village context to be educated began to be translated as to coming out of farm activities” developed. This prevailing perception further reinforced by the exposure to nontraditional activities, encouraged many young mountain people to enter into trade, business and as migrant wage workers.

In 1986, Annapurna Conservation Area Project (ACAP) was launched as Nepal’s first large area project managed by a nongovernmental organization for the benefit of both nature and people. Mustang area became part of the project (Gurung 1992). One of the activities of ACAP was to promote ecotourism. This provided opportunities to local people to carry out tourism-related activities. It also provided opportunities to the people of study area to sell their local products to the visitors. In addition, since the Project returned some portion of their revenue to the VDCs, it also supported local infrastructure development. Trekking tourism flourished in this area and subsequently Annapurna Trekking Circuit (ATC) which includes Kagbeni and Muktinath area became very popular. With the flow of adventure (trekking) tourists along Annapurna Trekking Circuit and the customary pilgrims to Muktinath, the demand for local products has increased. The woolen sweaters and blankets, *chauri* ghee (butter) and related dairy products and non-timber forest products were reported to be on high demand by the visitors. All these developments and innovative activities in the area seem to have functioned as impetus to livelihood diversification of Kagbeni people.

As discussed above, educational attainment level has improved successively over generation. This social capital has made many of them eligible for nonagricultural occupations to which some of them have been successful (refer Table 15.6). Large concentration of population in the economically active age group with reasonable education, who are looking for nonagricultural livelihood options with the extended family system operating as resource pool along with the national wide wave of youths toward external migration to West Asia, Southeast Asia, and Europe and USA, collectively reflect a conducive environment for external migration of these new generation of mountain people.

Over the years, the place attachment and the sense of place (home) are weakening. This perception was echoed in expressions “*ajakalko ketaketi bahira gaye pacchi uttai ramauna thale. Gaun chhodnu man ta chhaina bhanchha tara khai …*” (today’s generation began to enjoy external world once they are there for some time. They say that they do not want to abandon village but I am not sure if they really mean so]) of older generations there. Whereas the older generations perceive a risk of “empty nest syndrome,” the new generation is in a state of ambivalent belonging. On the one hand, they see their limited scope while remaining at home, they are also worried about what future holds for their children, on the other hand. As a result, the young generation of parents has been paying special attention to send their children to English boarding schools located at Jomsom, Pokhara, and Kathmandu in the hope of making them competitive with external world. Among

50 study households, seven households had their children studying in these three centers. No doubt the people of Kagbeni or Mustang state their belonging to Mustang and identify themselves as Mustangi, but with changing circumstances their belongingness through long-term physical stay in their homeland appears to become weaker compared to the past generations. This appears as an emerging scenario among members of mountain people who are engaged in bi-locality and multi-locality which deserves further investigation.

15.5 Conclusion

This case of Kagbeni (Mustang) on livelihood diversification highlights some notable features of mountain area and mountain people. Despite high altitude and remote location from power centers of the country, Mustang may not be considered as an isolated area. Kagbeni people in particular and Mustang people in general have been linked with north and south for generations. These people demonstrate special demographic and socioeconomic characteristics which differ from the "normal" national scenario. They demonstrate unique and mature demography where the dependency ratio is very low and the presence of children below 15 years is likewise. This may also be considered as worrisome situation with respect to future growth of population. Education wise there is a clear succession and so is the case for occupational and livelihood diversity. This is a dynamic population. Agriculture as main livelihood option has changed from the only means of sustenance to one of the many options of livelihood. This directly reflects a generational transition with new generation considering more of nontraditional and nonagricultural occupations. However, this does not mean they have abandoned their agro-pastoral way of living. At the individual level, a clear shift from the dependence on agro-pastoralism has been apparent but at the household level where two or more generations are living together, multiple livelihood options have been adopted. More importantly, all household heads state agriculture as their main livelihood option and this is irrespective of its lesser contribution to their overall household economy in recent years. Both the positive and negative drivers of diversification are functional and active, and it appears that these drivers continue to be functional as the link of this area and its people to the south and the external world continues to increase. In all likelihood, the links with south and external world will increase.

The stresses in the Trans-Himalayan region and random shocks related to natural phenomenon and unanticipated familial misfortunes are real in the livelihoods of mountain people and that the hardship of livelihood there is far stressful than in most of the hill areas in the country. This clearly demonstrates their resilience to the harsh reality of living in the mountain areas. More importantly, the fact that their livelihoods have been diversified, their residential arrangements are becoming more of bi-local to multi-local and that they have coped with the changes taking place within and outside the country means these are resilient as well as dynamic people.

There are enough lessons to learn from this area and its people for the overall development of the hill areas in Nepal. Mountain areas are not necessarily impediments of development but are areas of hope. Future studies and development efforts should pay particular attention to understand further the individual and household dynamics and their responses to physical (e.g., climate change and natural hazards) and social changes taking place at the regional, national, and international level. In the context of Nepal, mountain people need to be recognized as "dynamic" and "resilient" resources who need closer attention of the nation and the mountain areas as "plausible areas of hope" for future, if not the present and not impediments to the development and to the nation.

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Chapter 16
The Petty Street Vendors and Their Livelihoods of the Kathmandu Valley Cities, Nepal

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Abstract Street vendors are defined as informal traders who sell their goods or services whether or not it has fixed location for conducting business. They are generally found in most of the cities of poor developing countries. In the Kathmandu valley cities of Nepal, the petty street traders consist of features such as temporary structure, small size, self-employment, low investment, low skills and marginal groups. They are also known as 'invisible economy' and contribute largely to the national economy indirectly. The data for this paper were acquired from standard observation protocol sheet, GPS, informal discussions with the vendors based on checklist and available existing documents. This paper explores that 'convenient' is one of the most crucial factors to determine the variation in the spatial location pattern of the petty street vendors in the Kathmandu valley cities. GIS and the nearest neighborhood technique were used to identify the spatial pattern of the petty street vendors. The paper also briefly describes the historical account of the evolution of informal marketing activities in the Kathmandu valley cities. It is found that the petty vendors are mostly migrants with petty trading as their only income source, and they are moving on through hardship life.

16.1 Introduction

Informal sector is indeed emerged as a crucial subject as well as an important economic sector for the cities of poor developing countries due to features such as ease of entry, little investment and low skill. Available literature on urban-based development theories indicates that the developing countries' cities offer undoubtedly the most potential places for investment in development activities, thus the opportunities for employment (Lewis 1954; Fei and Ranis 1961; Todaro 1976).

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These attributes of the cities attract huge numbers of people from across different parts of the country. But the stream flows of the labor force are so large that the relative capacity of the cities is weak to fully absorb the labor force, creating a huge surplus of labor force together with the problems of unemployment. As a result, jobs are very competitive and finding jobs in the formal sector such as industries and public service is very difficult. The informal sector on the other hand is only an option for employment and income generation for such people who are seeking jobs in the cities. According to the dualism model (Lewis 1954; Fei and Ranis 1961), the informal also called as subsistence and traditional sector including petty retail trading in the large cities consists of a large portion of unlimited supply of labor.

Informal sector has planning and development implications. In 1972, ILO (1972) first used the term informal sector referring to the activities of microenterprises, and subsequently in 1993, the United Nations Statistical Commission (UNSC) and the United Nations Economic and Social Council endorsed it as a part of the System of National Account. However, it was Keith Hart who first coined in his research work the term informal sector as 'the area of self-employed' in the context of the Third World (Hart 1973). Further, informal sector usually is found associating with the alleviation of poverty that primarily concerns with the income and employment generation. According to Sethuraman (1976), informal sector associated with unregistered and unregulated small-scale activities or invisible economy generates income and employment particularly to the urban poor. According to Charmes (1990), it contributes to the national economy indirectly by generating employment and providing goods and services to the urban poor, while Moser (1978) argued that there is usually an absence of unemployment benefits and other forms of social security in the cities of poor countries that forces the adult population to find some means of livelihood through work or remuneration in small-scale enterprises and activities within the informal sector. Furthermore, Sethuraman (1981) and Mazumdar (1976) argued that in its application to issues of equity, economic opportunity and social development, the term informal economy first came into widespread use as a means of describing a dualistic economic structure found in developing countries. According to Chambers (1995), poor household livelihood strategies in the cities often involve different members in diverse small economic activities for the sources of support during the year. Despite the street traders who are generally poor and carry out economic activities as a means of livelihood, their importance in development policies for cities or improvement in the city planning is largely ignored (Brown 2006). On city revenue perspective, most urban development theorists argue that this sector should be improved, managed and planned, so that the informal activities gradually transform into the formal sector.

The key issues related to the informal sector prevailing in poor developing countries described above may also be relevant to Nepal. Yet, there is little or no attention on researches about the petty trading activities on the urban economic geographical perspective in the Nepalese context. This paper intends to explore and analyze livelihood of the people involved in the informal petty trading activities and their social development and management features prevailing in the cities of the Kathmandu Valley, the largest urban agglomerated region of Nepal.

16.2 Data and Methods

This paper draws the data and information from both primary and secondary sources. The secondary source comprises of research studies, population census, policy and program documents, and toposheets. The primary data gathered from the field survey included the observation survey, which has been carried out extensively across the Kathmandu and Lalitpur cities. In this survey, standard and structured observation protocol form was used to gather (observation and recording) data on the location of petty trading vendors and their types such as perishable (fruits and vegetables), durable mixed (clothing, electric and electronics, shoes, makeups, etc.), catering, personnel services (shoeshine), professional services (tailoring, hair cutting, etc.), and repairing, sellers' sex, age, education, family size, and other features such as tools and equipment used, display modes of goods and services, site environment, and physical infrastructure and facilities. In addition, data on their age, education, family size, income and expenditure pattern were also acquired through informal discussions. Here, the petty street vending (temporary) market places refer to those location sites having 20 petty vendors occupying an area of about 50 m. The observation survey was carried out in the morning until 8:30 am and in the afternoon between 3:00 and 6:30 pm and all days of a week. Thus, a total of 87 temporary market places were observed. This survey was accompanied by large-scale Google map, showing all streets, major built-ups, drainage and land uses. The Global Positioning System (GPS) was used for locating the sites of the petty vendors. Photographs of the petty trading vendors representing varied features were also taken and displayed wherever feasible.

Analysis of the data has been performed in the contextual manner. The temporary market places referring to the places or sites where petty vendors operate trade business/services are classified into different types and groups in terms of attributes such as nature, size and traded goods. In terms of traded goods, they are classified into seven broad groups such as: (i) perishable (comprising fruits, flowers, cut flowers, vegetables, meat/fish, leaf plate (*Tapari*), milk/curd, etc.; (ii) dry foods (including groceries, spices, beans, etc.); (iii) catering foods/drinks (including tea/coffee, snacks, fruits/juice, cold drinks, bottle water, ice cream, cigarettes, confectionary, fried and baked grains, soybeans, peanuts and beans, momo, sausage, puchhki/panipuri, betal, breads, packed foods, fried meat/fish, etc.); (iv) clothing (including clothes/readymade, bed covers, towels, mask, footwear, belt, etc.; (v) durable mixed (comprising utensils—metalwares, glasswares, plasticwares, bags/purse, suitcases; electronics—mobile, torch light, compact disks, cosmetics, bangles, goggles, toys/dolls, stone grinding (silauto), idols, toolkits, watch, clay pots, curios, souvenirs, candle, religious items, etc.); (vi) services (including footwear repairing, tailoring, hair dressing, weighing measure, watch and stove repairing, religious/astrologist, coin exchanger, umbrella repairing, magician, etc.); and (vii) others (including books, stationery, newspapers, magazines, calendar, posters, live animals—goat, chicken, fish and birds, herbs, toiletries, incenses, chemicals, etc.).

An index of randomness (R_n) has been used to measure the spatial distribution patterns of temporary market places (Clarke and Evans 1954), which is obtained from the following formula:

$$R_n = \sqrt[2\bar{d}]{\frac{N}{A}} \tag{16.1}$$

$$\bar{d} = \frac{\sum d}{n} \tag{16.2}$$

where R_n = index of randomness; d = distance (map distance) between locations of market places; N = total number of market places; n = total observed market places; A = area under study; and $\bar{d}$ = observed mean distance of market places under consideration. On map, location of each of the observed market places is indicated by point.

The index ranges values between 0 and 2.15. The index value (R_n) 0 or tending toward 0 means the distribution pattern is clustered or moving toward agglomerated. Alternatively, Rn value with above 1 would indicate a dispersed pattern, reaching a maximum of 2.15 signifying a regular pattern. Rn value 1 or close to 1 indicates the distribution pattern of market places is random. In addition, a relationship between number and size of the market places and population size (which is expressed in terms of population density per square kilometer) has also been acquired. This is shown in GIS-generated map.

16.3 Study Area—The Greater Kathmandu Urban Region

The greater Kathmandu urban region in this paper includes two cities—Kathmandu and Lalitpur (Fig. 16.1). This follows the definition made by the Department of Urban Planning, the Government of Nepal (DHPP 1969). Of these two cities, Kathmandu is the only metropolitan and capital city of Nepal and Lalitpur is a sub-metropolis. With slightly over 1 million population, Kathmandu is the largest city and Lalitpur with population of 227,000 is the fourth largest city of Nepal (CBS 2012b). Juxtaposing the area of these two municipalities extends over 64.6 km^2 (Table 16.1). The Kathmandu Valley defined by its surrounding mountain ridges with elevation of above 1800 masl has an area of 475 km^2, whereas the valley consisting of its three districts (Bhaktapur, Kathmandu and Lalitpur) has an area of 899 km^2.

However, the Kathmandu Valley as a whole is the urban region, as no parts within the valley are rural. Now the valley has 22 incorporated municipalities,[1] including five existing municipalities, viz. Bhaktapur, Kathmandu, Kirtipur,

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[1] The population census of Nepal defines towns as incorporated municipalities or urban areas, which have population size of above 10,000 for the hill and mountain regions. Administratively, district lies above municipality.

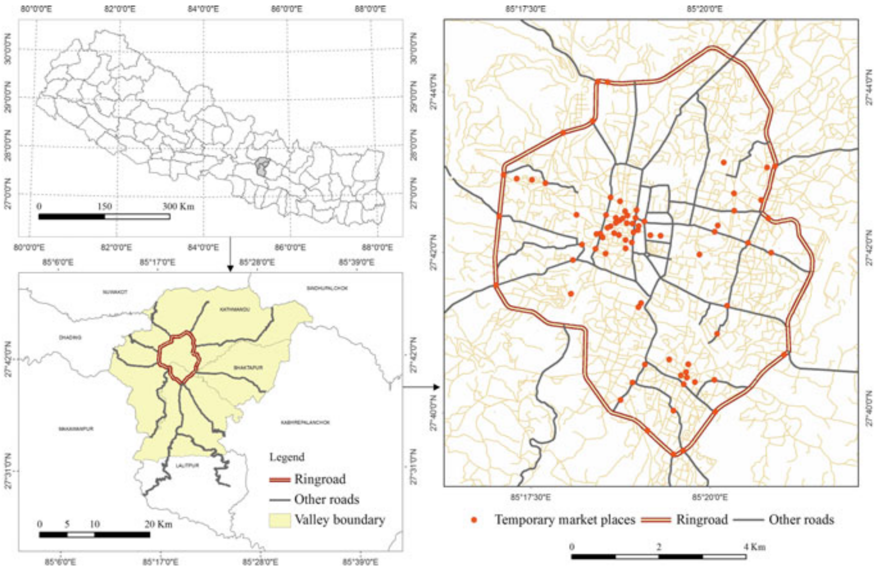

Fig. 16.1 Location of the greater Kathmandu urban region, Nepal

Table 16.1 Population characteristics of major five municipalities, Kathmandu Valley

Municipalities	Population size	Area km^2	Population density	Household size	Sex ratio
Bhaktapur	83,658	6.56	12,753	4.74	104.1
Kathmandu	1,003,285	49.45	20,289	3.94	113.4
Kirtipur	67,171	14.76	4551	3.45	126.3
Lalitpur	226,728	15.15	14,966	4.14	108.4
Madhyapur Thimi	84,142	11.11	7574	4.14	107.1
Total	1,464,984	97.03	15,098	4.1	111.9

Source CBS (2012a)

Lalitpur and Madhyapur Thimi plus 17 newly declared municipalities, viz. Anantalingeshwor, Bajrabarahi, Budhanilkantha, Chandragiri, Changunarayan, Dakshinkali, Godavari, Gokarneshwor, Kageshwori-Manohara, Karyabinayak, Mahalaxmi, Nagarkot, Nagarjun, Shankharapur, Suryabinayak, Tarakeshwor and Tokha. The population of all 22 municipalities is 2,420,505, sharing about 96% of the valley's total district population (2,517,023). Juxtaposing the population of greater Kathmandu (Kathmandu and Lalitpur cities) shares about 51% of the valleys' urban population.

The population density of Kathmandu city is 20,289 per km^2 and that of Lalitpur city is 14,966 per km^2 (Table 16.1). The average population density of greater Kathmandu comes to 19,040 per km^2, which is the densest in Nepal and can be compared to the national urban density of 1381 or the Kathmandu valley urban density of 5096. The valley's density of population becomes even much larger than this due to floating population, which is estimated to be over 1 million.

The size of greater Kathmandu urban region has evolved eminently over the last few decades. During the decades of 1991–2011, the urban population grew at over 138% in Kathmandu and nearly 96% in Lalitpur (Table 16.2). During the last census decade of 2001–2011, the annual growth rates of urban population in Kathmandu and Lalitpur were 3.04 and 3.73%, respectively, which can be compared with the national average annual urban growth rate of 3.38% (CBS 2012a).

The greater Kathmandu cities are the hub centers in Nepal for the economic, cultural and administrative activities, and thus, they attract people from different parts of the country as well as from neighboring country, India (Pradhan 2004). Migration of population[2] has been the main contribution to the rapid growth of urban population in the greater Kathmandu over the years. In 2001, such migrant population constituted nearly two-fifths of the total population for the whole Kathmandu valley urban region, the largest ever since the 1950s (CBS 2003). The migrant population for Kathmandu and Lalitpur cities was 46 and 35%, respectively. Of the total estimated valley in-migrants in previous decade (1981–1991), the Kathmandu city alone received about 78% of the rural migrants and 65% of the urban migrants from other districts (Pradhan 2003). Of several reasons of the urban-bound migrants across the country, still agriculture remained to be the main, followed by employment and trading and others.

The factors that exhilarated for the expansion of the cities in Nepal include the change in political system and therefore the increased needs of government infrastructure and functions in administration, health, education, banking, commercial activities, etc. Over the past years, there has been increase in the number of government and development organizations, foreign aids, tourism and its related activities, land and housing, and the expansion of road networks and urban utility facilities including drinking water, sewerage, electricity and communications (Pradhan 2003). These phenomena have brought about changes in physical, environmental, economic, social and cultural aspects in the Kathmandu Valley. Some of the striking features the greater Kathmandu has witnessed over the past few decades are a rapidly growing of squatter settlements and slums, and challenges with their planning and management. The number of squatter settlements grew from 24 in 1988 to 45 in 2008. They had total households of 2876 with at least 130 houses in each squatter settlement (NWUS 2008). They have occupied mainly the public land, shrine complexes and riverbanks, which are ecologically sensitive and deficient in basic facilities (Pradhan 2008). The problems of squatter settlements and slums remain unchanged but rather show even more complex, though the government had envisaged the Kathmandu Valley Plan 2020 for development

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[2] According to the population census of Nepal (CBS 2003), a person of the particular district (municipality/village) borne elsewhere in other districts within the country and foreign places is said to be 'migrant'.

Table 16.2 Growth of urban population, Kathmandu Valley's cities (1991–2011)

Cities	Population size			% Growth 1991–2011	Growth rate (%) 2001–2011
	1991	2001	2011		
Bhaktapur	61,405	72,543	83,658	36.2	1.5
Kathmandu	421,258	671,846	1,003,285	138.2	4.9
Kirtipur	31,338	40,835	67,171	114.3	6.4
Lalitpur	115,865	162,991	226,728	95.7	3.9
Madhyapur Thimi	34,587	47,751	84,142	143.3	7.6
Total	661,836	1,084,443	1,464,984	121.4	3.5

Source CBS (2003, 2012a)

initiatives of development nodes, efficient land use planning, conservation of agricultural areas, transportation network, settlement expansion with infrastructural facility, etc. (KVTDC 2000). Secondly, the urban-bound migration has involved a large number of youths, and youth unemployment has become a crucial problem in Nepal. A 'brain drain' among the educated and skilled youths is also an emerging economic problem (CBS 2006). Thirdly, the number of persons involved in the informal activities has increased as the cities grew. Thus, the informal sector is playing an important role in providing livelihoods and services to the urban poor. Note that the small and microenterprises including trade and business, service sector and manufacturing works dominate the urban economy in Nepal. Studies such as Sthapit (1999) revealed that the number of commercial vendors in Kathmandu city was recorded as 1300 in 1998 that increased to 2938 in 1999 and further increased to 9726 in 2006 (CIUD 2006). According to the study of Dawadi (2008), the youth migrants (15–45 years) constituted about 83% of the sample commercial vendors in Kathmandu city, of which over 57% migrated during the past decade. Similarly, the study carried out by Raut (2008) exhibited that urban agriculture also belonged to the informal sector in Kathmandu city has been an important sector for self-employment generation to the migrants. The migrants running this activity for livelihood were due to the principal reasons such as conflict in the origin places, entrepreneurship and employment opportunities in the city. Thirdly, the density of urban population has shifted from core to periphery of the cities. For instance, the housing density in the core area of Kathmandu in 1998 was 500–1000 persons per hectare, and during the same year, the built-up area had a growth rate of 3% and below per year (Pradhan 1998), which was less than half of the growth rate of 7.5% per year in the periphery (MOPE 1999). Indeed there is virtually no physical space being left for the construction of new buildings in the core area, and thus, the built-up area has expanded toward outward, indicating more of horizontal expansion than vertical expansion of the buildings.

16.4 Results and Analysis

16.4.1 Historical Exposé of Traditional Marketing System in Kathmandu Valley

The marketing systems in the Kathmandu Valley have evolved remarkably over the years. Transformation of the traditional marketing system can be attributed primarily to the urban growth in the valley as a result of population growth and migration, center of politico-socioeconomic activities, etc., but above all, the rich agriculture base, entrepôt trade and ancient cultural monuments being developed during the medieval period were by far the most important reasons (HMG/UN/UNESCO 1975; Regmi 1978; Wolfgang 1993). Secondly in 1769, Kathmandu city became the capital of the unified Nepal. Thirdly, the year 1956 marks the stark division of marketing systems between traditional and modern types in the Kathmandu Valley. There was no road until 1956, and so, all traffic flows in the Kathmandu Valley preceded on foot and most of the goods were conveyed to and within the valley by porters or producers or traders themselves carried them in locally built *kharpan* (baskets suspended by means of a thin, flexible wooden pole balanced across the shoulders) or large baskets (*dokos*) and traded them at few confined market places (Pradhan 1987). In earlier times, the marketing systems for the local products in the valley were traditional and the mobile vendors were commonly available to meet the local needs by moving themselves from place to place, as there were very scattered local retail stores and regular visits to the market places by the consumers on foot were difficult and time-consuming. Such trading was conducted by jobbers, locally known as *Banjaras* (DHPP 1969). A number of inhabitants of Thimi for instance were engaged in this particular kind of marketing. There were localized areas for production and marketing of particular products in the valley. For example, the mustard oil was produced by traditional method primarily in the Bungamati and Khokana areas in the south of the valley and then conveyed it usually in tins (18 l) to Patan and Kathmandu for selling to retailers or individual consumers. Other examples of agricultural products by such mobile vendors were grains, flour, ghee, curd, cream, rice flake and a few spices. Apart from these, the most common form of marketing of seasonal vegetables produced locally was held daily at the major street junctions, open spaces or roadsides. The fresh vegetables were used to move daily to the cities by the mobile traders. The selling of vegetables by growers themselves directly to consumers was very common in the cities. In addition to the agricultural products, a limited quantity of cottage industrial goods such as handloom cloth, mats (*sukuls* made up of rice straw), baskets, brooms, etc., was also produced in rural areas and conveyed them usually on foot to the main market places for selling. Except these, the selling of cigarettes, matches, nuts, cloves, etc., in piecemeal basis through street corners was also common. This traditional phenomenon exists even today.

Only after 1956, the valley saw the motor vehicles when the first road—the Tribhuvan highway—was being built connecting Kathmandu to Birganj and Indian border cities in the south. Thereafter, a number of roads connecting Kathmandu Valley to many outside places across the country as well as street networks within the valley have been built, and as a result, there has been a tremendous increase in the use of vehicles for the movement of goods and people between and within the valley (DHPP 1969). This also has brought tremendous changes over the traditional marketing systems of local farm products. Nonetheless, one key feature of traditional marketing systems associated with the agricultural products that used to be collected from the farmers' farm-gates by mobile traders or jobbers in the past for selling either to wholesalers or retailers or directly to consumers still continues to exist nowadays. But the products for trade that used to be local now come from extensively broadened growing areas and involve a multitude of producers.

16.4.2 The Petty Street Vendors—Type, Size and Spatial Distribution

The street vendors in the greater Kathmandu are classified into two main types: sedentary and footloose (mobile) vendors that operate trade from the early morning through evening every day, but both types disappear at their marketing places during the whole night. Thus, they are known as 'invisible markets.' The sedentary vendors usually operate their business at fixed locations (places), occupying street pavements, walkways, overhead bridges and open spaces, mostly at the street junctions where there are crowds of pedestrians. They use stalls, bags, sacks, baskets, tables, bamboo racks, hanging on walls and even bare (naked) floor for displaying their merchandise goods. On the other hand, the footloose or mobile vendors have no fixed locations, but they move from place to place in the core city mostly at the street junctions or public bus stands in search of potential customers. They carry their trade goods in baskets on head by themselves or by bicycle, through pushcarts, locally knows as *Thelas* (having 2, 3 or 4 wheels) or van. In some cases, the mobile vendors are used to speak out loudly about their traded goods (usually in limited varieties) carrying by themselves to attract customers toward them. A total of 87 street vending places across the greater Kathmandu have been observed, and all those trade vendors have occupied sedentary places, of which 81 places also have contained footloose sellers (Table 16.3). The number of petty sellers or participants or trade entrepreneurs involved in the sedentary type is preponderantly large with over 82% as compared to those involved in the footloose vending type. On average, each street vending place possesses 160 trade participants.

A total of 13,935 adults are being employed in the petty vending enterprises, with females exceeding over males on the whole. But there is a stark difference between men and women being employed in the two types of petty street vendors. In the sedentary type, women employment is larger than men employment, whereas in the footloose vendors, the reverse is the case, with men being employed

Table 16.3 Types of petty street vendors, greater Kathmandu [n = 87]

Gender	Footloose		Sedentary		Total	
	Number	Percent	Number	Percent	Total	Percent
Male	1742	70.1	4763	41.6	6505	46.7
Female	744	29.9	6686	58.4	7430	53.3
Total	2486	100	11,449	100	13,935	100.0
Percent	17.8		82.2		100	

Source Field survey, January 2014

Table 16.4 Distribution of temporary market places by class–size

Class	Size	Market places		Petty vendors	
		Number	Percent	Number	Percent
I	20–50	34	39.1	945	6.8
II	51–100	19	21.8	1330	9.5
III	101–150	13	14.9	1580	11.3
IV	151–200	8	9.2	1342	9.6
V	>200	13	14.9	8738	62.7
	Total	87	100.0	13,935	100.0

Source Field survey, January 2014

enormously larger over women. In fact, it is not unnatural because mobile vendors require special skills such as riding bicycles or driving *Thelas*, or moving around the streets until evening, which is a concern of social security (usually no street lights due to load shedding in the cities) for women, or women also need to look after their families or household chores such as cooking foods and other works at home.

Another striking feature of the temporary market places as depicted in Table 16.4 is that the smallest size market places with 50 and below petty vendors are the most, constituting over 39% of the total market places, but the number of petty vendors engaged in them represent the lowest. On the other hand, the largest size vending market place containing over 200 petty vendors is overwhelmingly big, almost 63% of the total petty vendors being employed.

It is evident from Fig. 16.2 that the distribution of the temporary market centers is quite uneven. The R_n = 0.7 indicates the distribution of the market places under consideration tending toward randomness. The spatial pattern of the market centers shows two distinct features: One is area of concentration, which lies in the core areas of two cities of Kathmandu and Patan (Lalitpur) and another is the area of dispersion outside the inner core areas. By size, the largest market places are mostly located in the city cores and few of them occupy strategic locations but at far apart in the city outskirts. Other market places with smaller size show dispersal pattern across the cities and thus located everywhere, making less travel or nearness to their potential customers. In greater Kathmandu, as elsewhere in others parts of Nepal, marketing particularly of fresh vegetables is an everyday phenomenon (Pradhan 1987).

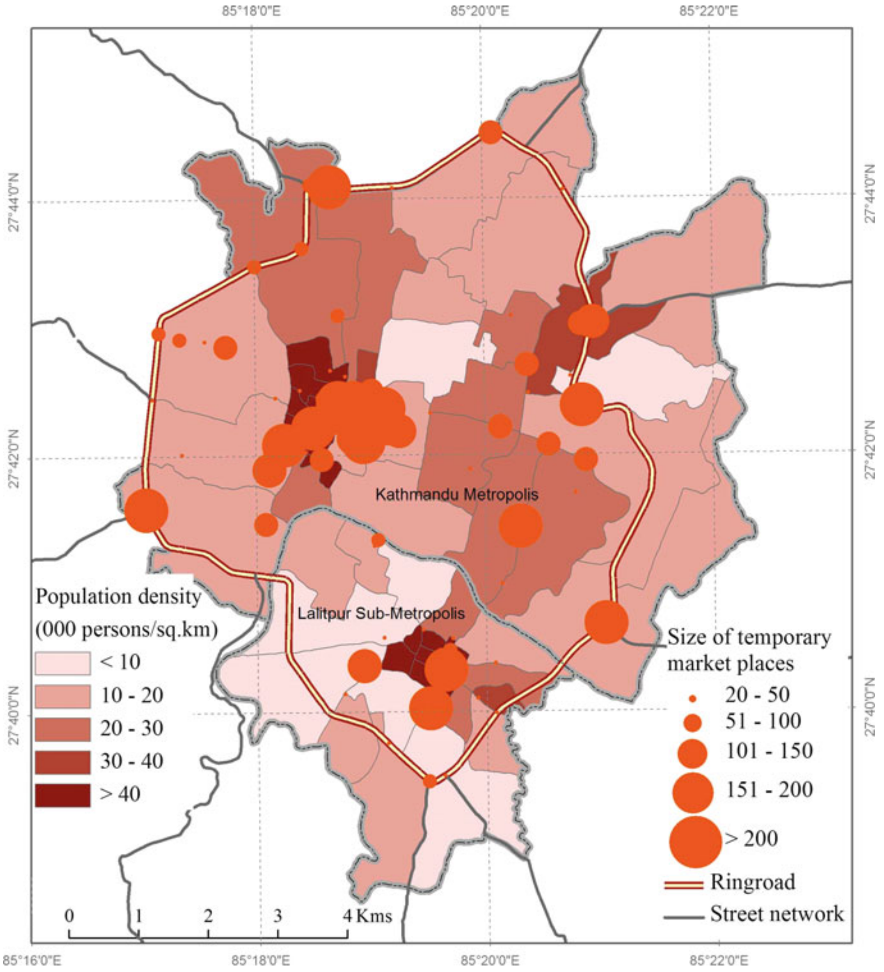

Fig. 16.2 Distribution of temporary marketplaces by size and population in greater Kathmandu, 2014

Therefore, the distance between residents' living places and vegetable markets is usually at convenient distance measured in short travel time or closeness to public transport stop (Fig. 16.3).

Undoubtedly, certain geographical factors are responsible for these patterns. The traditional city cores are located on the higher river terraces or plateau that are quite far away from the local rivers to avoid possible flash flood impacts (Pradhan 1998). Historically, the location of the city cores has been there from the very beginning. In other words, the early development of the two cities had taken place at those particular sites and later sprawled gradually outward (DHPP 1969; Malla 1978). In the core parts of these cities now the density of buildings as well as population is highest.

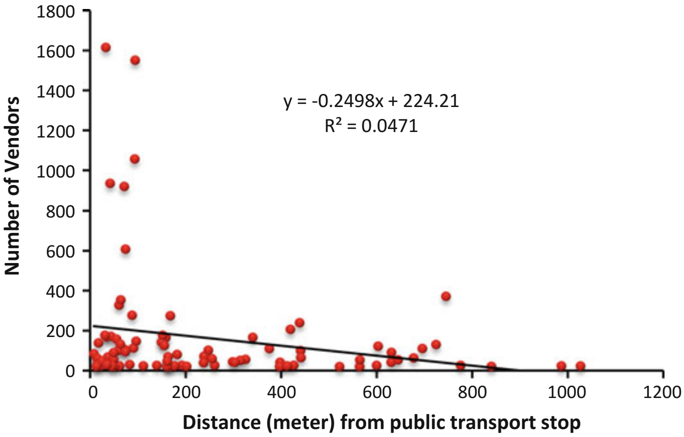

Fig. 16.3 Location of vendors and distance from public bus stop

Accessibility of the market places or number of vendors in terms of nearness to major public transport stops is another factor. Figure 16.4 depicts that both are largely concentrated within 300 m from near public transport stop. Culturally, most of the current traditional market places are of cultural and religious importance from the very beginning, such as Asan, Indrachok, Patan-Mangalbazaar and Chabel-Ganeshsthan due to renowned temples and monuments. Indeed, these localities (neighborhoods) have possessed a variety of trade items over the several decades, in addition to fresh vegetables, fruits and food grains.

16.4.3 Features of the Petty Street Vendors

Displaying mode for the trade items used by the vendors is important in terms of types, size, quality, value, weight, volume, etc. They differ between sedentary and footloose vendors (Table 16.5). In sedentary vendors, plastic sheet is most important, as about three-fifths of them use this, which is related to easiness for wrapping the trade items and run out of the site during the municipal police raids, or for protecting the items from rain, or effective use of given space. Further, of all displaying materials, it is the cheapest one. It is used basically for clothes items. Two other displaying modes in terms of order of importance are tables and baskets with different sizes and types. On the other hand, four-wheel carts and then bicycles are the most important displaying modes being used for the trade items in case of footloose vendors.

Second, the trade items of the petty street vendors are classified into seven types (Table 16.6). Of these categories, perishable item is the largest or ubiquitous at 81 market places among the total 87 market places. Next are foods and drinks and

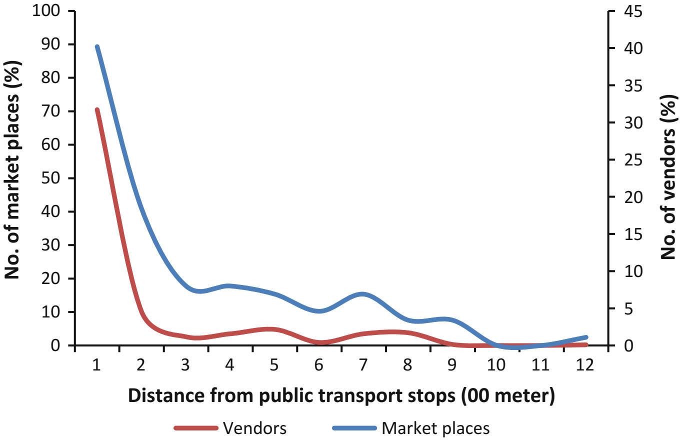

Fig. 16.4 Distance of market places and venders from public transport stop

clothes categories in terms of dealing for marketing by the number of market places, but clothing trading is being the largest in terms of number of employed petty vendors. The relative importance of market places dealing with perishable item trade is second in terms of employment of the petty vendors.

Third, the area occupied by displaying mode of the trade items at the site differs among the categories of trade item. Of the seven categories, perishable item shares the largest in the total area occupancy, due to its largest number. But the clothing item occupies the largest mean displaying area with 2.03 m^2, followed by 'others' and durable mixed categories. Each trade item type occupies a mean area of 1.71 m^2, which is larger in day shift than morning and evening shifts for trading (Table 16.6).

Fourth, the distribution of number of petty vendors by category of trade item varies between the footloose and sedentary market system types. In sedentary type, three trade items—clothing, perishables and durable mixed—are important in terms of order of relative proportion of the vendors, whereas only perishable is the dominant item in the footloose type, which has engaged the largest proportion of the vendors (Fig. 16.5). There is not a single vendor dealing with dry foods in case of footloose sellers. Figure 16.5 also depicts that clothing is the largest trade item in terms of vendors being involved in the case of 'sedentary' type.

Fifth, petty vendors operate trade all from morning through evening, which thus is divided into three time shifts: morning, day and evening. Items being traded vary among these time shifts. Table 16.7 shows that in terms of relative proportions of the total vendors, perishable items particularly fresh vegetables and fruits occupy largest in the morning and evening shifts, whereas clothing is the largest in the day shift. Among all shifts, the vendors are largest with almost half of the total vendors in the evening shift. Similar patterns (i.e., relative distribution of vendors by trade time shift) are seen for both footloose and sedentary marketing types (Fig. 16.6).

Table 16.5 Displaying modes of merchandise goods by market system type and vendors

Market system type	Display mode	Male		Female		Total	
		Number	%	Number	%	Number	%
Footloose (*n* = 81)	Bicycle	792	45.5	52	7.0	844	34.0
	Three-wheel cart	56	3.2	41	5.5	97	3.9
	Four-wheel cart	743	42.7	641	86.2	1384	55.7
	Self-carrying	144	8.3	10	1.3	154	6.2
	Vans	7	0.4	0	0	7	0.3
	Subtotal	1742	100	744	100	2486	100
Sedentary (*n* = 87)	Open floor	164	3.4	252	3.8	416	3.6
	Bags	78	1.6	111	1.7	189	1.7
	Plastic sheet	2824	59.3	4054	60.6	6878	60.1
	Baskets	553	11.6	1087	16.3	1640	14.3
	Tables	1009	21.2	1122	16.8	2131	18.6
	Hanging hook	114	2.4	46	0.7	160	1.4
	Racks	11	0.2	1	0	12	0.1
	Stalls with shed	10	0.2	13	0.2	23	0.2
	Subtotal	4763	100	6686	100	11,449	100
	All total	6505		7430		13,935	

Source Field survey, January 2014

Table 16.6 Site occupancy area by trade item categories and type of market places

Types of trade items	Market place	Number of petty street vendors				Area (m^2) coverage by vendors		
		Footloose	Sedentary	Total	%	Area	Percent	Mean
Perishables	81	1632	3234	4866	30.6	7282	30.6	1.50
Dry foods	24	0	175	175	1.1	254	1.1	1.45
Foods/drinks	80	554	918	1472	9.8	2332	9.8	1.58
Clothing	66	150	4842	4992	42.6	10,137	42.6	2.03
Durable mixed	59	138	1653	1791	12.3	2928	12.3	1.63
Services	52	3	481	484	2.4	580	2.4	1.20
Others	36	9	146	155	1.2	277	1.2	1.79
Total	87	2486	11,449	13,935	100	23,790	100.0	1.71
Morning shift	47							1.45
Day shift	27							1.72
Evening shift	77							1.60

Source Field survey, January 2014

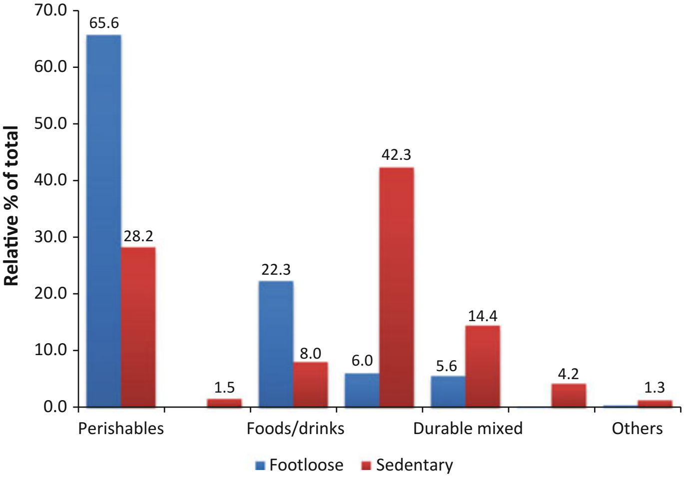

Fig. 16.5 Distribution of trade item category by type of petty street vendors

Compared to men, more women are engaged in the trading activities in the morning shift than in other two shifts (Fig. 16.7). Participation of men in trading in the evening shift is the largest, which is obvious because some of the men working in other sectors or offices during the day join in the evening shift for trading after the office hours. This is also supported by the fact that there are more footloose vendors than sedentary type in the evening shift, which belongs largely to men. By virtue of mobile nature, mobile vendors have more freedom to choose the site, operate trade longer time and do not need to preoccupy site for trading as do the vendors need with sedentary type. Relatively less number of women being involved in operating trade in day shift and evening shift are due to their engagement often in other works such as household chores, fetching children from the schools, washing clothes, and fixing tiffin and evening meals and so on. Our field survey indicates that income from engagement mere in the petty trading is not adequate to sustain their family expenditure (see details in following sections), and therefore, they mostly take on multiple occupations or operate such kind of trade in other neighborhoods or other shifts.

Next is the trade business, which is the main source of livelihood of the petty street vendors. Analysis of the livelihood of the vendors' households has been carried out based on the income acquired from the trade business of the seven item categories as described above. Also being made is the expenditure by the households on the essential items for sustaining their livelihood. This is based on a total of 230 as sample petty street vendors.

Expense on foods is by far the largest, constituting about 31% of the total monthly expenditure. Education expense for their children is very crucial that occupies position next to 'others' category (Fig. 16.8). Health is the least in terms of expenditure, but over 10% expense on rent for living is relatively large by

Table 16.7 Distribution of vendors by trading time shifts and trade item types

Trade item categories	Morning		Day		Evening		Total	
	No.	%	No.	%	No.	%	No.	%
Perishable	2081	50.2	386	12.7	2399	35.57	4866	34.9
Dry foods	67	1.6	33	1.1	75	1.11	175	1.3
Foods/drinks	236	5.7	394	12.9	842	12.48	1472	10.6
Clothing	1134	27.4	1477	48.5	2381	35.30	4992	35.8
Durable mixed	443	10.7	586	19.2	762	11.30	1791	12.9
Services	145	3.5	129	4.2	210	3.11	484	3.5
Others	39	0.9	40	1.3	76	1.13	155	1.1
Total	4145	29.7	3045	21.9	6745	48.4	13,935	100.0
Footloose	714	28.7	445	17.9	1327	53.4	2486	17.8
Sedentary	3431	30.0	2600	22.7	5418	47.3	11,449	82.2

Source Field survey, January 2014

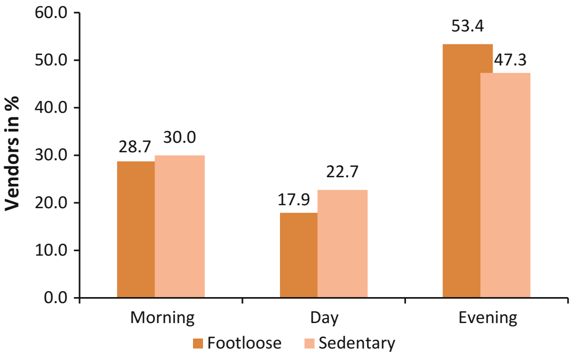

Fig. 16.6 Relative distribution of vendors by trading time shift and trading type

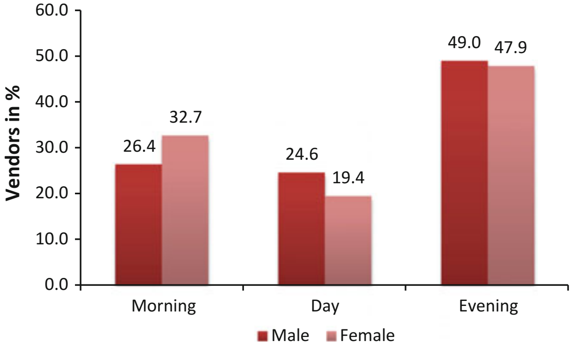

Fig. 16.7 Relative distribution of vendors by gender and trading time shift

average Nepalese standard. On average, the mean monthly expenditure for the vendors' household size of 4.7 is calculated at US$ 286. Each vendor has to earn this amount of money to sustain the livelihood.

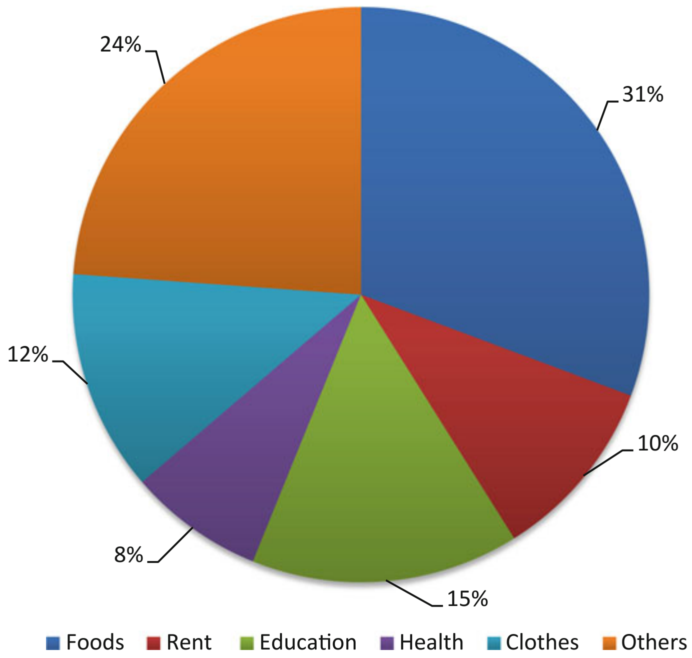

Fig. 16.8 Mean monthly expenditure of petty street vendors

The mean monthly income is US$ 289, which is slightly above the mean monthly expenditure. However, income of the petty street vendors varies among those seven item categories. The largest income source for the petty street vendors is the trading of fresh vegetables and fruits followed by clothing. The lowest income for them comes from trading of dry or package foods. The rest four categories provide more or less the same income to the petty vendors.

Though the income is slightly above the expenditure, this varies greatly among the petty vendors by type, trading shifts, festive seasons, family size and so on. Many of the petty vendors take on other options for income to manage expenses so as to maintain their families. The fact is that the marketing among the petty vendors is very competitive, due mainly to large number of participants in such business.

16.5 Discussions

The cities of the Kathmandu Valley are dynamic and often changing. Urbanization in the valley is rapid and has been rising over the years due mainly to immigrants (Pradhan and Sharma 2016), leading to change in spatial organization of economic and social activities within the cities. According to Christaller's central place theory (1966), firms often change their economic and service activities by size, distribution and number over urban space. Large cities being usually higher-order centers embrace all sorts and levels of functions, including petty informal trading. Location of market places having multitude of petty traders across the cities is to offer the items that needed frequently so that no consumer is very far from one of them. In other words, it takes account of convenience as measured in terms of physical distance from home to such places. The convenience can also be measured by an attribute like selectivity, which is expressed in terms of competitiveness of price and quality of goods and services. There exist two major types of trading firms in the cities of developing countries: One includes those providing services through fixed locations and the other one is the mobile vendors moving from place to place to offer services to the customers. Such mobile firms do originate in the cities when demand of the particular goods/services is very high or largely concentrated at specific places. But this is not a case in the rural region where mobile vendors origin when threshold demand exceeds over range, or demands are largely scattered (Christaller 1966). Alonso's bid-rent theory (1964) explains that the decision of locating firms and residents at places across the cities is based on the choices between closeness to the CBD, meaning less travel expenses, and suburban or urban periphery with more space to use, meaning greater commuting costs. Harrison and McVey (1997) and Yankson (2000) argued that the location of business activities and their features at places are the reflection of personal (private) decisions and the objective of personal decisions is to maximize consumer satisfaction and also minimize cost of service, while maximizing profit to owners. In case of greater Kathmandu, the market places dealing with essential items such as foods, vegetables and fruits which are on frequent demand or often required by the households are located dispersedly across the urban region, for which customers often do not want to travel far distance. The number and size of market places do not follow the hexagonal locational pattern of market places, as suggested by Christaller, but the pattern of hierarchical size of the market places follows somewhat the theoretical explanation, that is: large size and greater number of market places in the localities having high density of population (demand) while smaller size market places with few numbers in the localities having thin density of population. As the index considers only the number of the phenomenon under consideration, it ignores the size, which is generally associated with the size of population clusters or demand size.

Inadequacy of job opportunities in the formal sector within the cities of developing countries makes the people bound to engage in the informal sector activities like petty street vendors. This is mainly due to relatively large supply of labors by migration over actual demand (Lewis 1954; Todaro 1976). So, the informal sector remains as an important source of income and employment opportunities such as vegetables and fruits and clothing trading for urban poor in the cities of Kathmandu Valley.

In most cities of the poor developing countries, the petty informal traders often encroach upon the public uses such as pavements, walkways, parks, alleys, traffic intersections or road medians (Brown 2006). They are growing by virtue of such features such as small size, temporary nature, self-employment, no building structure, low investment, low skills and marginal groups. These are true in case of the petty vendors in the cities of the Kathmandu Valley.

The urban life in Kathmandu Valley is usually expensive due to bearing expenses by the households on room rent and maintenance, children education fee, health services, utility services, communications, entertainments and so on. The average income of the petty vendors is indeed far above the national poverty line, as well as the Kathmandu urban poverty line (CBS 2012b);[3] however, in many cases, income from a single occupation such as petty trading is inadequate even for the poor households, and therefore, they have to adopt multiple income sources to sustain their livelihood (Chambers 1995), which is not easy to many. Only few of them are lucky to get such opportunity, and the men or women with their family members (in most cases) have to work hard to keep on income-earning activities irrespective of time, hardship seasons, municipal harassments, etc. They all are most vulnerable to sustain their livelihood, when transport strikes, *bandha* (no movement of people and vehicles), improper handling of petty vendors by local government authorities, etc., which often occur in the cities of Nepal.

16.6 Conclusions

With increasing number of population by migration in the cities of Kathmandu Valley, there is growing pressure on the formal sector, which is not growing with respect to the growth of population. As a result, the informal sector such as petty street vendors is an only option to engage most of them for some time. However, the street vendors of the urban Kathmandu Valley are facing several problems and challenges. Of many, one is the absence of information on the informal sector activities including petty street vendors in Nepal. This problem is exacerbated by the lack of an official definition of such informal activities. This study is an attempt to understand the features of the informal sector particularly the petty street vendors and their livelihood. So, the discussions made here can be helpful to the urban planners and policy makers in Nepal to formulate appropriate policies and responsive legal and regulatory framework to manage informal sector including petty street vendors.

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Part IV

Geo-hazards, 4.25 Earthquake and Its Impacts

Chapter 17
Water Hazards in the Trans-boundary Kosi River Basin

Ningsheng Chen, Guisheng Hu, Wei Deng, Narendra Raj Khanal, Yunhua Zhu and David Han

Abstract The Kosi River is an important tributary of the Ganges that passes through China, Nepal and India. With a basin area of 71,500 km^2, the Kosi River has the largest elevation drop in the world (from 8848 m of Mt Everest to 60 m of the Ganges plain) and covers a broad spectrum of climate, soil, vegetation and socioeconomic zones. The basin suffers from multiple water-related hazards including glacier lake outburst, debris flow, landslide, flood, drought, soil erosion and sedimentation. This paper describes the characteristics of water hazards in the basin based on the literature review and site investigation covering hydrology, meteorology, geology, geomorphology and socioeconomics. Glacier lake outbursts are a huge threat to the local population in the region, and they usually further trigger landslides and debris flows. Floods are usually a result of interaction between man-made hydraulic structures and the natural environment. Debris flows are widespread and occur in clusters. Droughts tend to last over long periods and affect vast areas. Rapid population increase, decline of ecosystems and climate changes could further exacerbate various hazards in the region. The paper has

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proposed a set of mitigating strategies and measures. It is a huge challenge to implement them in practice. More investigations are needed to fill in the knowledge gaps.

Keyword Kosi River · GLOF · Debris flow · Drought · Soil erosion · Sedimentation

17.1 Introduction

The Himalayan region is an important part of South Asia where water plays a crucial role. Ninety percent of water in the region is from three trans-boundary rivers: the Ganges (the most densely populated river system among all the five river systems in Asia) (Walter et al. 2010), the Indus River and the Brahmaputra River. The three river basins include high mountainous areas and low-lying plains, covering parts of China, India, Nepal, Bangladesh, Pakistan, Bhutan and Afghanistan. The region is 2500 km wide and 1000 km long with an area of 2,750,000 km^2 and a population of 660 million. In addition to a large population and scarce natural resources, water-related disasters have been an important factor in contributing to long-term poor economy, political disorder and inadequate education in the region (Reynolds 1999; Ives 1986; Ding and Liu 1992). With climate change, the region's water hazards are expected to have even more impact on the local human lives and socioeconomic development.

As a representative river basin in the middle Himalaya, the Kosi River is a trans-boundary river across China, Nepal and India, and is also an important tributary to the River Ganges. The basin covers six geological and climatic belts: the Tibetan plateau, the high Himalaya, the midland hills, the Mahabharat Lekh (range), the Chure (Siwalik range) and the Terai (Dixit 2009), and has the main strata developed from the Quaternary System to the Proterozoic (Owen 1995). The average discharge of the river is 1564 m^3/s (the Chatara hydrological station provide the data), and about 49 × 10^9 m^3 of water flows into the Ganges and merges into the Indian Ocean every year (Gleick 2003). The population in the region consists of 15.3 million in 10 ethnic groups, and this number is still increasing. According to the statistics in 2010, the annual population growth rates in the region were 2% in China, 2.24% in Nepal and 1.93% in India.

This trans-boundary river has a wide range of water hazards, and as a case study, it is useful to understand the characteristics of multiple water hazards and explore potential mitigating measures. This paper describes a study based on literature review and a series of site investigations on this river basin. The site investigations for the Kosi River basin are determined based on the types and characteristics of water hazards: (1) glacier lake outbursts in the upstream of the river basin, in Tibet, China. Its influential area is in the upper and middle stream of the river basin, especially in the boundary of China and Nepal. On the one hand, the site investigation is carried out along the glacier lakes in Tibet, China. On the other hand, it is carried out at the boundary of China and Nepal for the influential characteristics of outburst flood; (2) flood hazards mainly in the middle and downstream of the river basin, in Nepal and India. For the sake of that, the site investigation of floods focuses on the two countries; (3) debris flows in the upper and middle stream of the river basin, especially in the boundary of China and Nepal. The selection for the site investigation is determined based on the types and distributions of debris flow in the river basin. There is more than one place of site investigations for each type; (4) droughts in the middle and downstream of the river basin, in Nepal and India. Clearly, there are still many knowledge gaps in this challenging region and we hope this paper will stimulate more studies in this basin. The knowledge gained would be valuable for dealing with multiple water hazards in other similar trans-boundary river basins such as the Andes, the Alps and the Rocky Mountains. The paper has proposed a set of mitigating strategies and measures in the end.

17.2 Natural and Socioeconomic Characteristics of the Kosi Basin

The Kosi River is an important river in the Himalayas and located in the middle of the region (Fig. 17.1). As a major tributary of the Ganges (Rajiv and Sujit 2009), it is the largest river in Nepal and also one of the important trans-border rivers in China. The river originates in the Himalayas with Mount Everest (the highest peak in the world) within its basin.

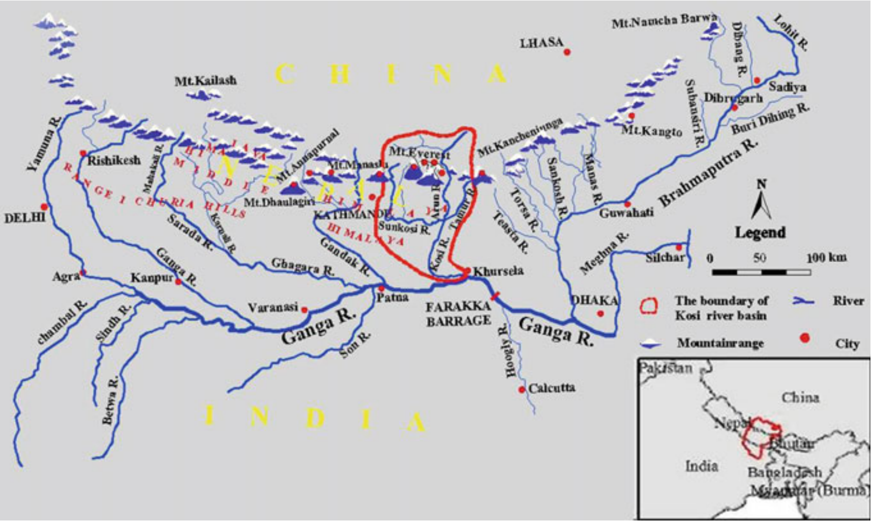

Fig. 17.1 Geographic location map of the Kosi River basin

17.2.1 River Basin Characteristics

The river generally flows to the south following the terrain of Kosi River basin (however, the upstream tributaries are along the east–west directions due to Everest). The length of the main river is 255 km with a drainage area of 71,500 km^2 (including 5770 km^2 of glaciers). Among the total basin area, 28,500 km^2 is located in Tibet, 31,600 km^2 in Nepal, and 11,400 km^2 in India (Dixit 2009).

The upstream is divided into three tributaries: the north branch is the main tributary named as Arun, the west branch as Sunkosi and the east branch as Tamor. The three come together to form the Kosi River, near Dan Kute, which finally flows into the Ganges River in India (Birol and Das 2010) (Fig. 17.2). The characteristics of the tributaries are given in Table 17.1. The part of the Kosi River valley in India is an alluvial plain in India, an important part of the Ganges plain. The part in Nepal has a great elevation drop of 8848 m (Everest) to 60 m. The part in China includes mainly the Pumqu and Poiqu rivers with the length and drainage area of 376 km, and 25,300 km^2 for the former (Che et al. 2004) and 87 km and 2018 km^2 for the latter (Chen et al. 2007).

17.2.2 Topography

From the south to the north, the terrain generally ascends till Everest and then descends. The southern region with the altitude below 2000 m is named as ‘Small Himalaya,’ and the bedrock is known as ‘Siwaliks.’ The area from the north of the Kosi River to Nyalam with the altitude between 2000 and 3000 m above sea level is named as ‘Middle Himalaya.’ The area to the north of Nyalam with the altitude above 3000 m is called ‘Greater Himalaya.’ ‘Tibetan Himalaya’ refers to the region north of Tingri. The precipitation in the Middle Himalaya area is the largest and starts to decline toward the Great Himalaya (Burbank et al. 2003).

17.2.3 Geology

The geological structure in the region is very complex (Sinha et al. 2005) (Fig. 17.3). The southernmost Ganges plain is made of the Quaternary deposits with a wide range of molasse and Siwalik gravels accumulated in the south of the lower Himalayas, which are subject to erosion from flash floods and thin debris flows. The rich gravel layers cover the areas of Sindhuli to Rajbas. There are widely developed schist and slate rocks in the lower south of the Himalayas, which are the source materials of debris flows and landslides in this arid area (including the central banks and the tributaries of the Kosi River). Our recent field visit revealed a rich deposit of

Fig. 17.2 Hydrographical network of the studied area

Table 17.1 Characteristics of the tributary rivers

No	River	Catchment area (km^2)	Mean discharge (m^3/s)	Mean sediment load (m^3/s × 10^6)	Average longitudinal gradient (%)
1	Sunkosi	18,800	471	54.2	0.0062
2	Arun	34,300	451	34.6	0.0134
3	Tamor	5800	347	29.6	0.0276

slates in an area from Kathmandu and Khuhot. In the north of the Middle Himalayas, there are widely distributed igneous and metamorphic rocks such as granite gneiss, granite amphibolite gneiss and migmatite. In the Zhangmu–Nyalam area along the left bank, there is abundant granite gneiss. In the middle of the High Himalayas, there are mainly hard rocks such as granite and granite gneiss. In the north, there is

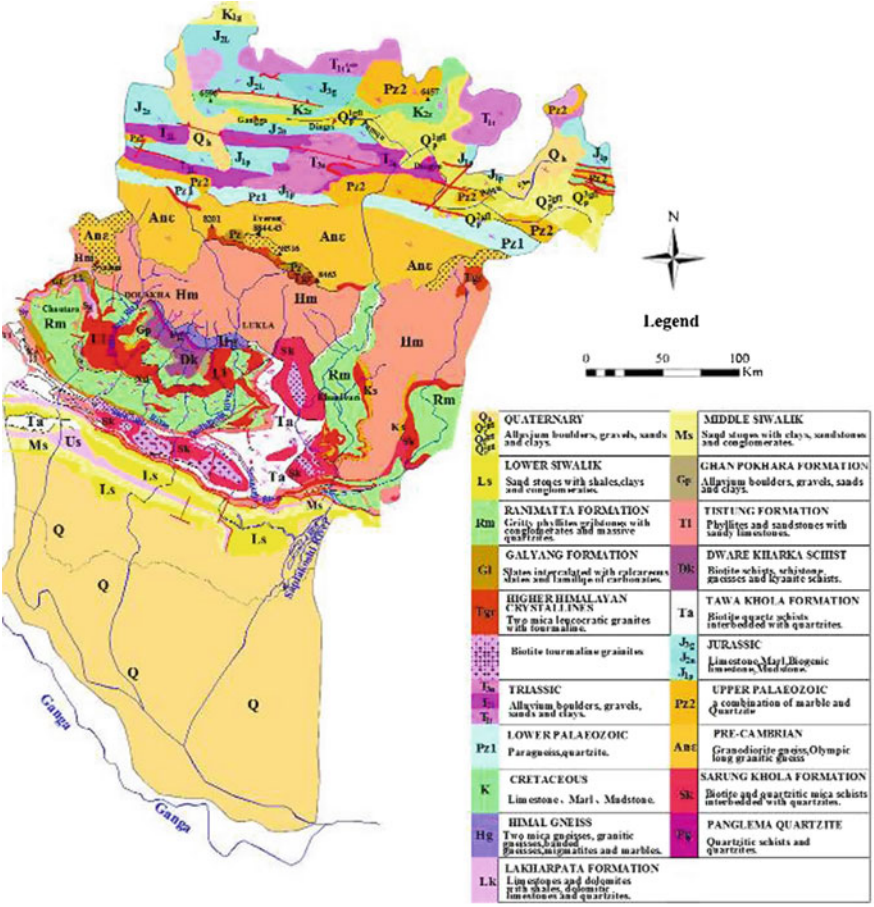

Fig. 17.3 Geological map of the Kosi River basin

mainly a set of sedimentary rock deposit of slate and schist including sandstone and limestone. The Tibetan Himalayas has a large area of sedimentary rocks and a small area of metamorphic rocks. The area from Tingri to Mount Everest base camp has many soft rock layers of well-developed slate and schist, etc. The regional structure from the northwest to the southeast has three significant faults/sutures. The main boundary fault divides the thick layer of gravel deposits and metamorphic schist slate in the south side. The main central fault has promoted the hanging wall of granite to become the roof of world. The rocks on both sides of the Yarlung Zangbo suture zone have crushed against each other and suffered from severe weathering. The aforementioned geological features are depicted by the site visit photographs in Fig. 17.4.

Fig. 17.4 Geological features from site visit photographs in the Kosi River basin

17.2.4 Climate, Soil and Vegetation

The climate in the Kosi River basin ranges from the tropical south to the frigid north. The tropical zone covers the south of Janakpur–Barehachtera, the subtropical zone covers the surrounding area along the Sino-Nepal highway to Zhangmu, the temperate zone covers the areas along a line from Zhangmu to Nyalam, and the frigid zone covers the area above the Nyalam mountain pass. Precipitation is very unevenly distributed throughout the basin. The annual precipitation is about 300–400 mm in the northern Himalayan region, 1000–1500 mm in the subtropical and tropical region and 1500–2500 mm in the temperate region. Some parts of the basin have extremely high potential evapotranspiration (such as Sunkosi), and they suffer from frequent droughts and soil erosion. The temperate region has the best vegetation cover and a clear correlation between land elevation and precipitation with the maximum precipitation at Zhangmu of 2200 m above sea level. Affected by the diverse climate and geology, the soils in the basin change from the alluvial soil and upland red loam to the yellow loam in Sunkosi, then the yellow brown loam in Zhangmu–Nyalam, and the frigid desert soil at the region above 5000 m. In correspondence with the soil and climate, vegetations in the basin change from the mixed forests of tropical/subtropical/temperate zones, to the shrub and grass land of the frigid region. The land is barren at the high frigid zone.

17.2.5 Earthquake

Seismic activities in the basin are frequent, and the region is classified as a VIII degree zone (Bilham et al. 2001). In the last two hundred years, there have been two major earthquakes with the magnitude greater than 8.0. The first one happened on August 26, 1833, at Shisha Pangma west of Nyalam (28.3°N, 85.5°E) with an intensity of X degrees and the second one occurred on January 5, 1934, at Dabanjia between Nepal and India (26.5°N, 86.5°E). Moreover, a magnitude 7.0 earthquake occurred at Pulan (30.2°N, 81.2°E) in October 1883 with its seismic intensity of 9° and a magnitude 6.25 earthquake occurred at Tingri (28.0°N, 92.5°E) on June 17, 1834, with its seismic intensity of 8°.

17.2.6 Socioeconomic Conditions

The basin has an area of 71,500 km^2 and a population of 15 millions (2009). The total GDP is about 10.4 billion USD in 2009 (i.e., less than 700 USD per capital). The region in India is mostly alluvial with subtropical climate and is very productive in agriculture. However, due to its large population (about 1000 people per km^2), the average income in the region is below the national average of India (1134 USD in 2009). The Nepalese in the region are about 6 million (1/4 of the country's population). The population density is 200/km^2 varying from 32 (Solukhumbu) to 276 (Kavre) in the central part of the Kosi River. Forty percent of the residents are below the Nepal's poverty line (higher than the national average of 30%), but the GDP per capita in the region is near to the Nepal's national average (427 USD). The population in China's territory is 94 thousands (with an average population density of 3.2/km^2 varying between 1.9 and 5.5/km^2). The GDP per capita is 1970 USD. Clearly, the region in the middle of the basin has the worst economic condition. The population density increases rapidly from the upstream to downstream.

17.3 The Characteristic of Water-Related Hazards

Water-related hazards in the Kosi River basin include glacier lake outburst, flood, debris flow, drought, etc. They are characterized by high frequencies, great impact areas, long durations and close interactions with each other.

17.3.1 Glacier Lake Outburst

The glacial lake outburst frequently happens at high-altitude and high-latitude areas, such as Canada (the Ekalugad valley 1967 from Church 1972 and the Hazard Lake 1978 from Clarke 1982), USA (Lake George 1958 from Stone 1963), Switzerland (Gomer 1944 from Wilfried 1983), Norway (Demmevatan 1937 from Clague and Mathews 1973 and Strupvatnet Lake 1969 from Whalley 1971) and Iceland (Graenalon 1939 from Thorarinsson 1939 and Gjanupsvatn 1951 from Arnborg 1955). The south slope of the Himalayas is one of most frequent glacier lake outburst areas (Reynolds 1995). There have been 33 recorded disasters resulted from glacier lake and dammed lake outbursts in the region (Liu and Sharma 1988; Richardson and Reynolds 2000), over the half of which concentrated in the upper Kosi River basin. The glacier lake outbursts in the region deserve further studies due to its high frequency and impact.

Fast glacier retreat during the past decade has resulted in the rapid accumulation of melt water in most of the moraine-dammed lakes in the basin, has increased their potential energy and reduced the shear strength of the damming material. Ultimately the loose-moraine dam will be breached, causing a GLOF (Ives 1986; Richardson and Reynolds 2000). During the past decade, Himalayan glaciers have generally been shrinking and retreating faster while moraine-dammed lakes have been proliferating. Although the number of lakes above 3500 m a.s.l. has decreased, the overall area of moraine-dammed lakes is increasing (Bajracharya and Mool 2009). That is, glaciers in the Mount Everest (Sagamartha) region, Nepal, are retreating at an average rate of 10–59 m a^{-1}. From 1976 to 2000, Lumding and Imja Glaciers retreated 42 and 34 m a^{-1}, respectively, a rate that increased to 74 m a^{-1} for both glaciers from 2000 to 2007 (Bajracharya and Mool 2009).

17.3.1.1 Frequent Outbursts

Relative to many other natural hazards, the glacial lake outburst is less frequent but has more serious impacts. Based on the observation records, there have been 17 large-scale glacial lake outbursts in the Kosi River basin (Mool 1995; Yamaba and Sharma 1993) (Table 17.2). There was a potential glacial lake outburst, but it was discovered earlier and mitigated by human interventions (Liu 2006). However, most of them were undiscovered and caused significant losses to the downstream areas, such as Cirenmaco glacial lake outburst at Poiqu, July 11, 1981; Galongco glacial lake outburst, northwest of Nyalam County Xigaze region, May 23, 2002, and June 29; Tarraco glacial lake outburst, in Nyalam County August 28, 1935; and Ayacuo glacial lake outburst in Tingri County, August 17, 1968, August 17, 1969, and August 18, 1970. Among them, the most severe ones are Tarraco glacial lake outburst (August 28, 1935) in Nyalam County and Zhangzangbo glacial lake outburst in 1964 and 1981 (Lü et al. 1999).

Table 17.2 Historical GLOFS in the Kosi River basin

No	Lake	Date	Volume/peak flow (10^6 m^3/m^3 s^{-1})	Summary of devastation
1	Taraco, Nyalam, China	1935.8.28	6.3/–	Flooded 66,700 m^2 of wheat field
2	Qiongbixiamaco, Yadong, China	1940.7.10	–/–	Flood, debris flow
3	Gelhaipco, Dinggye, China	1964.9.21	23.4/4500	Damaged Nepal–China Highway, 12 trucks, etc.
4	Longdaco, Jielong, China	1964.8.25	–/1000	Flood, debris flow
5	Ayaco, Tingri, China	1968.8.15	–/–	–
6	Ayaco, Tingri, China	1969.8.17	–/–	–
7	Ayaco, Tingri, China	1970.8.18	90/–	Damaged roads and bridge up to 40 km away
8	Zhangzangbo, Nyalam, China	1964	–/–	
9	Zhangzangbo, Nyalam, China	1981.7.11	19/1600	Destroyed bridge, highway, hydropower station, farmland
10	Yindapuco, Dinggye, China	1982.8.27	12.8/–	Devastated 8 villages and farmland, killed 1600 livestock
11	Jialong lake, Nyalam, China	2002.5.23	–/–	–
12	Jialong lake, Nyalam, China	2002.6.29	–/2.36×10^7	Destroyed bridge, economic loss amounts to 3.05 million RMB
13	Phucan, Tamur Khola, Nepal	1980	–/–	Water level raised by 20 m. Including heavy debris of large rocks, etc. Damaged forest, river bed, etc.
14	Jinco, Arun River, Nepal	1985.8.27	–/–	Damaging eight villages, livestock, farm land, roads, bridges, etc.
15	Nare Drangka, Dudh Kosi River, Nepal	1977.9.3	–/–	Damaging min-hydro plant, roads, bridges, cultivation fields, etc.
16	Dig Tsho, Dudh Kosi River, Nepal	1985.8.4	–/2000	Destroying Namche hydropower plant completely, damaging roads, bridges, farm land, livestock, houses, inhabitants
17	Chubung, Dudh Kosi River, Nepal	1997.7	–/–	Damaging houses, cultivation field at Beding village

Although the Kosi River basin is 2.6% of the southern slope region of the Himalayas (2.75 million km^2), 51.6% of glacial lake outbursts over the whole region occurred in the Kosi River basin. In China, the area of the Kosi River basin is 28,500 km^2 (2.4% of Tibet of 1.22 million km^2), but 66.6% of glacial lake outbursts occurred in the river basin (12 out of 18) (Liu 2006; Fan et al. 2006).

17.3.1.2 The Extreme Discharges

The discharges from glacier lake outbursts in the Kosi River basin are extremely large which can reach over 100 times of the normal discharge (Xu 1985). The outburst impact areas are widespread and could reach to tributaries by three levels up. For example, the summer normal runoff at the Zhangzangbo River is 100 m^3/s (at Zhangmu Port). The maximum runoff caused by the Zhangzangbo glacier lake outburst in 1981 reached 16,000 m^3/s, 160 times greater than its normal runoff (Xu 1985). Apart from the entire Zhangzangbo River basin, the disaster area was distributed mainly in the Boiqu River basin higher than the Zhangzangbo River basin. The China–Nepal highway and its related infrastructure were severely damaged.

17.3.1.3 Severe Consequences

Glacial lake outbursts in the Kosi River basin can lead to serious trans-boundary disasters. For example, the Zhangzangbo glacial lake outburst in 1981 destroyed the Sunkosi hydropower plant in Nepal with 200 deaths. Many villages and roads along the river within 60 km were severely damaged (Fig. 17.5). The direct economic losses were estimated at 7.2 billion Nepal dollar, and the indirect economic losses were at 13.8 billion Nepal dollar. The total economic losses were at 3 billion US dollars, equivalent to 20% Nepal's national revenues (Meon and Schwahz 1992).

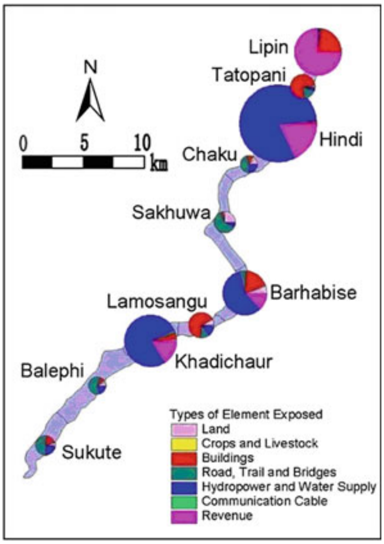

Fig. 17.5 Estimated amount at risk with flood level same as in 1981 GLOF

17.3.1.4 Cascading Debris Flows and Landslides Hazard

Since the massive floods triggered by glacier lake outbursts usually occur in highlands above 5000 m, those floods could seriously erode the slopes of the Greater Himalaya and Middle Himalaya. They could also trigger debris flows and massive landslides. For example, at Quxam–Friendship bridge (Nyalam) (Fig. 17.6), a large number of traction type landslides (707 times) were induced since the Zhangzangbo glacier lake outburst in 1981.

17.3.2 *Flood*

The Kosi River basin suffers from frequent floods, and in the last 60 years, Nepal has been affected by 10 large-scale floods from the Kosi (Dixit 2009) and a similar number of major floods also occurred in India (Bhalme and Mooley 1980). Those floods have caused severe sedimentation problems.

Those floods are a result of human–nature interaction. On the one hand, the frequent rainstorms in the river basin lead to the increase in floods directly. On the other hand, there are communication problems in the management of hydraulic engineering facilities. Due to a lack of shared information of early warning between the upper and downstream countries, information on the floods erupted in the upper stream fails to be passed on to downstream communities so insufficient warning is issued for any pre-emptive actions to operate hydraulic structures for flood defense.

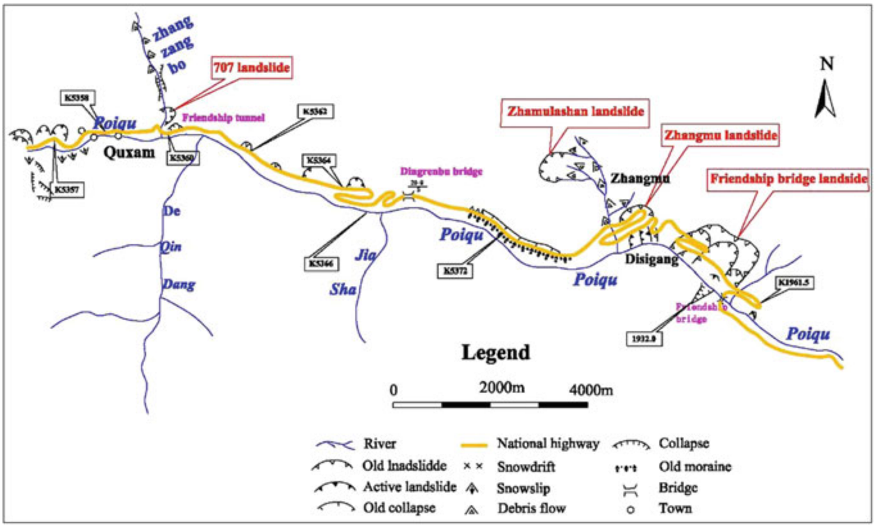

Fig. 17.6 Geomorphic hazards distributions from Quxam to Friendship bridge along Poiqu

17.3.2.1 Flood and Sedimentation

The Kosi River basin is highly erodible, and its erosion modulus is 19 m^3 ha^{-1} yr^{-1}. If the sediment density is calculated by 1.8 g/cm^3 (based on the field investigated data), the erosion modulus is 3420 t/km^2/a and this is greater than the main stream of the Yellow River in China whose erosion modulus is around 2330 t/km^2 (Zhao and Ba 2002; Ran et al. 2004; Feng et al. 2010). A recent flood in August 18, 2008, caused 3–7 ft of sediment deposition (Rashmi et al. 2010). The Kosi River transports 120 million m^3 of sediment per year into the downstream and its river mouth moved westward by 115 km in the past 220 years (Yamada 1991).

17.3.2.2 Floods Risk Management

The flood damage from the Kosi River usually occurs in the middle and lower reaches. Although the river dykes and many hydraulic structures (such as sluice gates) along the river are designed and constructed to stand 100 year floods, their effective management has not been achieved. The flood embankment is above 4 m, and the channel width is more than 1000 m. Based on a simple estimation, such a channel should be able to cope with a flood discharge up to 12,000 m^3/s (the average water speed is 3 m/s based on the field investigation, 27° 28′45″N, 85° 44′ 11″E). However, a flood of 50-year return period broke out at the border between Nepal and India on 18 August, 2008 (Ramaswamy 2008). As a result, 2.1 million people were affected with 42 dead and 150 missing, and 650 km^2 of land flooded. One of the main reasons for this severe flood damage was that the downstream sluice gates were not opened earlier enough to discharge the flood water since no information was shared between the upstream and downstream countries. Although Nepal and India signed the Kosi River agreement in 1954 and has set up appropriate institutions, in order to jointly control and manage the Kosi River floods, no practical information sharing activities have happened. In fact, the Joint Committee on Water Resource (JCWR) has stopped its meetings since 2004. In addition, the Joint Nepal–India Ministerial Commission on Water Resource (JNIMCWR) stopped its function from 2006 and the Kosi High level Committee (KHLC) was not in action since 2006.

17.3.3 Debris Flow

Debris flows in the Kosi River basin can be classified into four types (Fig. 17.7). Tibetan Himalayas is extremely dry, and its physical weathering is very intense. Small-scale rainfall-triggered debris flows are common. In the high lands, the GLOF debris flows are triggered by glacier lake outbursts, but they occur infrequently. In the middle of the basin, rainstorm debris flows are widely distributed. In this area, there are rich loose materials from metamorphite slate, schist and phyllite.

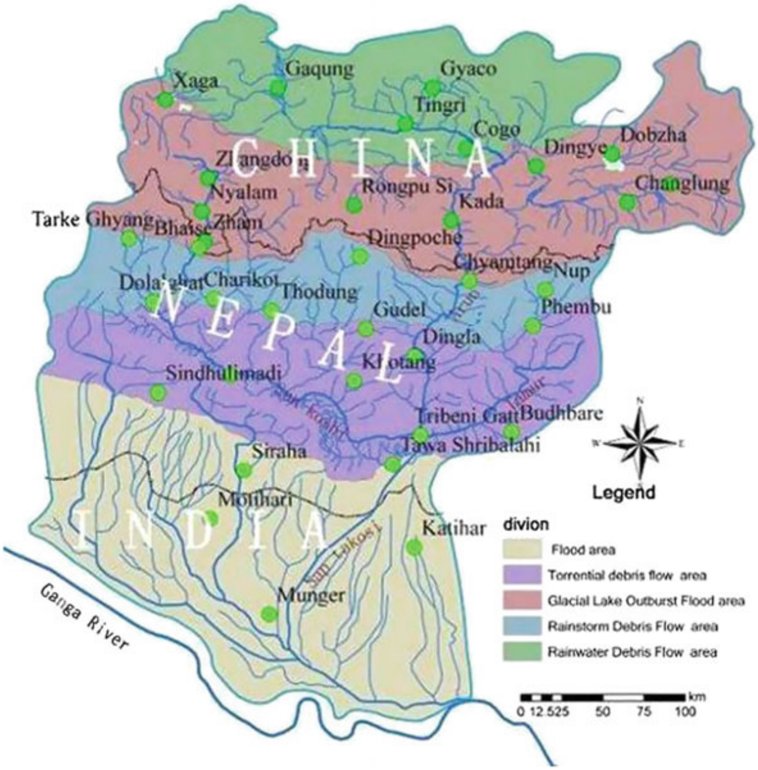

Fig. 17.7 Regionalization of debris flow types in the study area

These metamorphites offer a large amount of solid materials for the debris flow. In the meantime, summer rainstorms are highly concentrated from June to August (over 70% of the annual precipitation). In addition, the dry soils are highly collapsible and changeable under the action of rainfall, which could trigger the outbreak of geotechnical mudslides easily. There are more torrent debris flows in the small Himalayas.

The rainfall flood debris flows in Tibetan Himalayan concentrate along the Sino-Nepal highway. Figure 17.8 illustrates the Menbudui gully debris flow field investigation (28° 44′56.0″N, 86° 09′38.3″E). The area of the gully is 2.3 km^2, and the elevation drop is 450 m (5134–4684 m). The bedrock of the gully is J_{3m} Slate and metamorphose stratum. In the debris flow deposit, the gravels with more than 2 mm sizes are 62%, the sands of 0.05–2 mm are 24%, the powder grains of 0.01–0.05 mm are 3%, and the clay particles with less than 0.005 mm are 6%. There are 1.25 million cubic meters of loose solid materials in the investigated site, and they occupy 5.3% of the whole area. The gully has 1–2 debris flows every summer. The debris flow alluvial fan covers an area of 875 m^2. The accumulated materials of each debris flow event are estimated at several hundred thousands of cubic meters.

Engineering measures such as barrage and platoon guide are effective tools to protect the highway from debris flow damages.

The Zhangzangbo debris flows are a type of the Himalayan glacial lake outburst debris flows located at Nyalam County, on the southern slope of Himalayas. At 10:30 on July 11, 1981, the Cirenmacuo glacial lake outburst and eroded the loose solid materials along the way to form a loose debris flow. The Zhangzangbo ditch (28° 04′46.2″N, 85° 59′59.7″E, and its outlet altitude at 3259 m) was a tributary of the River Boqu with an 8.5-km-long channel and a drainage area of 50.5 km^2 in a broad-leaved form (Fig. 17.9). The highest point of the catchment is 6109 m, and

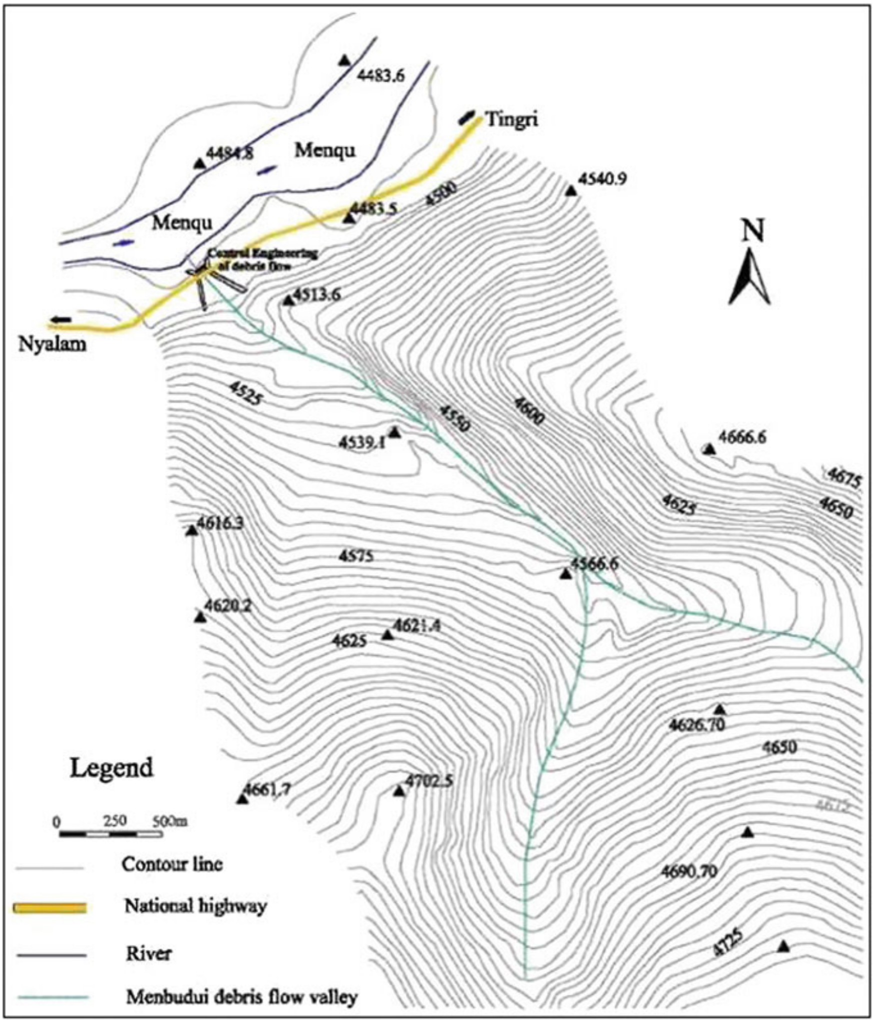

Fig. 17.8 Terrain map of Menbudui gully along the Sino-Nepal highway

the outlet attitude to the Boqu River is 3168 m with a relative relief of 2941 m. The glaciers and permanent snow covered an area of 27.7 km^2 (45.15% of the catchment). The average slope of the hillside above the road is >40°. At an altitude of 3550 m above the valley, including seven major tributaries, the vertical channel gradient is large, about 149.6–478.9‰. There are many high mountains, deep valleys and steep slopes in the Zhangzangbo catchment. The exposed strata are Presinian Kornhill Bridge Group (AnZk) with Quartz mica schist, biotite gneiss, and gravel of Quaternary slope deposits from soil residual. Landslides and avalanches are widespread. The Zhangzangbo Gully moraine platforms are widely distributed on both sides. Modern glacier tongue and front surface are covered by lateral moraine and end moraine. Before the 1981 outburst, the Cirenmacuo glacial lake was located in the branch gully 3# of the Zhangzangbo ditch with its water levels between 4640 and 4690 m. The glacial lake was 1.5 km long with an area of 0.643 km^2. The water storage capacity was only 2×10^7 m^3. Since this debris flow, 707 landslides have occurred and more are expected in the future. The roads in the area are frequently blocked during the rainy seasons.

The arid valley of the middle Kosi River mainly suffers from rainstorm debris flows. A typical example is located at the Khurkot debris flow gully (Figs. 17.10 and 17.11). The basin area of the gully is 3.8 km^2. There have been a large number of landslides in the middle upstream of the gully. In the past, the debris flow

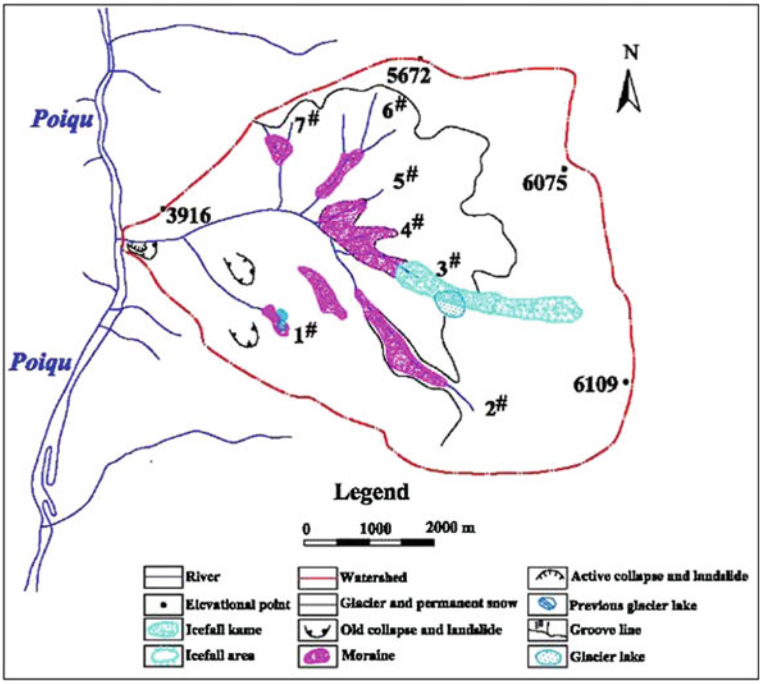

Fig. 17.9 Basin characteristic map of Zhangzangbo debris flow gully and 707 landslides

Fig. 17.10 Field investigation of Khurkot debris flow gully

activities had led the river to change its courses. In a midnight of July 1985, the gully experienced a debris flow with eight deaths. The maximum debris flow boulder reached 4.8 m × 2.4 m × 1.9 m. The flood and debris flow lasted for 3–4 days. The debris flow contained a lot of stones, woods and roots. The debris flow speed is equivalent to people's running. According to the clay content analysis measured in the debris samples, the debris flow density was about 1.8–1.6 g/cm^3. The peak flow in the measurement section was 80–100 m^3/s, and the velocity reached 5–6 m/s. The accumulated debris volume reached 30,000 m^3.

In the small Himalayas, debris flows caused by torrents are quite common. They often threaten roads, farmlands, residential areas and other infrastructures and lead to the damage of forest along the way. Mitigating engineering measures include stone walls with barbed wire, trap dams combined with diversion channels (Fig. 17.12). The photographs were taken at the investigation site: 27° 08′13.2″N, 85° 56′03.9″E and altitude 428 m.

17.3.4 Drought

The Kosi River basin has a severe drought problem characterized by vast affected areas and interrupted human activities. The drought mainly affects the middle Kosi River basin, the Tibetan Himalayas and the downstream plain. In the Indian region alone, there were 11 large-scale droughts during a 70-year period (1905–1975) with serious losses in human lives and properties (Bhalme and Mooley 1980). In Nepal, major droughts occur once every 2–3 years (Sharma 1979).

The middle Kosi River basin's potential evapotranspiration is about 1500 mm–2000 mm/year. However, the annual precipitation in the area is only about 900–1200 mm. Therefore, the region is hydrologically short of water. In addition, the seasonal distribution of precipitation is very uneven with 70% in the summer months from June to August (Fig. 17.13). The vegetation cover is less than 60%. The regional human population has significantly expanded, and 30% of the arable lands are located in hilly slope lands with more than 15° in slope gradients.

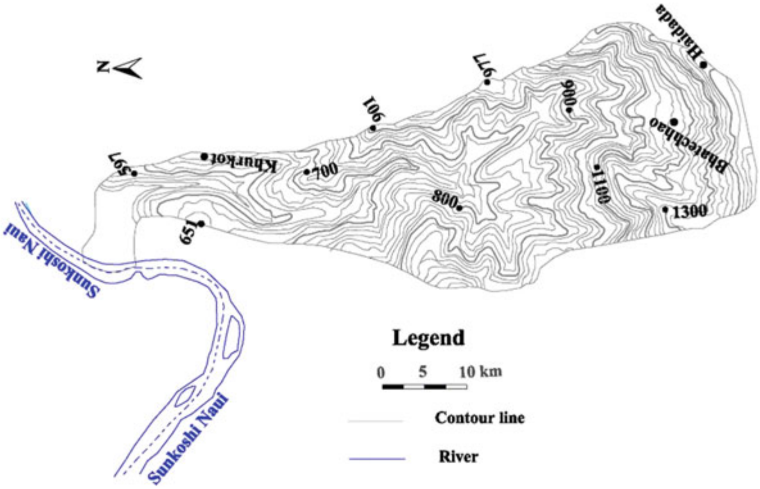

Fig. 17.11 Terrain map of Khurkot basin

Fig. 17.12 Control engineering

There is a severe shortage of hydraulic engineering facilities to store and regulate water supply. All those factors jointly exacerbate the drought problem. In the future, global climate change has a potential to amplify the existing drought situations (Xue et al. 2009).

A field visit to a village located at the middle and lower reaches of Nepal Jhigu (27° 37′50.5″N, 85° 38′26.5″E with elevation 830 m) demonstrated a typical example in the drought region (Fig. 17.14). In 1972, a new highway was constructed and there was an economic boom in the surrounding area. More population moved in and commercial crops such as mongo, papaya and others were widely planted. Forested lands were destroyed (from 70 to 80% dropped to 40–50%), and soil erosion was very serious. During the drought season, lowland residents need to excavate ditches in the river bed to get water. The residents on the hillslopes need to drill wells at least 20 m deep. For the residents on the high land, the wells have to be 74 m deep. During our site visit, more than 90% of the rivers are totally dry. The farmlands in the region are mainly rain fed, and only 10% of them are irrigated. There are massive glacier retreats in the Tibetan Himalayas. Since the annual precipitation in the area is only about 300–400 mm, many lakes are shrinking. The Peigucuo Lake has shrunk by 5–6 m every year since 2006.

17.4 Mitigating Strategies and Measures

Clearly, there are urgent demands for mitigating strategies and measures to tackle the water hazards in Himalayas. The existing strategies and measures are as follows (Bajracharya and Mool 2009; Mool et al. 2001; Dixit 2009):

1. Monitoring—key indicators including changes in the lakes and their impoundments which should be observed using different data sets at varying time scales to evaluate glacier hazard and stability of moraine dams;
2. Early Warning—provision of timely and effective information, through identified institutions, that allows individuals exposed to imminent hazards to take action to avoid or reduce their risk and prepare for effective response;
3. Mitigation—measures to mitigate hazard risks by structural and non-structural means;

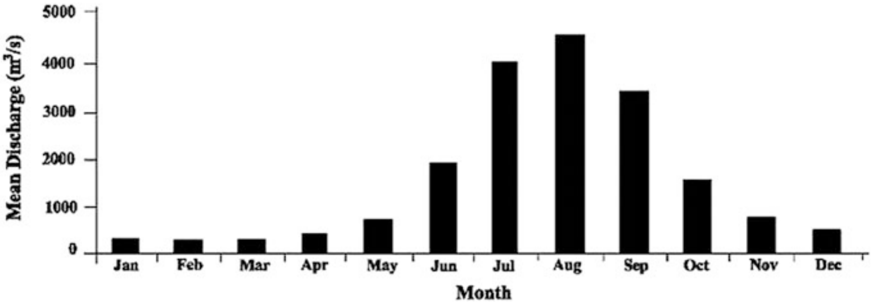

Fig. 17.13 Monthly distribution of the Kosi River mean discharge (the Chatara gauge station)

Fig. 17.14 Site visit to the drought region in Nepal

4. Awareness Raising—education to raise local awareness and increase the relevant knowledge about how to respond;
5. Community participation and institutional arrangement.

Although the existing strategies and measures are very valuable for dealing with water hazards in Himalayas, there are still many shortages in them. For example, the current monitoring and early warning systems cannot share the relevant information between upstream and downstream areas. An effective cooperative management model in the basin is needed. The scales and modeling tools of structural and non-structural measures should be different according to the different types of water hazards. For examples, it should mainly take preventive and non-structural measures to mitigate the glacier lake outburst. For the drought, small terraced reservoirs and composite hydraulic structures should be used to provide power, irrigation and water supply, and so on. In this study, we found that the existing studies on strategies and measures were focused on a limited area (e.g., a country or a town) and one or two types of water hazards in Himalayas (Richardson and Reynolds 2000; John and Shroder 1989). Since systemic and comprehensive studies are rare in the region, we propose the following mitigating strategies and measures to tackle various types of water hazards for this trans-boundary river basin.

17.4.1 Mitigating Strategies

The Kosi River is a typical river among many trans-boundary rivers in Himalayas. However, little research has been carried in the region and scientific and technological support on natural hazards is lacking. There is an urgent need to deal with the natural hazards in order to protect local residents and promote sustainable development in the region. We propose the following strategies (summarized in Fig. 17.15).

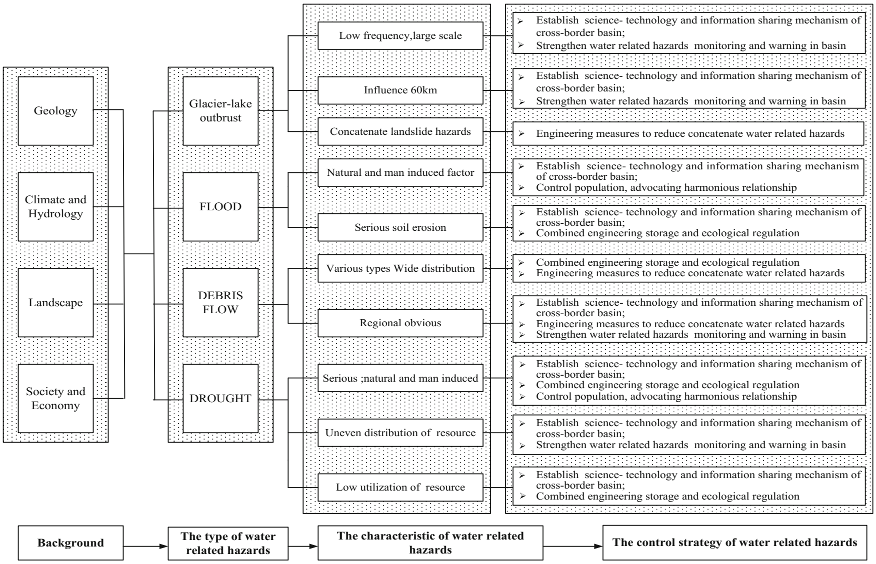

Fig. 17.15 Mitigating strategies for the Kosi River water hazards

17.4.1.1 International Collaboration

The Kosi River runs through three nations (China, Nepal and India). It is important to collect and share the relevant information across the nations in meteorology, hydrology, geology, ecology and socioeconomic conditions. Collaborative scientific research is needed to explore and understand the characteristics of water-related hazards. An integrated information database should be established for sharing among the countries concerned and the international research community. Water resources management should be coordinated among the countries to minimize the potential conflicts and maximize the common benefits. Measures should be taken to control the rapid population increase in the region. The harmony between human, natural and resources should be promoted.

17.4.1.2 Integrated Water Resources Management and Hazard Mitigation

Joint intergovernmental policies on water resources and hazard mitigation should be established. Flood water may be turned into water resources if there are sufficient water storage facilities. For a start, it may be useful to set up a demonstration area to test and implement such policies (e.g., the Poiqu–Sunkosi area) so that valuable experience and lessons could be learned. With the accumulated knowledge gained, it may be possible to apply the improved policies to other parts of the basin.

17.4.1.3 Interdisciplinary Measures

Bio-engineering measures for ecological restoration are ideal long-term solutions. However, they should be complemented by other engineering measures since the Kosi River basin suffers from very uneven water distribution, poor vegetation cover, inefficient water resources utilization that prevent the bio-engineering measures to take full effect. In addition, non-engineering measures such as hazard early warning systems should be developed. A systematic monitoring system should be built with appropriately sited meteorological and hydrological stations in the region. Satellite and numerical weather models can also provide valuable warning information. Effective warning dissemination channels should be established.

17.4.1.4 Cascading Hazard Control

Glacier lake outbursts are able to trigger debris flows and floods. They will in turn cause severe erosion along the downstream river banks. Erosion is able to trigger widespread landslides. In order to mitigate cascading hazards, we suggest that more effort should be placed in monitoring the upstream basin for early warnings. Engineering measures such as dams could be built in the middle basin to regulate the river discharge in order to prevent or reduce the water hazards.

17.4.1.5 Education and Training

Public awareness of the hazards will help local communities to actively participate in hazard mitigations. Various education and training schemes should be explored to find a suitable system effective for the region with consideration on local culture, population, infrastructure and hazard types.

17.4.2 Mitigating Measures

17.4.2.1 Glacial Lake Outbursts and Cascading Disasters

The integrated measures include the combination of monitoring, warning, engineering structures and watershed management (Fig. 17.16): (a) for glacial lake outbursts, risk assessment on glacial lakes should be carried out. Monitoring and early warning systems should be developed. The observations should include temperature, precipitation, lake water level and video images. The information should be disseminated to the stakeholders in different countries (mainly China and Nepal for glacial lake outbursts); (b) for debris flows, engineering design standards

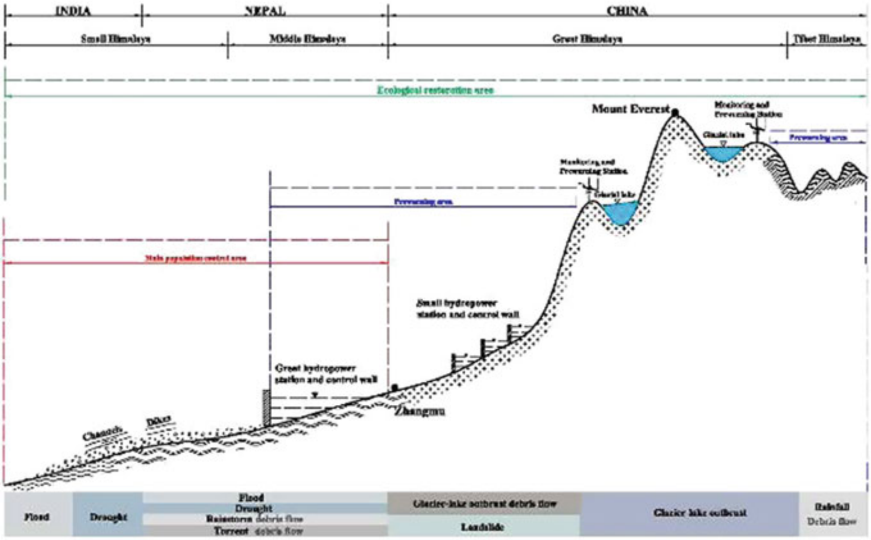

Fig. 17.16 Mitigating measures for the Kosi River water hazards

should be modified to reflect the increased discharges from the glacial lake outbursts. Engineering structures such as bridges should be designed with long spans and no piers in the main valleys (e.g., for the Sino-Nepal 707 Bridge, its main span is 200 m); (c) for landslides, since the floods from glacial lake outbursts erode the downstream slope foot, the lands above are disturbed to initiate landslides. Step dams should be constructed to ensure the slope stability, and dams should be high enough to stand above the debris flow siltation.

17.4.2.2 Storm Flood-Induced Debris Flows

Debris flows from storm floods are mainly distributed in the Himalayas at the upstream of the river basin and the small Himalayas in the middle basin where clastic rocks and pebbles are well developed. The scales of those debris flows are mainly small or medium. Prevention and control methods should adapt to the regional characteristics of socioeconomic development and debris flows. They may include (a) in Tibetan Himalayas with sparse population, debris flows from storm floods are on small scales and could be treated with engineering measures. Non-engineering measures are complementary; (b) in the middle Kosi River basin, debris flows are more wide spread with different scales. The roads have been built with low standards against water hazards and many residents live in alluvial fans. Large boulders are visible in this area which could cause significant damages during debris flows. Mass education on water hazards should be carried out to increase the understanding of local residents on the early signs of imminent hazards. For concentrated populations (such as towns), engineering measures should be used to mitigate the hazard risks and non-engineering measures should be used to complement the engineering ones.

17.4.2.3 Droughts

Drought is concentrated in the middle and lower Kosi River basin. Since the population density is very high in those areas, the consequences of droughts are severe. Possible measures are (a) to construct cascade reservoirs to store water from wet seasons for use in dry seasons. The reservoirs should be of multiple purposes such as hydropower, irrigation, water supply; (b) to control the rapid population increase and restore the damaged ecosystem. Water resources assessment should be carried out so that the population and water demand could be appropriately matched.

17.4.2.4 Floods

The flooding disaster is mainly concentrated in the downstream plains of the Kosi River. Currently, the embankments are of high standards. Siltation of the river is a major long-term problem. Mitigating measures include (a) to reduce upstream land soil erosion in order to reduce river siltation; (b) to increase monitoring of the real time river information so that hydraulic structures could be operated more effectively to ensure efficient passing through of flood waters.

17.5 Conclusions

This paper describes water-related hazards in the Kosi River basin through a comprehensive literature search and site investigations. Although the basin is only 71,500 km^2 in size, it has the largest elevation drop in the world (from 60 m to over 8000 m including Mt Everest) and covers a broad spectrum of climates (from tropical, subtropical, temperate to frigid zones), soil and vegetation. It is a challenge for the existing earth system models to be applied here. It would be very interesting to test modern Numerical Weather Prediction (NWP) models in this region to check whether the models could cope with this highly heterogeneous domain. The multiple water hazards such as glacier lake outbursts, debris flows, landslides, floods, droughts, soil erosion and sedimentation are all challenging problems in science and engineering. Those hazards could be further exacerbated by the rapid population increase and climate change. Detailed quantitative analysis from the hydrometeorological and demographic data is needed to assess their contributions to the hazard change. Since the river passes through three nations with different socioeconomic development states, international collaboration in dealing with water hazards is crucial. We hope this paper will draw attention to this region from the international research community and stimulate more active research to deal with aforementioned natural and anthropogenic problems.

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Chapter 18
Landslides Inventory and Trans-boundary Risk Management in Koshi River Basin, Himalaya

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Abstract Koshi River basin, which is a trans-boundary basin shared by China, Nepal and India, covers an area of about 87,500 km^2. This study investigated the landslide locations in this basin by means of interpreting remote sensing images as well as field work. We could map 5653 landslides that are located within China and Nepal. Landslide caused different kinds of disasters including damage to public and private properties. The most common hazard pattern is supplying sources to debris flow, accounting for 48.38% of the number of landslides. The following patterns are soil erosion and blocking river, accounting for 25.18 and 18.98%, respectively. Cascading hazards related to landslides are very common in Koshi River basin. Three main cascading events were found there: landslide-dammed lake-outburst flood, GLOF-landslide and landslide-debris flow. These features make the disasters extend temporally and spatially. A framework for risk management in trans-boundary river basin was proposed to develop cooperation at academic and administrative levels among the involved countries.

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Keywords Landslide inventory · Trans-boundary · Koshi River basin · Himalaya

18.1 Introduction

Due to the Himalayan region's rugged topography, active tectonics, soft and fragile rocks, frequent earthquakes and concentrated rainfalls during monsoon periods, landslides have become the most devastating hazards with characteristics of wide distribution, large quantity and high frequency (Laban 1979; Dhital et al. 1993; Dahal and Hasegawa 2008). Every year landslides cause causalities and huge economic loss, and they even prove to constrain economic development in certain regions of the basin.

Landslide risk management is an essential method for risk reduction and mitigation. The basic work for the management is landslide inventory, which includes causative factors collection, characteristics analysis and landslide investigation. The following step is calculating the potential loss caused by landslide. The final work is mitigating or avoiding the risk by means of engineer control, landslide avoidance and disaster response. Generally, landslide risk management includes four phases: the first and basic phase is landslide inventory, which is based on remote sensing, geographical information system technology and field work; the second phase is landslides susceptibility and their hazards assessment, aiming to show the area being prone to sliding and to know their scale and frequency; the third phase is to identify the elements that would be effected by landslides so as to carry out risk assessment; the last phase is to manage the landslide data, to establish methods of engineering and ecological control as well as to make evacuation route and carry out escape training.

Like in other mountainous regions, several researches have carried out landslide investigation (Shorder and Bishop 1998; Hewitt 1998; Khattak et al. 2010), susceptibility assessment and risk evaluation in the Himalayan region (Dahal et al. 2008; Kamp et al. 2008; Das et al. 2010). However, in this region there are many trans-boundary rivers, i.e., their up reaches and down reaches belong to different countries. Sometimes the risk induced by landslide crosses border line and affects several other counties downstream. This fact brings new issues for landslide risk management. The Koshi River basin, a trans-boundary river basin located in the central Himalayas, was taken as the study area. Landslide investigation was conducted based on both remote sensing image interpretation and field work. Disaster patterns and cascading events related to landslide are summarized. A framework for trans-boundary landslide risk management is finally discussed.

18.2 Study Area

Koshi River is located in the central Himalayas and is a major tributary of the Ganges River. It is a trans-boundary river that covers parts of China, Nepal and India. The upper reaches of the Koshi River basin consists of mountainous region belonging to Nepal and China, where landslides predominate, whereas the river flows through flat land in India; hence, flooding occurs frequently there.

The upper reach of the Koshi River contains three tributaries: the north tributary is the main stream named as Arun River, the west one as Sun Koshi and the east one as Tamor. After the three tributaries join together, the river is named as Koshi River (Fig. 18.1).

The topography of the Koshi River basin ascends from south to north. Elevation rises from 60 m (outlet of Koshi River) to 8844 m (Mountain Everest) and descends to near 4000 m at the north side of Mountain Everest, which is the southern edge of Tibetan Plateau. The physical features of the basin can be classified into 9 divisions from north to south: Terai, Siwalik Hills, Mahabharat Lekh, Middle Mountains, Transition belt, Great Himalaya, Inner Himalaya, Tibetan Marginal Range and Tibetan Plateau (Ives and Messerli 1989).

The climate in the Koshi River basin ranges from tropical to frigid significantly correlated with elevation from south to north. The basin receives most of the

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Fig. 18.1 Location of Koshi River basin precipitation from July to October (monsoon season), and the precipitation varied regionally and temporally there. Tropical climate zone locates in the south of the basin with elevation lower than 1000 m. Subtropical zone locates in the region with elevation of 1000–2000 m. The region with elevation of 2000–3000 m is temperate climate zone. The subtemperate climate zone locates in the region with elevation of 3000–4000 m. The alpine climate zone locates 1000 m up to the subtemperate climate zone, and the snow line is above 5000 m generally.

18.3 Dataset and Methodology

Landslides include a wide range of mass movements controlled by gravity. Various scientific disciplines have been developed to define the types of landslides. Landslide classification is mainly based on the type of material and type of movement. The material types include rock, earth, soil, mud and debris, and the movement types include fall, topple, slide, spread and flow. Landslide classifications are the combination of the two terms, such as rock fall, rock slide, earth slide, earth spread. (Varnes 1978). In this study, debris flow is not included because its mechanism is different from other landslide types.

Topographic maps, Landsat ETM/TM and Google Earth were utilized to identify landslide boundaries. Topographic maps were created based on the aerial photographs taken in 1992. Landslides were marked on the maps (Fig. 18.2a), and then digitalized landslide boundaries were produced. In this way, a total of 3559 landslides were obtained in Koshi basin in Nepal. Alternatively, Landsat ETM/TM image were used to identify landslides by manual image interpretation (Fig. 18.2b). Google Earth supplies high-resolution remote sensing imageries (Fig. 18.2c), where small landslides can be recognized. Because of the low precision of these data

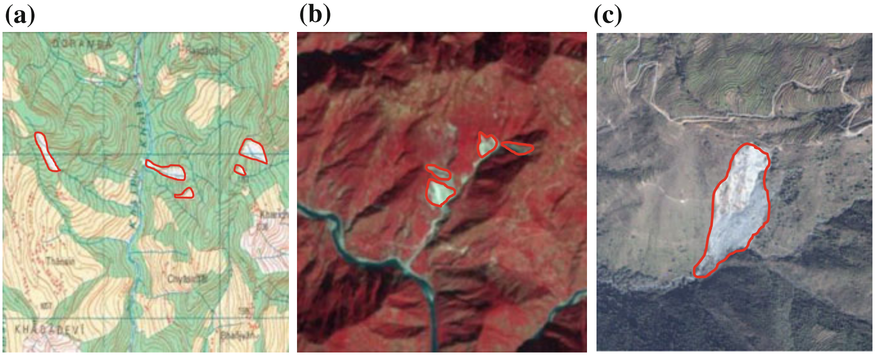

Fig. 18.2 Landslide identified by topographic map and remote sensing images: **a** landslides in topographic map, **b** landslides in Landsat ETM image, **c** landslides in high-resolution image from Google Earth

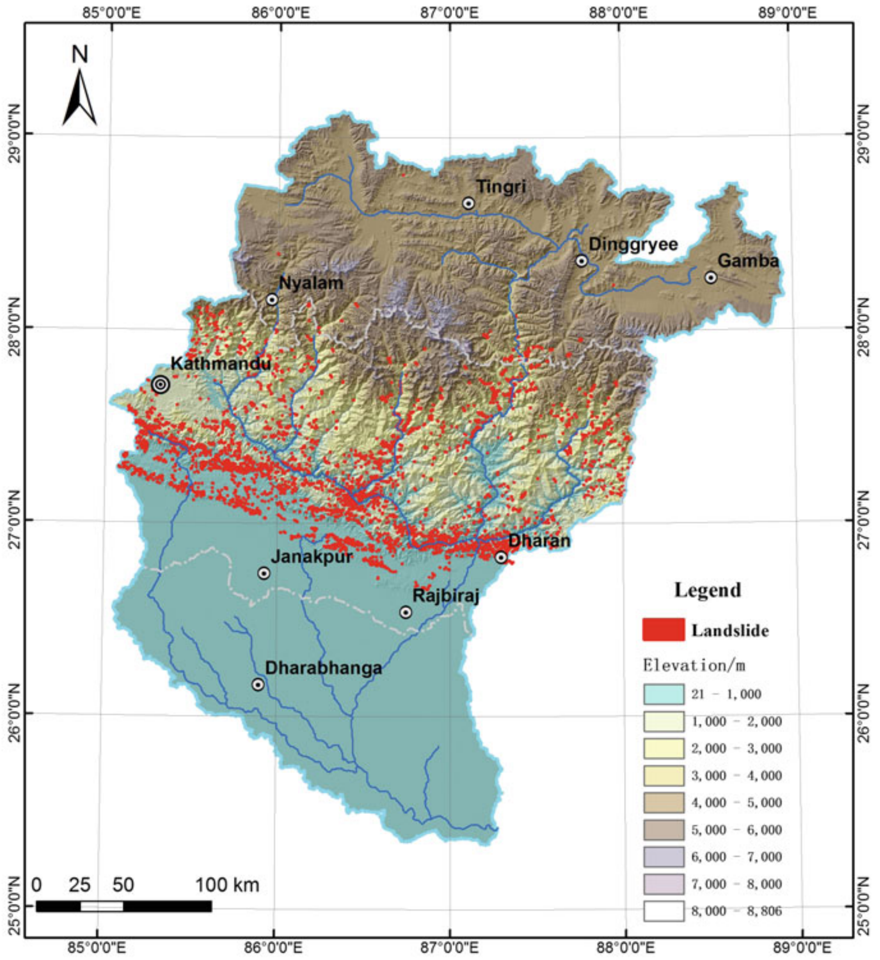

Fig. 18.3 Landslides distribution map in the Koshi River basin

source, Landsat ETM imageries and ASTER DEM data were therefore used to adjust the location of landslides. Thus, a total of 3402 landslides were mapped in the Koshi River basin, of which 3285 landslides are located in Nepal and the remaining 117 in China (Zhang et al. 2016).

By combining these two sets of landslide data and deleting overlapped landslides, we finally mapped a total of 5653 landslides in the Koshi River basin (Fig. 18.3).

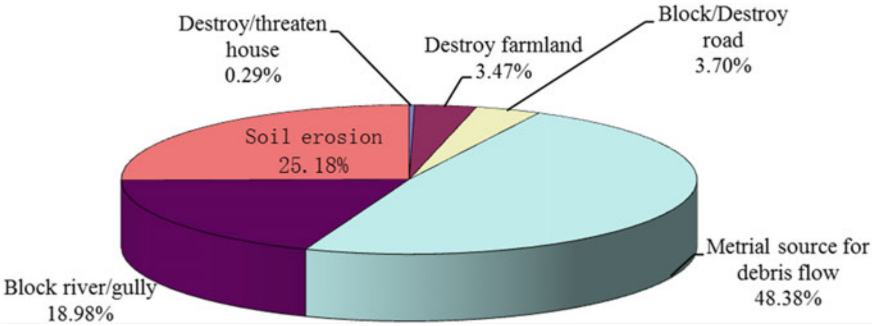

Fig. 18.4 Landslide hazard patterns in the Koshi River basin

18.4 Disasters Induced by Landslides

Landslides cause many damages in the Koshi River basin. The disasters induced by landslides are summarized into six types: threaten or destroy buildings, destroy farmland, destroy and block road, block river, supply sources to debris flow and erode soil.

Based on remote sensing image interpretation as well as other related publications and reports, we counted the number of landslide as per different hazardous patterns (Fig. 18.4). If a landslide triggers more than one type of hazard, it will be counted multiple. Statistic result shows that most landslides supply sources to debris flows and this situation takes up 48.38% of the number of landslides. The second most common hazard pattern is the soil erosion, which accounts for 25.18%. The third is the river blockage, which accounts for 18.98%.

18.4.1 Threaten or Destroy Buildings

The houses located on landslides or along the landslide runout areas will suffer tremendous destruction (Table 18.1). By destroying houses, landslides always bring in casualties and economic loss. The hazard patterns depend on the relative location of buildings to landslides. Cracks are formed at the back of landslide, while sliding occurs at both sides of a landslide. Houses in these parts will first show some cracks, which expand as the landslide moves. Buildings located on the landslide body will incline at the beginning and then be destroyed when the landslide body crushes. The houses in front of landslides will always be buried by landslide body.

Few landslides destroyed or are threatening buildings in the Koshi River basin. But once the threatening landslide destroys the building, it always brings casualties and property loss. The Jure landslide destroyed 24 houses, and Zhangmu landslide is threatening 453 buildings in total.

Table 18.1 Examples of landslides that destructed or are threatening houses in the Koshi River basin

Landslide	Location	Damage	Time
Rumeila landslide	Zhangmu Town, Nyalam County, China	14 buildings destroyed	2000
Zhangmu landslide	Zhangmu Town, Nyalam County, China	453 buildings threatened	2014
Suspa landslide	Suspa VDC, Nepal	23 houses threatened, 14 houses cracked	1986
Gairimudi landslide	Gairimudi VDC, Nepal	1 building destroyed, 14 buildings cracked, and 23 buildings threatened	September 15, 2010
Manamaiju landslide	Manamaiju VDC, Kathmandu,Nepal	1 building destroyed	2013
Jure landslide	Jure village, Ramche VDC, Nepal	24 buildings destroyed	August 2, 2014

- Zhangmu Landslide

Zhangmu, a town located in Nyalam County, Tibet Autonomous Region, is a first-level land port of China to Nepal. Zhangmu landslide is located on the left bank of Boqu River at the south foot of the Himalayas. The whole town is located on an ancient high-positioned landslide body (Fig. 18.5). This ancient landslide deposit is the main stratum in this area, with 0–7 m depth loose slope deposition on the top. The area of Zhangmu landslide is 1.48 km^2, with an average depth of 66.17 m and a volume of approximately 9793.16×10^4 m^3. Free faces were formed in the south, north and west directions due to the erosion of Zhangmu gully, Bangcun east gully and Boqu River. The biggest cutting depth of Boqu River, Zhangmu gully and Dianchang gully is 180, 40 and 70 m, respectively (Li and Wen 1995). This region is influenced by the Indian monsoon and has a humid subtropical monsoon climate. Annual precipitation is 2400–3100 mm, and the highest daily precipitation can reach up to 93.2 mm. The precipitation is mainly concentrated in the months from June to September, which accounts for 80% of the whole-year precipitation (Mao 2008). In the past, the landslide stayed stable under natural or saturated condition. However, in the last decade several infrastructures have been constructed in Zhangmu, and they increased the load of landslide body. In the meantime, more precipitation in this region has been observed than before. These turned to be the main triggering factors that reactivated Zhangmu landslide. Some new and shallow landslides were formed in the front and sides of the ancient landslide, imposing direct threat on the premises of Zhangmu.

There are 4 communities in Zhangmu with 1774 residents. A total of 453 buildings are identified in Zhangmu town on Google Earth image dated on January 16, 2014. At present, cracks appeared in some houses and on the national road in the front of Fuliyuan landslide. The cracks are still enlarging and expanding. The depression has become severe in front of the police station.

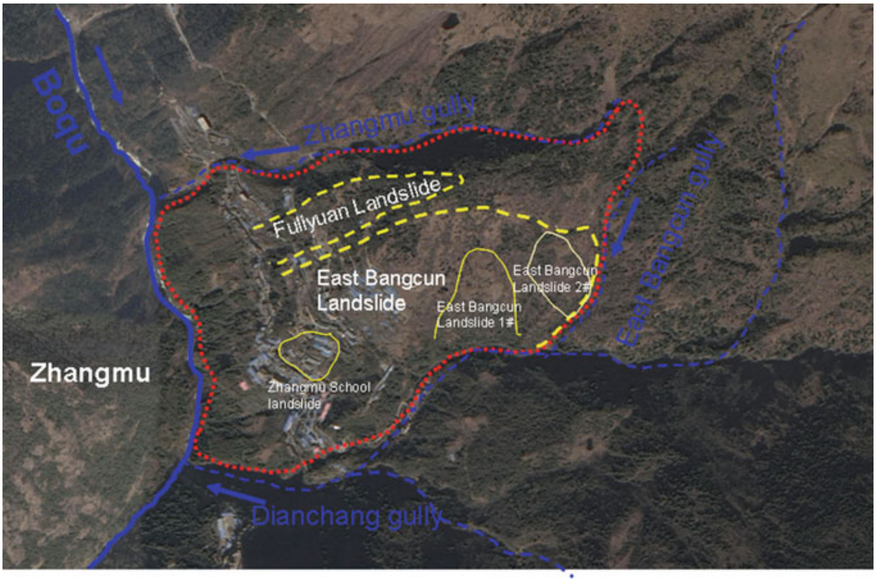

Fig. 18.5 Overview of Zhangmu landslide: the whole town is located on the landslide

18.4.2 Destruction of Farmland

Since arable lands are very limited in mountainous region due to constraints of terrain, most of the farmland is reclaimed on the slope or river terrace. The reclamation has changed land cover types and influenced runoff production and infiltration. In addition, irrigation increased the moisture of soil. As a result, the farmland located on landslides is at risk of collapse and gliding, while that at the foot of hill is always prone to being buried.

Take the landslide that centered at 27° 37′ 10.39″N, 86° 06′ 33.46″E near Kahriswara village, Gairimudi VDC, Nepal for example, the absolute elevation of the slope is 1256 m and the relative elevation to the gully is nearly 124 m (Fig. 18.6). This landslide has become active since 20 years ago. On October 15, 2014, the landslide collapsed because of continued rainfall for weeks. Nearly 350,000 m^3 of debris slided down along the slope and destroyed the farmland on the landslide body. The landslide then moved to the hill foot and buried parts of farmland. In total, 3 ha of farmland was destroyed by this landslide (Sudmeier-Rieux et al. 2012).

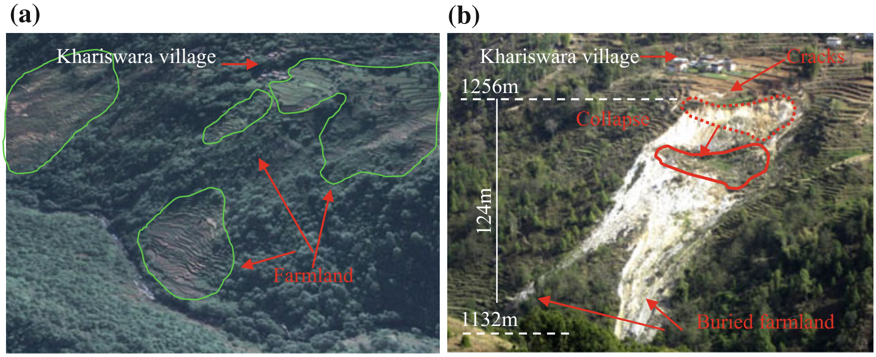

Fig. 18.6 Landslide occurred in the Khariswara village, Nepal and destroyed farmland: **a** before landslide (Google Earth), **b** after landslide (Sudmeier-Rieux et al. 2012)

18.4.3 Destruction and Blockage of Road

Road construction in general is a large, complicated and belt-shaped project. On one hand, as roads always encompass different geomorphologic and geologic units, they are oftentimes at risk of different kinds of geo-hazards. On the other hand, evacuation and waste slog by road construction disturbs geologic environment along the road and destroys the stability of hill slopes. Therefore, landslides usually developed along roads. Although landslides occurred only at one or some points along the road, they could block or destroy sections of the road and affect the whole transportation connected by the road.

Many important highways are located in the Koshi River basin, including National Road G318 in China, Arniko Highway, Lamosangu–Jiri Highway, Nayapool–Ramechhap Highway, B.P. Highway and East–West Highway in Nepal (Fig. 18.7). The road G318 joins the Arniko Highway to form the Sino–Nepal friendship road. Along the highway from Dhulikhel, Nepal to Zhangmu, China distributes 106 landslides, among which 26 landslides affect the highway directly. The Sun Koshi landslide, which occurred on August 2, 2014, destroyed the Arniko Highway for 2 km. As a result, the Arniko Highway, a major trade link between China and Nepal with trade exchange standing at nearly NPR 38 million per day (nearly USD 400,000) was blocked for nearly two months. Specially permitted by the Chinese government, a lot of goods were transported to Gyirong Port, Nepal, via an alternative trade route which though did not officially open at that time. Such natural disaster would mean serious medium-term impacts for Nepal. The landslide mass also damaged two gates of Sun Koshi hydropower plant, and the powerhouse of Sanima Hydropower project was submerged. Power supply from several other hydropower plants in the valley, including Bhote Koshi, Chaku and Larcha, was interrupted due to collapse of transmission lines. The interruption led to the country's scheduled power cuts (Shrestha et al. 2014).

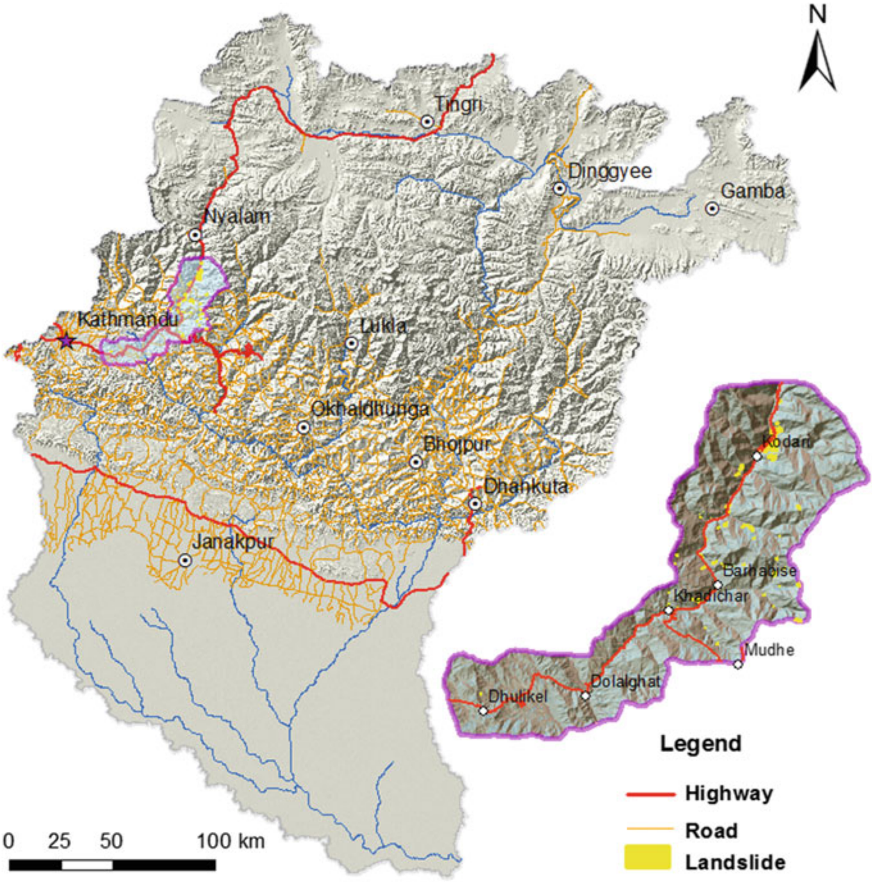

Fig. 18.7 Road networks and landslides along Arniko Highway

18.4.4 Supply Sources to Debris Flows

Debris flows are widely distributed in the Koshi River basin. Landslides play a significant role in supplying abundant materials to debris flows (Fig. 18.8). Generally speaking, landslides are the source of debris flows in two patterns. In one pattern, landslide is directly transformed into debris flows, while in other pattern landslides move to hill foot and block gully to supply sources to debris flows.

18.4.5 Block River

In alpine regions with deep-cutting gorges, river bank is prone to landslides because river erodes both banks to form free faces. Landslides are widely distributed along

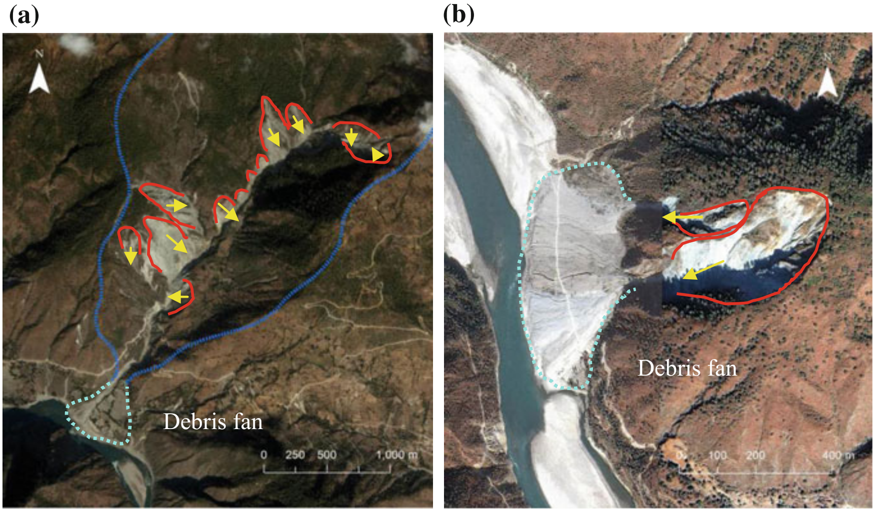

Fig. 18.8 Patterns of landslides supplying sources to debris flows: **a** landslides block gully and supply material sources, **b** landslides transform into debris flows

the river and move easily from banks into the river. Large landslides can change the channel of river or even block the river and form dammed lake. Jure landslide that occurred on August 2, 2014 blocked Sun Koshi River, a branch of Koshi River, for more than 45 days.

18.4.6 Soil Erosion

Landslide is one kind of severe gravitational erosion. In this study, the analyzed landslides did not directly trigger any of aforementioned hazards. The mass of landslides just deposits on slope.

18.5 Cascading Hazards Related to Landslides

Sometimes landslides do not happen alone. Other kinds of hazards, such as floods or debris flows, may be triggered before or after landslides. This can be called a hazard chain or cascading hazards. In the Koshi River basin, there are three kinds of cascading hazards related with landslides in general: landslide-dammed lake-outburst flood, GLOF-landslide and landslide-debris flow (Fig. 18.9).

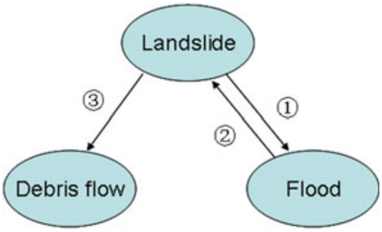

Fig. 18.9 Cascading hazards related to landslides

18.5.1 Landslide-Dammed Lake-Outburst Flood

When a large-scale landslide occurs on the riverbank, sometimes it blocks the river and forms a dammed lake in the upstream. The dammed lake can inundate villages, roads and farms along the river. With an increasing water level, the water will surge over the dam or the dam will collapse under water stress and then comes the outburst flood. The burst flood can destroy villages, roads, farmlands or even threaten the cities downstream.

- Jure landslide and dammed lake

Jure landslide is located on the right bank of the Sun Koshi River, 1.4 km upstream of Sun Koshi hydropower station. It is a deep landslide with an average depth of more than 25 m. The width is approximate 500 m and the length is 1500 m. The relative altitude from slope foot to the back scarp is 1440 m (Fig. 18.10). The landslide buried Jure village. Dozens of houses were destroyed or buried, and more than 156 people were killed (Pokharel et al. 2014). The landslide blocked the Sun Koshi River and formed a dammed lake. The height of the dam was about 70 m, and the length of the dammed lake along the river was 1250 m. The dammed lake, although no longer exists at present, inundated the Arniko Highway as well as some farmlands upstream (Shresta et al. 2014).

18.5.2 Landslide-Debris Flow

Landslides and debris flows usually occur simultaneously. Landslides supply loose mass to debris flows; debris flows erode the bank of gully, affect the stability of slope and trigger more landslides. In particular, areas that have been hit by earthquakes are prone to collapse and landslides. In a certain period after earthquake, debris flows will prevail as the main type of mountain hazards. This is typical during Kashmir earthquake in 2005 and Wenchuan earthquake in 2008. In these two cases, large amount of landslides were triggered and then debris flows became extremely active. This is also the case in the Koshi River basin, where landslide-debris flow is the most common hazard chain.

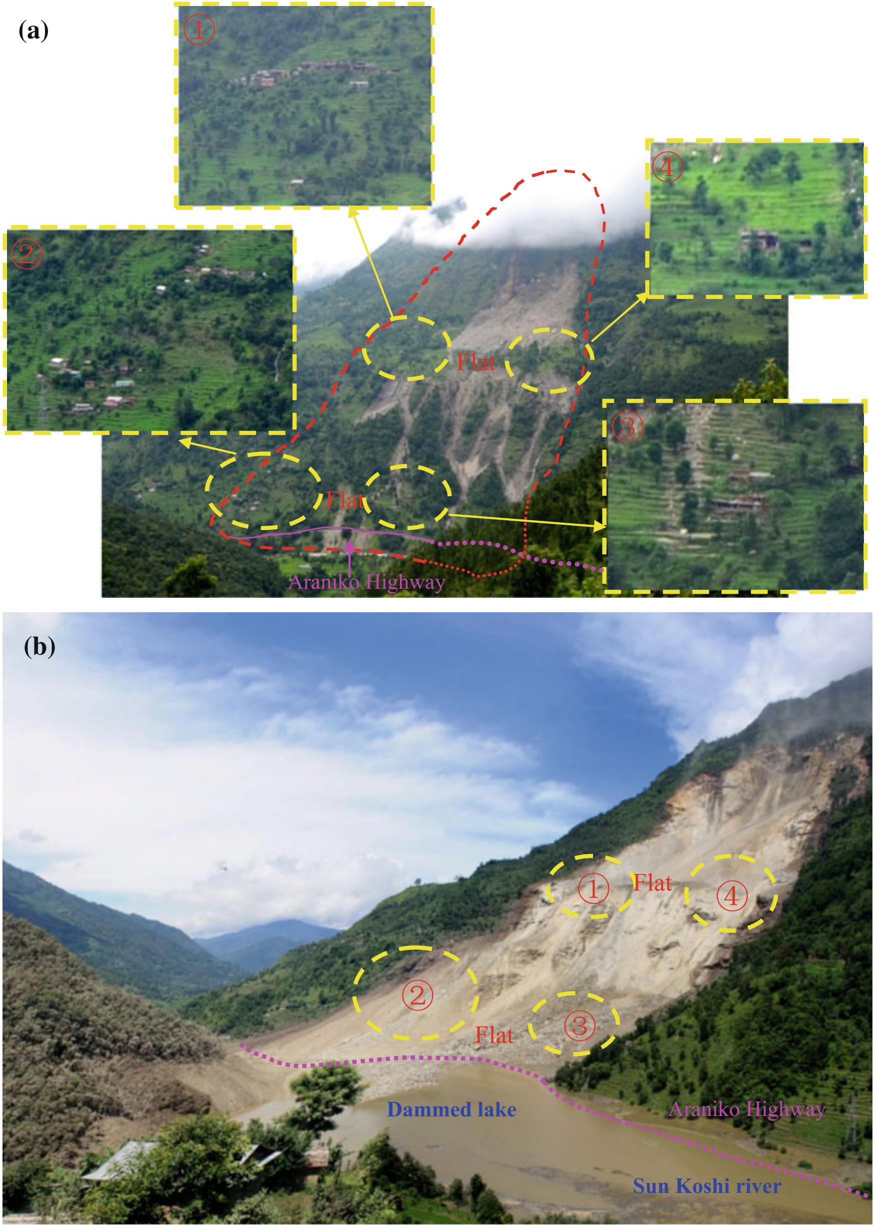

Fig. 18.10 Full view of Jure landslide in Sun Koshi River basin: **a** before landslide occurred, **b** after landslide occurred

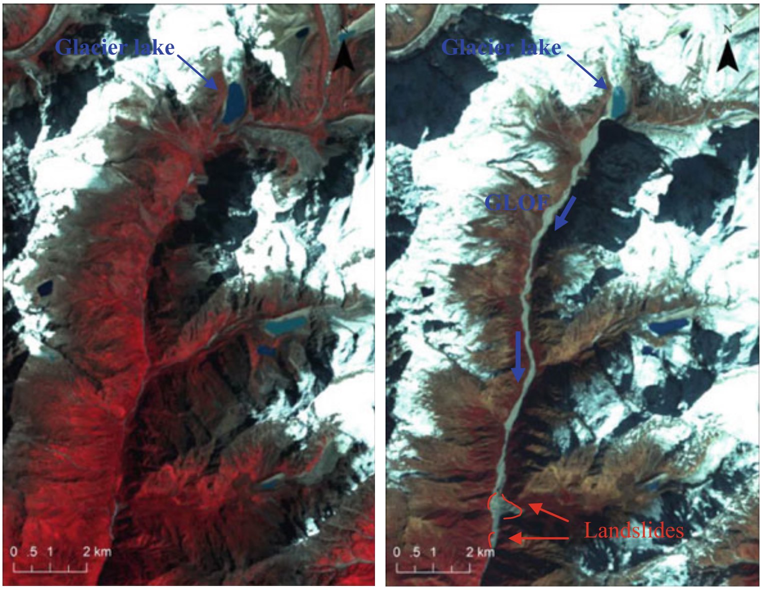

Fig. 18.11 GLOF triggers landslides in the Inkhu Khola River (Location of the glacial lake: 27° 44′35.02″N, 86°50′41.66″E)

18.5.3 GLOF-Landslide

Large-scale floods erode the banks of river or gully, which in fact accelerates instability of the banks and then triggers landslides. During the monsoon, floods occur frequently in the middle and lower reaches of Koshi River basin. Additionally, glacial lake outburst flood (GLOF) is widely distributed in the region. There are 779 glaciers with a total area of 1410 km^2 distributed in the Koshi River basin. The glaciers formed 599 glacial lakes covering an area of 25,958 km^2 so that GLOFs occurred from time to time (ICIMOD 2011). This kind of flood would always trigger landslides in the downstream. The latest GLOF occurred in the upper reach of Inkhu Khola River, a branch of the Dhudh Koshi River, triggering several landslides 11 km downstream (Fig. 18.11).

18.6 Landslide Risk Management in Trans-Boundary River Basins

Landslide risk management includes risk identification, risk assessment and risk control. Risk identification analyzes landslide patterns, characteristics and triggering factors to produce a comprehensive understanding of the hazard. Risk assessment, the core part of risk management, includes susceptibility assessment, hazard assessment and vulnerability assessment.

Landslide susceptibility assessment is carried out by analyzing the relationship between landslide and geology, topography, climate and anthropogenic activities via statistic or physical models. Then a landslide hazard assessment can be obtained by analyzing landslide scale and frequency. The risk assessment can be performed based on hazard and vulnerability assessment. Based on the result of landslide assessment and varied levels of landslide risks, the government will be able to deploy differentiated approaches such as monitoring, engineering control or relocation to handle landslide risk (Cui 2015).

To assess landslide risks in trans-boundary river basins, concerned countries need to establish collaboration at different levels, among which sharing landslide data is crucial.

At institutional level (academic level), scientific institutes and universities are the main players. Sharing of data, information and technology should be first carried out at this level. The data include landslide formative data, landslide distribution data and economic-social data. Information about highly dangerous landslides and potentially affected victims should also be shared. However, due to technology gaps among different countries and diverse characteristics of landslides, various technology solutions may be required to cope with landslides. Technology sharing will help to optimize and enhance technical capacity of the concerned institutional parties.

At governmental level (decision-making level), each concerned country shall establish a focused disaster risk-reduction unit or agency that works closely and

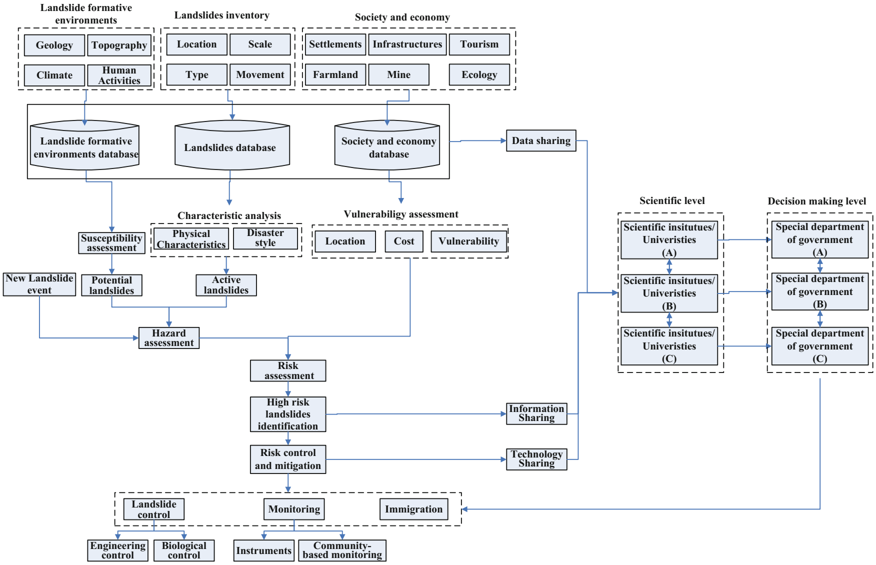

Fig. 18.12 Landslide risk management in trans-boundary river basins

directly with its own government as well as its counterparts in other countries. Research institutes can submit concerned research outcomes to such units for evidence-based policy decision on landslide monitoring, control and relocation measures. When sudden landslide happens, research institutes can timely update disaster status for government agencies to facilitate rescuing activities. When landslides lead to hazard chains that affect downstream countries, research institutes of the upstream country can submit landslide characteristic data as well as landslide risk assessment to their government through whom such information will be transferred to downstream country's government who will then quickly respond including making risk control measures and evacuating people from highly risky areas to safe places (Fig. 18.12).

18.7 Conclusion and Discussion

Koshi River basin is a representative basin for trans-boundary landslide risk management. Landslides are widely distributed in the mountainous area of the basin. According to the investigation, most of landslides supplied source material to debris flows, which happened frequently. Slopes along river are prone to landslide, and numerous landslides occurred along the river valley. Large size landslides possess risk to block the river and form dammed lakes. Besides, highway and road are also vulnerable to landslide. When they are blocked by landslides, a long time is needed to rebuild them so that life and commercial intercourse will be significantly impacted. Landslides that destroy or bury farmlands are also very common along the basin. Such farmlands are very difficult to be recovered.

Landslides seldom occur alone; sometimes they induce other hazards or are induced by other hazards. In Koshi River basin, 3 types of cascading events relate to landslide are summarized. The first type is that landslide blocks river and forms dammed lake. The break of these dams would cause flooding downstream. The second type is that landslides supply solid mass to debris flow. The third type is that flood erodes the foot of slope and trigger landslide. These cascading events make the risk extend temporally and spatially and always affect different counties. So trans-boundary risk management is an urgent need.

A preliminary framework of trans-boundary landslide risk management is discussed in this paper. The basic work is to develop landslide inventory of Koshi River basin, collect the landslide formation factors including topographic, geological and precipitation data and conduct the susceptibility, hazard, vulnerability assessment as well as risk assessment in the basin. The cooperation should be carried out at institutional level (academic) and governmental level (decision make). Universities and scientific institutes can involve in the institutional level to manage the data and information, and their task should include data sharing, information sharing and technology sharing. When trans-boundary hazards occur, information for hazards, fast assessment and disposal measures could be shared at institutional level and then submitted to governmental level. The governments could take measures to mitigate or avoid the risk.

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Chapter 19
Investigation and Analysis of Geohazards Induced by the 2015 Nepal Earthquake Based on Remote Sensing Method

Wei Zhao, Ainong Li, Zhengjian Zhang, Guangbin Lei, Jinhu Bian, Wei Deng and Narendra Raj Khanal

Abstract The devastating earthquake that occurred in Nepal on April 25, 2015, caused widespread damage and ravaged rural communities and economy. It triggered numerous geohazards in the steep mountains and hills throughout the impact zone, including catastrophic landslides in the Langtang Valley. Potentially, these landslides can have devastating effects on humans, destroy infrastructure, obstruct river flows and cause outburst floods. In order to understand the effects of the earthquake-induced geohazards and their risk assessment, number of scientists have carried out numerous geohazard investigations using remote sensing approach. This paper presents evaluation results based on the study of earthquake-related geohazards. Later, three main geohazards related to the Langtang avalanche, landslide dam and glacial lake monitoring are discussed in detail. Finally, the zones around the two China–Nepal roads are selected as the study areas. A change detection method is applied to identify the geohazards occurred in these areas and to understand their spatial distribution pattern. The study offers awareness about the earthquake-induced geohazards in Nepal. Landslide is identified as the major geohazard induced by earthquake, and its regional impact will continue in near future.

Keywords Geohazards · Nepal earthquake · Remote sensing · Investigation

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19.1 Introduction

The 4.25 earthquake struck Nepal at a depth of approximately 15 km, with its epicenter approximately located at 28° 15′ 07″N and 84° 07′ 02″E, at Barpak, Gorkha, about 80 km NW of Kathmandu (the capital of Nepal). According to the United States Geological Survey (USGS), the magnitude recorded was M7.8, followed by more than 300 aftershocks greater than magnitude of M4.0 (as of June 7 2015) (Fig. 19.1). The largest aftershock of M7.3 magnitude was recorded on May 12, and the epicenter was near the Chinese border between capital and Mt. Everest. USGS suggested that the earthquake was caused by a sudden thrust, or release of built-up stress, along the major fault line where the Indian Plate is slowly diving underneath the Eurasian Plate. The earthquake-induced rupture propagated from west to east and from deep to shallow parts of the shallowly dipping fault plane, and consequently, strong shaking was experienced in Kathmandu and the surrounding municipalities.

As a result, hundreds of thousands of people were left homeless with entire villages flattened across many districts of the country. Thirty-one of the country’s 75 districts have been affected. Among these affected districts, seven were declared ‘severely hit’ (the worst category) and seven were declared ‘crisis-hit’ for the purpose of prioritizing rescue and relief operations; the rest 17 neighboring districts were partially affected (Fig. 19.2).

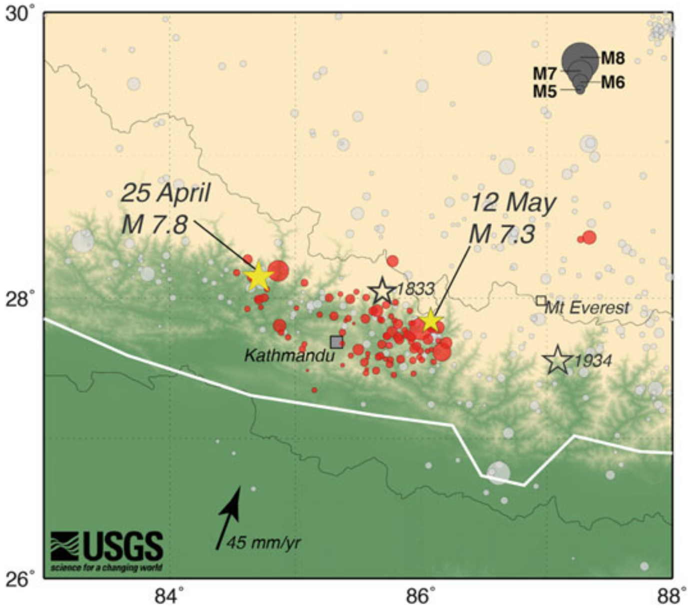


Fig. 19.1 Map of the earthquake and aftershocks, showing locations of major historical earthquakes. *Source* USGS

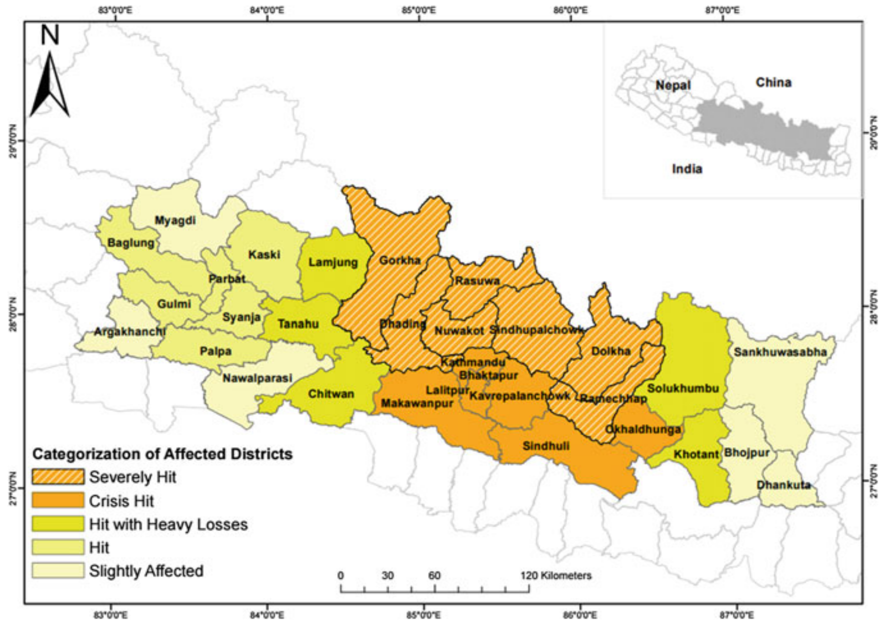


Fig. 19.2 Categories of earthquake-affected districts in Nepal. *Source* GoN/MoHA as of May 21, 2015

According to the 'Post Disaster Needs Assessment' provided by the Government of Nepal (NPC 2015), there were over 8,790 casualties and 22,300 injuries in Nepal. Among the nearby countries (Nepal, China, India, Bangladesh and Bhutan), Nepal bore the brunt of the quake's impact. It was estimated that the lives of eight million people, almost one-third of the population of Nepal, were affected by these earthquakes. The destruction was widespread covering residential and government buildings, heritage sites, schools and health posts, rural roads, bridges, water supply systems, agricultural land, trekking routes, hydropower plants and sports facilities (NPC 2015). In the Kathmandu Valley alone, several archeological sites and monuments were either destroyed or severely damaged at UNESCO World Heritage sites, including some at the Kathmandu Durbar Square, the Patan Durbar Square, the Bhaktapur Durbar Square, the Changu Narayan Temple, the Boudhanath Stupa and the Swayambhunath Stupa.

19.2 Secondary Geohazards Induced by the Earthquake

Generally, a geohazard is usually defined as a geological state that may lead to widespread damage or risk. Geohazards are geological and environmental conditions and involve long-term or short-term geological processes. They can be relatively small features, but can attain huge dimensions (e.g., submarine or surface landslide) affecting local and regional socio-economy to a large extent.

Although earthquake brought devastation but intense shaking was not the only geohazard associated with it, secondary geohazards induced by earthquake also played an important part in destruction and loss of lives. Secondary geohazards primarily include landslides, rockfalls, debris flows and barrier lakes and usually occur as a result of cascading hazardous processes. For instance, the ground motion induced by earthquake will destabilize the mountain slopes and cause rockfalls or landslides, which in turn produce an abundant amount of unconsolidated materials or rocks. These materials or rocks can eventually become a major source of subsequent debris flows. According to the analysis conducted by Huang et al. (2012), there were thousands of landslides, debris flows and barrier lakes reported after the 2008 Wenchuan earthquake.

Therefore, it is crucial to identify the size and location of geohazards induced by earthquake on urgent basis. In order to achieve this, two methods are most commonly used (Xu 2015). First method is the field investigation, and the second is remote sensing-based image interpretation. Prior to remote sensing technology, field investigation was widely used as a tool for geohazard study. Based on observations in the field, researchers delineate or locate the earthquake-induced geohazards on topographic maps, geologic maps or other thematic maps and finally prepare associated geohazards distribution maps (Xu 2015). Not only results obtained through this method are highly accurate and reliable but also considered important for geohazard investigation. However, field investigations are costly and often requiring large number of labors. It also has some limitations. For example, its efficiency is compromised in an inaccessible or treacherous mountain terrain. As compared to field investigations, the advantages of remote sensing technology (large-scale spatial information) are far reaching. It is a valuable source for monitoring geohazards at different spatiotemporal scales, and its utility has now been proven globally (Kieffer et al. 2006; Lee and Lee 2006; Martha et al. 2015; Moosavi et al. 2014; Razak et al. 2011; Travelletti et al. 2012). The visual interpretation of remote sensing images, especially aerial photographs or high-resolution images, has been frequently used now for geohazard inventory. It can also obtain detailed and comprehensive earthquake-triggered landslide inventories without missing a large number of landslides on smaller scales (Petschko et al. 2015; Xu et al. 2015). With the development of remote sensing image processing technologies, automatic extraction methods have become popular and are readily used in geohazard change detection.

In the aftermath of the deadly earthquake, an international team of volunteer scientists from different institutes, led by Dr. Jeffrey Kargel of the University of Arizona and NASA, worked swiftly to identify, (using remote sensing imagery obtained from government and private agencies) not only the earthquake-induced landslides but also other potentially dangerous sites, such as landslide-dammed rivers and glacier lakes (Kargel et al. 2016). Different satellite data were used in this survey, including the optical imagery with the spatial resolution ranging from 15 to <1 m, from Landsats 7, 8, the Advanced Spaceborne and Thermal Emission and

Reflection Radiometer (ASTER) onboard Terra, Advanced Land Imager on EO-1, WorldView-1, 2, 3, GeoEye-1, Pleiades, Gaofen-1, radar data from ALOS-2, RADARSAT-2 and topography from the Shuttle Radar Topography Mission (SRTM). Around 4312 earthquake-induced landslides (including co-seismic and post-seismic) were identified and mapped by the joint team at their point location. The spatial pattern of the landslides indicates that most of them were distributed in a broad swath between the two largest shocks occurred on April 25, 2015, and May 12, 2015. After comparing the earthquake data, the total number of landslides found were fewer than those of others, probably due to lack of surface ruptures and the geology of the region (Kargel et al. 2016). Besides landslide survey, 491 glacier lakes were also investigated for earthquake damage, but only nine landslide-impact lakes were found and no visible satellite evidence of outburst was observed.

In addition to the systematic survey conducted by Kargel et al. (2016), a geohazard investigation team was assembled with the collaboration of the Institute of Mountain Hazards and Environment (IMHE) and Chinese Academy of Sciences (CAS) to map the earthquake-induced geohazards primarily based on Chinese satellite data. Figure 19.3 shows the spatial distribution of the detected landslides. Due to the limitation of remote sensing data, the number of the identified landslides was relatively small than that of Kargel et al. (2016). However, results also indicated that the central part, between the epicenters in the east and west, was highly struck by the earthquake-induced landslides.

The geohazard investigation results indicated that landslide is the major secondary geohazard associated with this earthquake. The landslides mainly occurred on steep slopes, in areas of high shaking, near ridge crests, in the tectonically dropped blocks, in certain lithologies, and near lithological contacts or interbedding

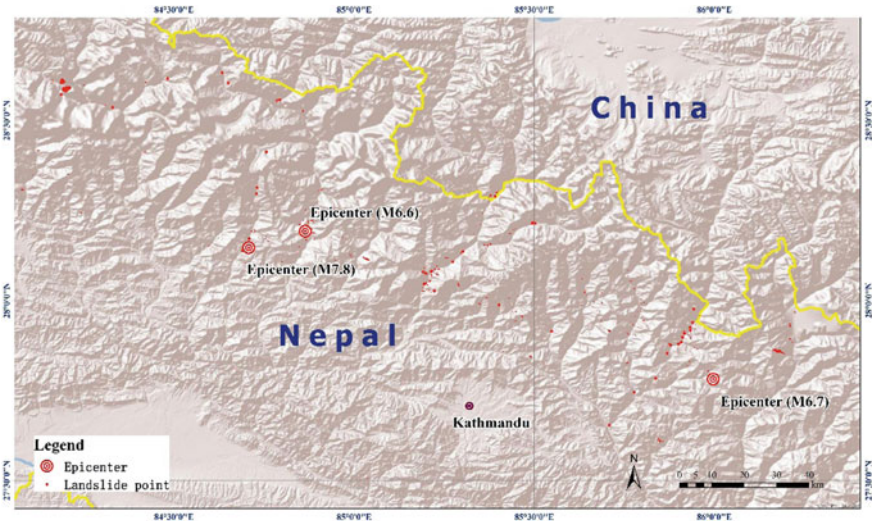


Fig. 19.3 Spatial distribution of the landslide investigated by IMHE, CAS

(Shrestha et al. 2016). Although much of the damage came from the direct shaking, the impact of geohazards, especially landslides, occupied a considerable portion. The observations showed that the majority of earthquake-induced landslides affected only forest land and/or small amounts of cultivated land but did not cause any significant damage to property, infrastructure or human life. However, only fewer landslides caused extensive damage. The earthquake-induced geohazards investigation conducted by International Centre for Integrated Mountain Development (ICIMOD) generally analyzed the impact of landslides on infrastructure (Shrestha et al. 2016). The results showed that the landslides (around 464) mainly damaged roads, hydropower projects, bridges, irrigation systems and buildings (houses, schools and others). Figure 19.4 shows the field pictures of damage caused by landslides to agricultural land, roads, buildings and bridges.

Fig. 19.4 Damage caused by landslides

19.3 Severe Geohazard Examples

19.3.1 Geohazard in the Langtang Valley

The Langtang Valley (Rasuwa) is located in Langtang National Park. The Langtang River flows through the main valley and is typically U-shaped. The elevation ranges from 1406 m in Syaphru Besi to the summit of Langtang Lirung at 7234 m. The great topographical relief and the accumulation of debris and ice provide favorable environment for geohazard development. Severe shaking triggered debris flows and avalanches in the valley, and over 350 people were killed in Langtang village and nearby villages. Langtang and Gumba villages, containing more than 100 houses, were completely destroyed. Structures that were not directly buried in Langtang village and the surrounding areas were completely levelled by the landslide-induced air blasts. Lacroix (2016) quantitatively analyzed the volumes and initiation processes of the landslides by using high-resolution digital surface models, and the results indicate that the main debris avalanches accumulated about 7 million m^3 of debris deposits in the valley with thicknesses reaching 60 m. Change detection was conducted by using the pre- and post-earthquake satellite images acquired from Landsat 8, and significant changes can be observed from the bi-temporal images of the two severely damaged villages (Fig. 19.5). The field photographs taken by David Breashears presented in Fig. 19.6 show the huge destructive force of the landslide.

19.3.2 Landslide Dam in the Trishuli River

Landslide dams are formed by landslide deposits or moving landslides that block a permanent or ephemeral water course leading to the formation of a natural reservoir that fills with water and/or sediments (Hermanns 2013). Generally, large-scale landslide dams are extremely dangerous as they retain massive amounts of water and failure can trigger flash floods, potentially endangering the lives of the people in the downstream reaches. Interpretation of a series of aerial photographs and satellite images revealed that there are more than 250 landslide dams triggered by the 2008 Wenchuan earthquake (Xu et al. 2009). The earthquake also created the largest and most dangerous landslide dam (Tangjiashan landslide dam), with the extension of approximately 600 m across and 800 m along the valley and the height ranging from 80 to 124 m. The Tangjiashan landslide dam has impounded the largest lake with an estimated maximum volume of 3×10^8 m^3.

Considering the high risk involved and similar topographic conditions to Wenchuan earthquake, the landslide dam investigation and monitoring became a priority task in the Nepal earthquake geohazard survey. Several rivers cut across the hardest hit regions, including the Trishuli River (one of the major tributaries of the Narayani River basin in central Nepal) and Sun Koshi River. Based on the Gaofen-1

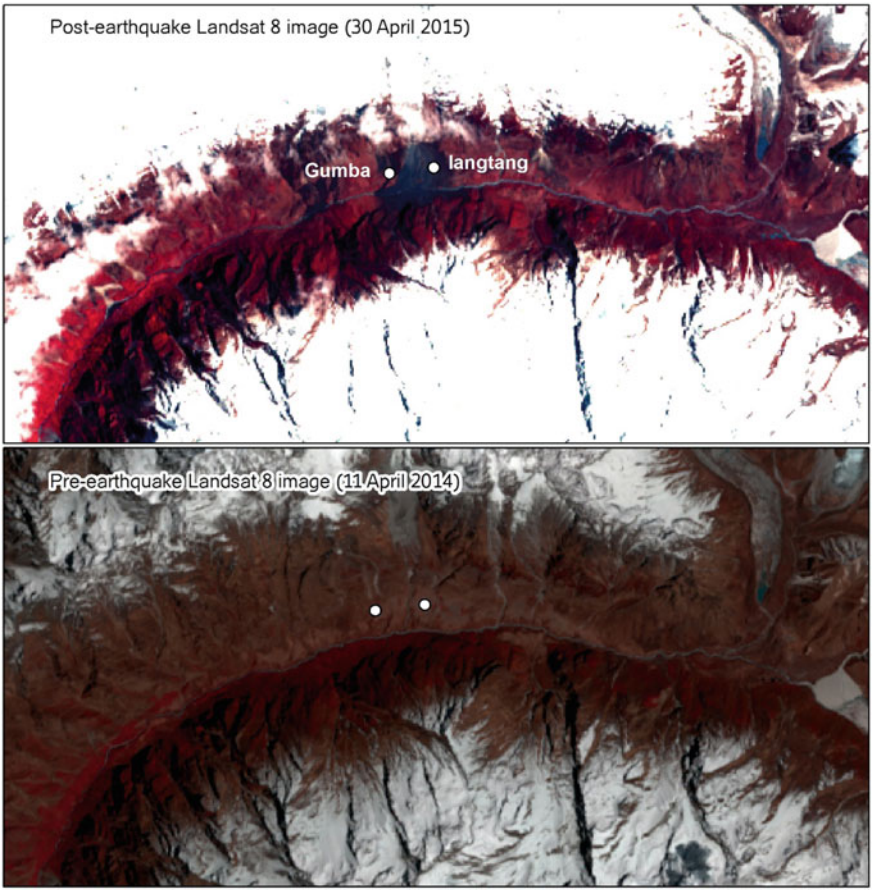


Fig. 19.5 Pre- and post-earthquake Landsat 8 images of the Langtang Valley

high spatial resolution (8 m) satellite data, a large landslide measuring (800 × 200 m) was spotted, on May 1, 2015, that eventually dammed the Trishuli River (Fig. 19.7a). To effectively monitor the development of the reservoir, satellite data of adjacent days are a proven source of data. Figure 19.7b shows the Spot 6 image, acquired on May 3, 2015, and can be clearly observed that during these two days no significant change occurred in the reservoir. Consequently, the possibility of outburst floods is low and the reservoir drains naturally. There were other landslide dams along the Trishuli River; however, most of them were of significantly low risk.

Other than Trishuli River, some other landslide dams were also found using remote sensing imagery. Figure 19.8 shows two landslide dams along the Marsyangdi River and the Tom Khola River, respectively. WorldView 01 and ZY-1-02C satellite data have been used to show the post-earthquake condition of the

Fig. 19.6 Pre- (*above*) and post-earthquake (*below*) photographs of Langtang Valley, showing the near-complete destruction and burial of Langtang village. *Credits* David Breashears/Glacier Works

dams and the rivers. Compared with the pre-earthquake DigitalGlobe data, acquired from Google earth, the impact from the landslides has been hazardous. Fortunately, the landslide dams did not totally block the river and the water drains naturally.

19.3.3 Glacial Lake Risk Assessment

A glacial lake is a lake with origins in a melted glacier. They are formed when a glacier erodes the land and then melts, filling the hole or space that it has created. Dam failure, containing a glacial lake, can induce a glacial lake outburst flood (GLOF) and pose a great threat to the people living downstream.

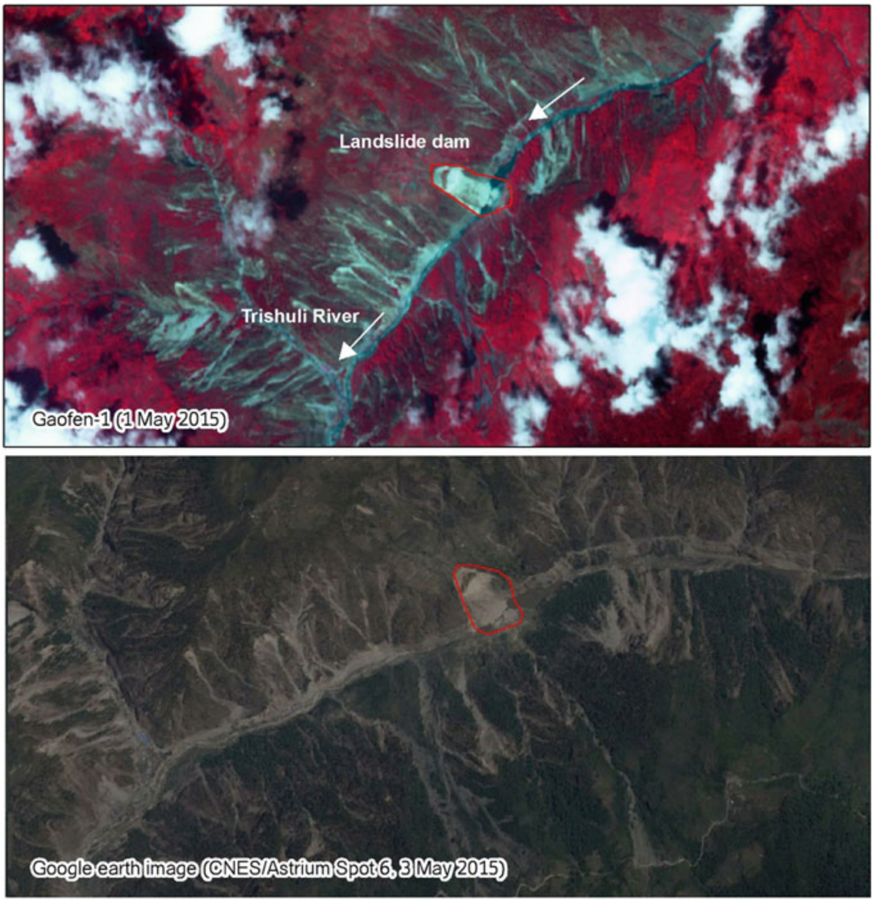


Fig. 19.7 Landslide dame along the Trishuli River in Haku VDC, Rasuwa

Due to high concentration of glaciers in Nepal, many glacial lakes are developing in the high mountain regions. It is reported by ICIMOD that Nepal has 24 GLOF incidents in the recent past and there are about 20 potentially dangerous lakes in Nepal. Among these lakes, many of them have generated GLOF in the past few years.

In order to mitigate GLOF hazards in future, there is an urgent need to regularly monitor potential GLOF lakes. Among all the glacial lakes, Tsho Rolpa and Imja Tsho caught the attention due to their big size and high-risk location (Fig. 19.9). Tsho Rolpa is located at an altitude of 4,580 m in the Rolwaling Valley, Dolakha district, and has grown considerably over the last 50 years due to glacial melting in the Himalayas. Imja Tsho is located at an altitude of 5,010 m in Everest region of Nepal. A remote sensing-based survey of Tsho Rolpa and Imja Tsho was conducted by scientists from different institutes with the help of the images taken on May 17

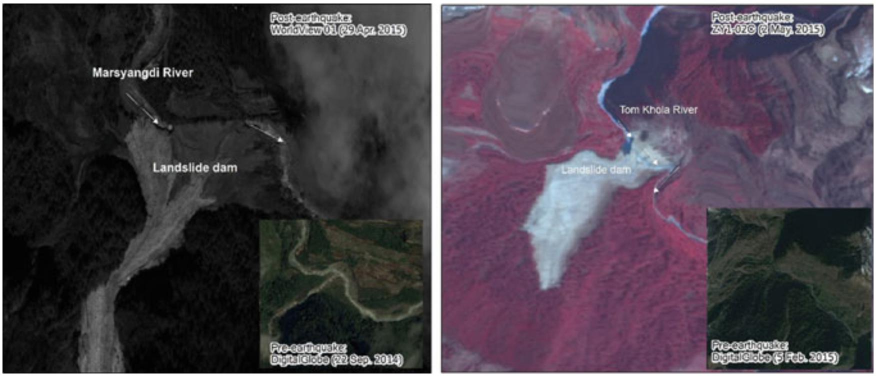


Fig. 19.8 Landslide dams observed in the Marsyangdi River and the Tom Khola River

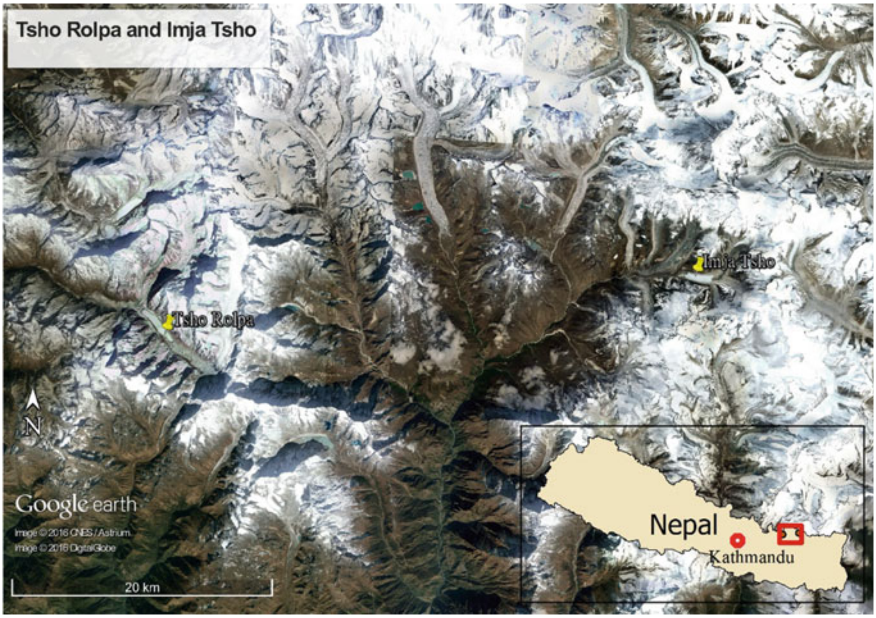


Fig. 19.9 Geolocation of the Tsho Rolpa and Imja Tsho

(NASA's EO-1 satellite and the Japan/US instrument ASTER aboard the NASA Terra satellite). The results showed that there was no definitive evidence that Tsho Rolpa's moraine or other parts of the glacier or lake has been damaged, and similar results were obtained for Imja Tsho. Although the evidence suggested that the earthquake impact on the two lakes was limited, monitoring and observations from space and field should be a continuous process.

19.4 Typical Area for Geohazards Investigation

19.4.1 Study Area

Central Nepal, the area heavily struck by earthquake, has two important roads linking China and Nepal. One is the Zhangmu port direction in the northeastern part of Kathmandu, connecting to Kathmandu with the Sino-Nepal friendship highway along the Sun Koshi River valley. And the other is from Kathmandu to the Gyirong port direction in the northwestern part of Kathmandu, along with the Trishuli River valley.

Prior to the earthquake, the friendship highway from Kathmandu to Zhangmu port was one of the vital business routes linking China with Nepal. However, this road suffered horrendous damage due to the earthquake. Although tremendous disaster-relief efforts have been done by both countries, risk is still very high and reopening of the Zhangmu border seems like a distant future, while Gyirong port is another important gateway linking China and Nepal. Although these two roads play vital role in the economic and cultural exchanges between the two countries, however, after the earthquake, large number of landslides occurred in both the regions. Therefore, these two river basins, along with the two roads, were selected as the study area (Fig. 19.10). These cover Middle Mountain, High Mountains and High Himalayan areas and characterized by rugged terrain and steep slopes in the northern part.

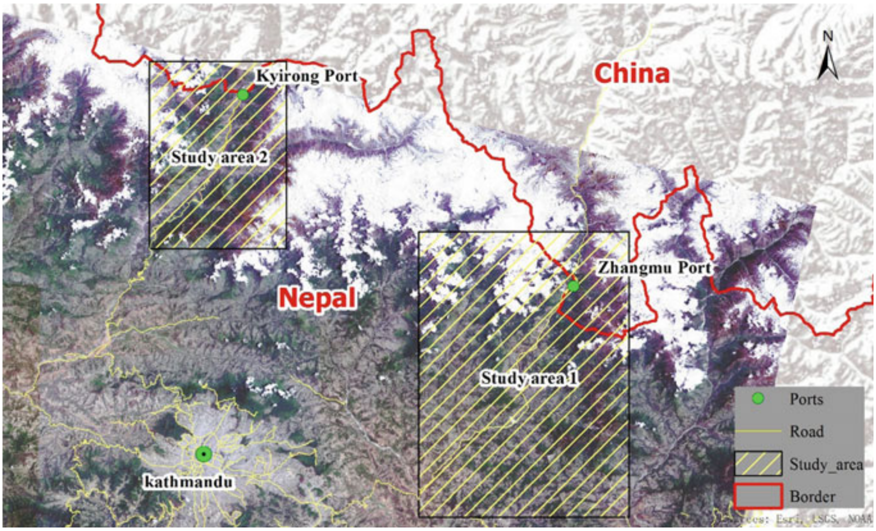
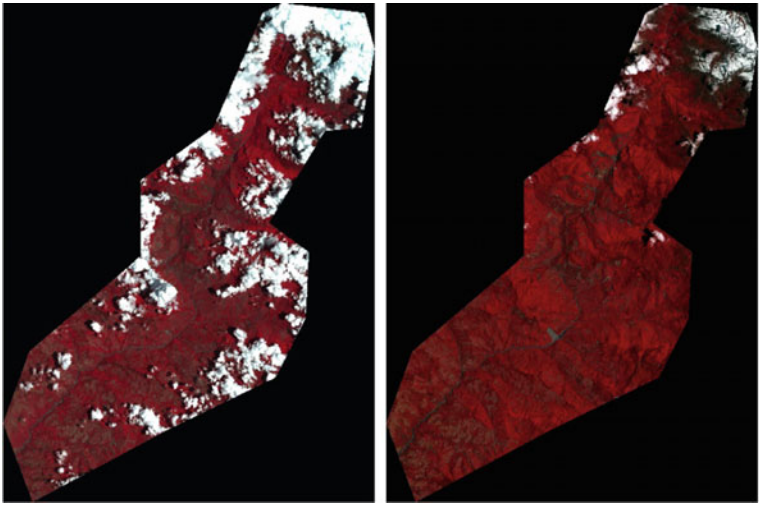


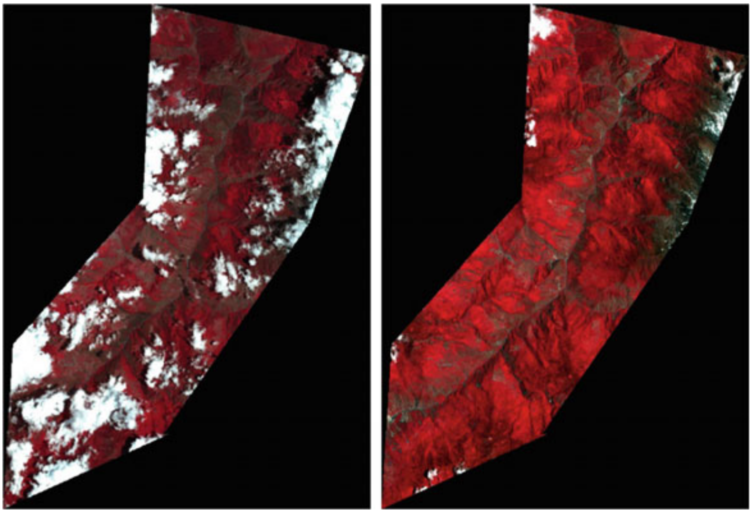
Fig. 19.10 Locations of study areas 1 and 2

19.4.2 Remote Sensing Data

To quantitatively assess the impact of the earthquake on these areas, pre-earthquake Landsat-8 image, acquired on May 29, 2014, and post-earthquake Landsat-8 image, acquired on June 1, 2015, were used to map the geohazards. Figure 19.11 shows the pre-earthquake and post-earthquake false color images of the two study areas.



(a) Pre-earthquake (b) Post-earthquake



(c) Pre-earthquake (d) Post-earthquake

Fig. 19.11 Pre- and post-earthquake false color images of study area 1 (**a** and **b**) and study area 2 (**c** and **d**)

19.4.3 Result

Destruction of surface vegetation cover induced by geohazards suggests that the satellite band which exhibits a large spectral difference in vegetation and bare surface would be a good choice to detect the geohazards. However, excluding the influences from surface destruction by geohazards, the changes between bi-temporal remote sensing data are affected by other factors, including spatial, spectral, thematic and temporal constraints, radiometric resolution, atmospheric conditions, vegetation growth conditions and soil moisture conditions. Therefore, before geohazard investigation, radiometric normalization was firstly performed between the pre- and post-earthquake images.

After the image preprocesses, the band difference images were calculated to get the surface reflectance changes between the bi-temporal images. Equation 19.1 presents the definition about the band difference:

$$\rho_b(X) = \mathrm{SR}_{b,t_1} - \mathrm{SR}_{b,t_2} \quad (b = 1, \ldots, n) \tag{19.1}$$

where X represents pixel X, SR_{b,t_1} and SR_{b,t_1} are pixel surface reflectance obtained at times t_1 and t_2, b is the band and n is the total band number. The band difference image highly connected with geohazards was involved in the change detection. Finally, a threshold method was applied to figure out the changes related to earthquake-induced geohazards. Figure 19.12 shows the geohazard detection results for both study areas. From the spatial distribution, it is obvious that the majority of geohazards are located at the valley along the river and road, dominantly composed of landslides and collapses. These geohazards greatly threaten safety of the commuters and the local settlements along the road.

According to the geohazard investigation results, the spatial distribution of the geohazards induced by the earthquake was analyzed based on the SRTM 90 m DEM data. Figure 19.13a, b shows the histogram maps of the elevation and slope information about the geohazard distribution for both study areas, respectively. It is clear that both histograms apparently follow a one-dimensional normal distribution. Most of the geohazards in study area 1 fall within the range of 1200–2200 m, with the mean value of 1624 m. While the elevation of the geohazards in study area ranges from 1600 to 2600 m, with the mean value of 2215 m. The values show that the geohazards present in study area 2 are generally distributed at higher altitudes then those of study area 1. In addition to elevation analysis, the slope distribution of the geohazards in both study areas also exhibits different patterns. Because of the high elevation distribution for study area 2, the topographic conditions are more complex than study area 1; hence, it can be inferred that the geohazards in this area are mainly distributed at high slope areas (from 30° to 55°) with the mean value of 38.18°, while for study area 1, the slopes of the geohazards mainly fall within the range of 20°–50°, with the mean value of 31.61°.

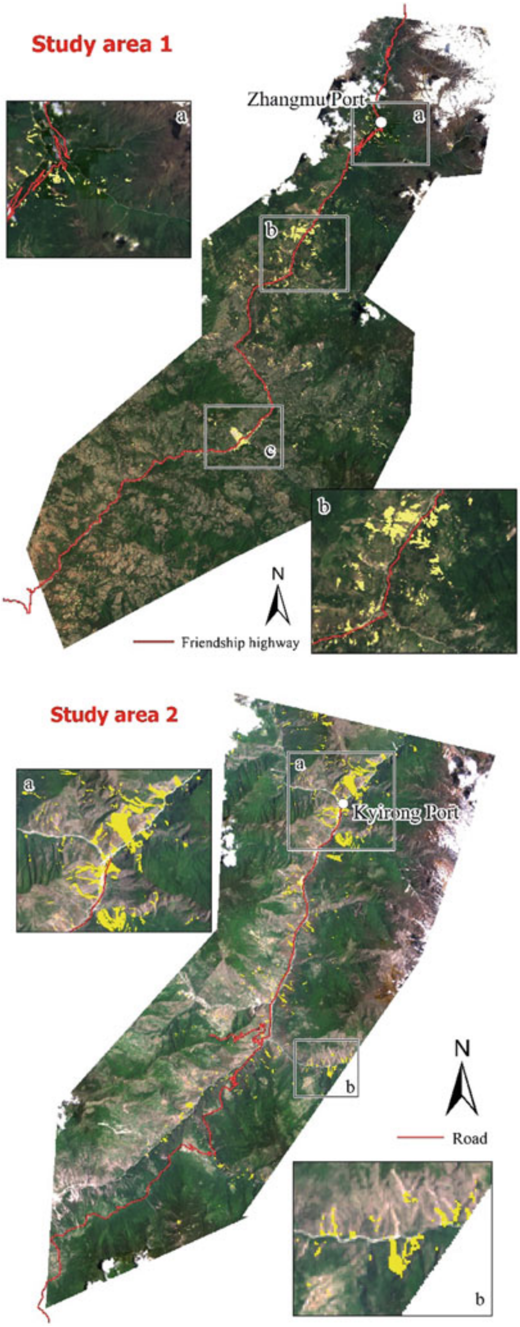


Fig. 19.12 Earthquake-induced geohazard investigation results for both the study areas

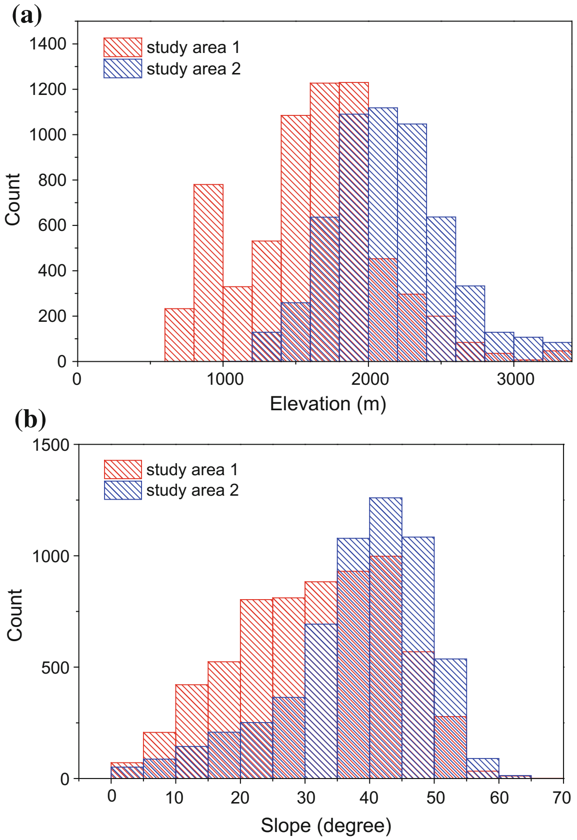


Fig. 19.13 Topographic distribution analysis for the geohazards in study areas 1 and 2

19.5 Conclusion

This paper provides an overview of Nepal earthquake-induced geohazards in conjunction with the previous geohazard investigations. The study identifies landslide as the main geohazard associated with this earthquake. Other than the catastrophic landslides of Langtang Valley and the Mount Everest Base Camp, the remote sensing data reveal landslides of relatively small size and formation of few river dams, when compared with other recent earthquake-triggered landslides of similar magnitude in Pakistan and China (Lacroix 2016). Results also indicate that most of the geohazards occurred in high mountain regions of very steep or near vertical slopes. Areas with no forest cover and loads of unconsolidated material are highly susceptible to slope instability and can cause geohazards especially landslides and debris flows. This study therefore suggests establishing a robust and continues monitoring system in the earthquake impact zone at least for the next few years.

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Chapter 20
Earthquake Mitigation and Its Effect on Eco-environment and Social Development: A Case Study from Tamakoshi River Basin of Central Mountain Region, Nepal

Uttam Sagar Shrestha

Abstract Earthquakes are very unpredictable incidents and suddenly on April 25, 2015, the ground at Kathmandu shook so violently that they were once more reminded of the terrible earthquake (1934) of the past. It was later followed by an almost equally violent earthquake (7.3 Richter Scale) on May 12, 2015. The epicenter of May 12 was on Sunkhani, 3 km aerial distance (12 km road distance) from Charikot, district headquarter of Dolakha. Most of the structures of the area which had withstood first quake with some crack were razed entirely to the ground by the second quake. The present paper tries to describe the earthquake impacts along with mitigation measures adopted by government. The study is based on the field observation of the study area from June 26 to July 3 and September 17 to October 3, 2015, mainly through Key Informant Interview (KII), expert opinion, and literature review. In total, 70 and 95% of houses of urban and rural settlements, respectively, were damaged completely. Similarly, out of total 40 observed locations about 50% have totally damaged. The present study found that more damages occurred at the northern upper part than the southern part. The earthquake bought about significant number of ecological consequences such as triggering a number of dry landslides, and disturbances of wild life habitat causing increasing number of wild animal raids at the human settlements. The social development got more vulnerable specially on livelihood of basin people.

Keywords Earthquake · Landslide · Settlement · Structures · Vulnerable

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20.1 Introduction

Earthquakes are very unpredictable incidence. Over the last century, the Himalayan arc has been struck by six devastating earthquakes, e.g., 1897 (M8.1) Shillong earthquake to 1991 (M6.9) Uttar Kashi earthquake claiming lives of thousands of people in the region (Bhattrai and Bhandari 2011). The terrible earthquake that occurred in 1934 had left tremendous impact in the minds of the people in such a way that it could not be erased from their memory for a long time. And suddenly on April 25, 2015, the ground at Kathmandu shook so violently that they were once more reminded of the same terrible earthquake of the past. Immediately after about 30 h, there was another tremor, which again caused a great shook, though a scale was a little lower, but it caused a great havoc at Sindhupalchowk and Dolakha districts to a great extent. It was later followed by an almost equally violent earthquake on 12 May 2015, and it created a sense of perpetual fear in the districts of the people of Nepal particularly in the Central Region.

So far, 8790 people have been killed, 22,300 injured, while about 300 people are estimated to have been missing (Ministry of Finance 2015/16). Likewise, 507,017 houses have been completely destroyed, while 269,190 are partially damaged. The tremor is estimated to have affected about one-third (8 Million) of the total population. The situation points toward recession; official directive (Government's White paper) indicates that every aspect of the economy is feeling the pinch. The paper has shown black picture of economy with an estimation of about 2% economic growth contrary to 6% economic growth as targeted for the Fiscal Year 2015/16 (Ministry of Finance 2015/16).

The Tamakoshi River Basin (TRB) is one of the most victimized areas by the second quake whose epicenter is Sunkhani, 3 km (12 km road distance) north of the district headquarter. Reportedly, 134 people have been reported dead and 304 people injured of these 57 people have died as a result of second quake. The massive destructions (at least 10 big hotels in from Satdoato to Charighyang complete damage, subsidence of the dam across the river in the upper Tamskoshi Hydropower Project, causing halt to the construction works of the projects Upper Tamakoshi Hydro projects (456 MW), destruction of Sipring Hydropower projects (10 MW) and some other minor projects) are to be seen at the every part of the basin. The effect on eco-environment and social development is more acute. The purpose of this paper is to understand the existing pattern of disaster, effect on ecological and social development and suggested mitigation measures in TRB.

20.2 Data and Study Area

20.2.1 Data

The present paper is based on field survey of the area from June 26 to July 3 and September 17 to October 3 and September 8–15, 2015. Similarly, the secondary data have been derived from daily national news, key informants interview (KII) and weekly papers. The data provided by International Centre for Integrated Mountain Research and Development (ICIMOD) and Nepal Government have also been utilized.

20.2.2 Study Area

The study area covers parts of Dolakha as well as Ramechhap District, Janakpur Zone in the Central Development Region (CDR) of Nepal (Fig. 20.1). Geographically, it lies between the latitudes 28°10′00″N and 27°50′00″N and longitudes 86°15′00″E and 86°05′00″E. The area is accessible from Kathmandu via 122 km long asphalt road up to Charikot bazaar and by another access road of 68 km up to Lamabagar village (Fig. 20.2). Similarly, southern part of the study

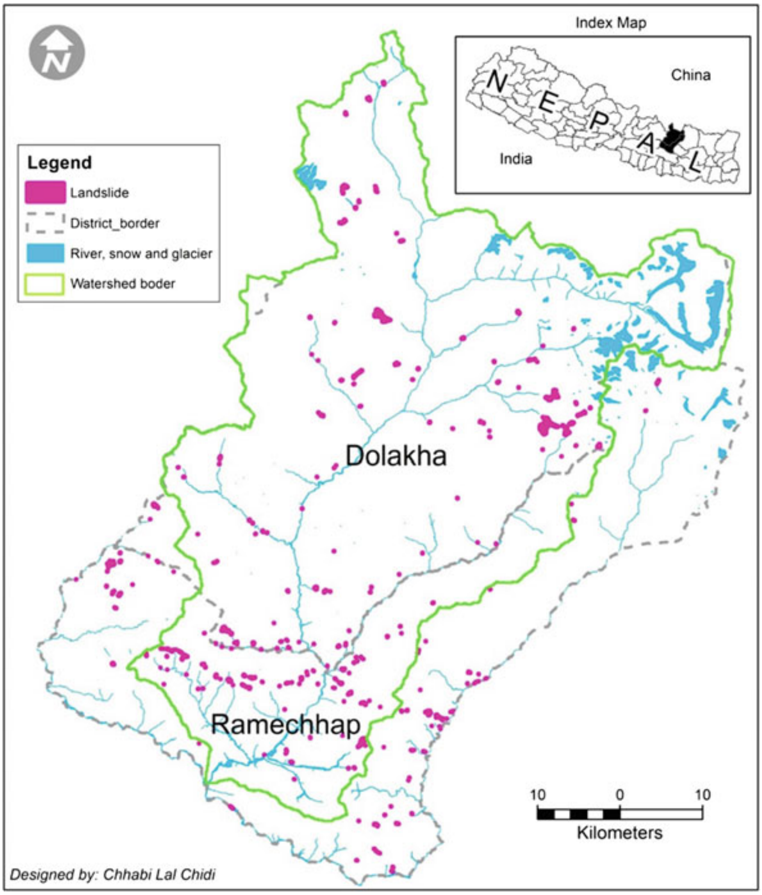

Fig. 20.1 Location of river basin

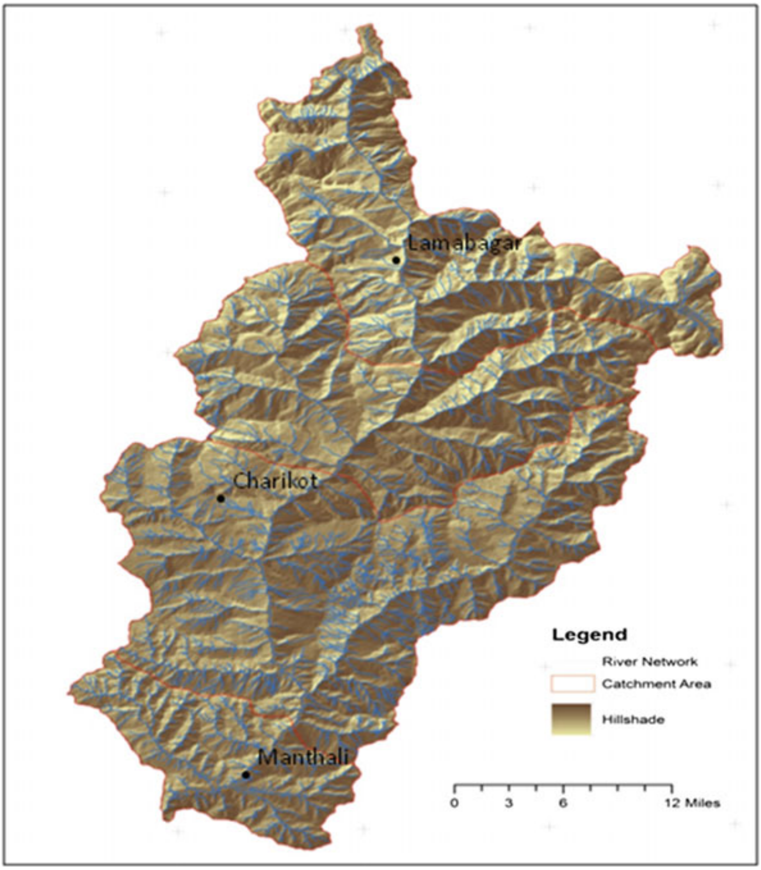

Fig. 20.2 Three-dimensional figure of Tamskoshi River basin

lies at distance of 58 km south east from Charikot and is also accessible through Banepa—Bardibas road, which is shorter than Charikot bazaar.

Dolakha and Ramechhap Districts contain 48 and 55 Village Development Committees, respectively, and two municipalities each. Bhimeshwar Municipality, the municipality of Dolakha district, is divided into 13 wards and Manthali municipality of Ramechhp into 15 wards.

20.3 Brief Geology and Existing Pattern of Disasters

20.3.1 Geological Background

The study area lies between the Lesser Himalaya and Higher Himalaya zone from the south to the north. The Main Central Thrust (MCT) separates Higher Himalayan and Lesser Himalayan zones. The Main Boundary Thrust (MBT) is approximately located 45 km south, and the MCT is located 35 km north from the district head quarter Charikot of Dolakha district.

The northern part of the basin is composed of gneiss, slate dolomite and phyllite, and southern area consists of recent alluvium deposits, old alluvium terrace, colluviums and quartzite phyllite with inter-bedded schist and gneiss rock. The gneiss was well exposed along Tamakoshi and its tributaries from Chyadu river to Bhatauli rivers.

20.3.2 Damage Statistics

The observation of 40 locations (Lamabagar, Gongar, Chochet-Chochet, Jamune. Bhorle, Gurumphi, Singati, Gumukhola, Nagdaha, Dolakha, Charikot, Kiratichhap, Hatdanda, Jiri, Karambote, Jakhantaar, Kunauri, Pakarbas, Seleghat, Majhigaon, Jeelu, Marbu, Namdu, Mainapokhari, Barbase, Kirnetaar, Khimti, Tilbung, Haldebensi, Odari, Kaunauri, Hattitaar Manthali, Malu, Bhatauli, Mugitaar, Kunauri, and Chisapani) shows that 50% of the settlements of the north and central locations have been totally damaged (Category V), followed by partly damaged ones 20.00% (category IV), moderate crack development 10.00% (category III), small crack development 12.50% (category II), and no damage has occurred at only 5.0% (category I). Based on this categorization, the major portion of the settlements from Singati to upward area can be said in category V, whereas the locality south of Kirne belongs to III–I category (see Table 20.1). Majority of houses of poor and marginalized people are damaged more than others.

Table 20.1 Devastation pattern of Tamakoshi River basin

Category	Number of settlements	Percentage	Major locations
V	20	50	Lamabagar, Gongar, Choetchoet, Bhorle, Gurumphi, Singati, Gumukhola, Nagdaha, Dolakha, Hatdanda, Karambote, Pakarbas, Kunauri Seleghat, Majhigaon
IV	8	20	Jamune, Rang, Jeelu, Marbu, Namdu, Kiratichhap
III	4	10.00	Mainapokhari, Barbase, Kirnetaar, Khimti, Haldibensi etc.
II	5	12.5	Charikot, Tilbung, Haldebensi, Odari, Kaunauri, Hattitaar
I	2	5	Manthali

Source Field survey 2015

Note Category of damage by Nepal Earthquake Society Technician (National Society of Earthquake Technology) I—no damage happen, II—small crack development, III—moderate crack development, IV—partially damage, V—totally damaged (NSET 2015)

20.3.3 Housing Pattern and Quake Damage

Housing pattern in basin can be divided into five grades: bamboo with mud, stone with mud mortar, brick with mud mortar, stone with cement mortar and brick with cement mortar. Poor people construct their house using bamboo with mud and stone with mud mortar and rich people by using stone with cement mortar and brick with cement mortar. Reportedly, 90% of the damaged houses of the locality are made of stone with mud and mortar. The houses of river side settlements are mostly constructed using bamboo with mud and stone with mud mortar. Observations show that the wall of those houses is not totally built with stone and mud so that small force can be enough to demolish houses. Initial reports show that 6155 buildings from Bhimeshwar Municipality (BM), 1900 buildings from Manthali Municipality (MM) and 800 buildings from Jiri Municipality (JM) are completely damaged. In rural, more than 95% of the houses have been damaged. Out of that, 56.2% building types were constructed with stone in mud (approximately 9000). More damage due to earthquake is in house made with stone in mud (56.2%) followed by adobe (10.9%), brick block cement (6.2%) and brick block in mud (5.5%) in Bhimeshwar municipality (NSET 2015).

During quake, due to liquefaction process, the houses of river side of both Bhimeshwar Municipality (Nagdaha, Charange) and Manthali Municipality (Chisapani, Gadahar, Masantari, Bhatauli) as well other rural sector are completely damaged. Building damage assessment report shows that 52.6% stone in mud, 10.2% adobe, and 6.2% brick block cement were completely damaged in Bhimeshwar Municipality.

Over 50 and 30% rod concrete and cement (RCC) buildings of Singati and Charikot, respectively, were completely damaged and remaining have developed crack in several structures. RCC structures near the epicenter are completely disoriented too. Cement buildings of the main road of Charikot have been damaged, and almost 15 such buildings are tilted, but not completely collapsed in Charikot–Chrighyang area where hammered either side was supported by other cement structures. Figure 20.3, 20.4, 20.5, 20.6 and 20.7 shows the earthquake devastation in Singati, Dolakha, Charikot and Charikot Bazar. Different housing patterns can be observed for different places.

Dalits are the lower castes, and they are marginalized group in the community. The composition of Dalits in the study area is Damai, Kami, Sarki and Badi. Table 20.2 shows housing pattern by ethnic identity. It can be found that majority of houses are made of stone with mud mortar (82.53%), followed by bamboo with mud mortar (6.28%) and less than 1% houses are made of brick with cement mortar. Ethnically, all houses of Dalit are made of stone with mud mortar. Five percent houses of Janajati and 7% of other casts are constructed with materials better than stone with mud mortar which withstand the quake a little better. Therefore, most of the houses were damaged by the quake.

Fig. 20.3 Earthquake devastation in Singati

20.4 Earthquake Mitigation

Mitigation measures are actions recommended to reduce, avoid or offset the potential adverse impact on the people, life and property resulting from the earthquake. The existing available technology and equipment with government and non-governmental agencies were not sufficient to combat the earthquake damage.

The initial mitigation measure taken by the government was based on principle of 3R (rescue, rehabilitation and reconstruction). Rescue operation was done through the coordination of Home Ministry and concerned line agencies of the government.

20.4.1 Rescue

Major rescue was done to save life of people of the area by national and international agencies. The major mobile health camp was set up in Charikot, and patients were air-lifted from different locations like Lamabagar, Gongar, Singati, Marbu, Chankhu, Orang, Bhirkot. Health camp established by different international agencies and non-governmental organizations rescues hundreds of casualties of the earthquake from the northern and middle parts of the basin.

The financial mitigation measures were only concentrated on distribution of five thousand Rupees to local people and additional twenty thousand during post-winter period in the name of buying cloths for those who are severely bit by cold. The

Fig. 20.4 Landslides in Singati due to earthquake

mitigation assurance of providing goods is served only after increase in death of population in earthquake area. Government has not taken care of local production and its proper distribution.

20.4.2 Rehabilitation

The victimized persons were rehabilitated by different NGOs, INGOs and government at places like Pikhuti (Singati, Fig. 20.8), Gumukhola, Dolakha, Nagdaha, Charikot, Chitre, Malukhola, Bhirkot, Gaikhura and Manthali. Most of the rehabilitation centers were found in the upper side. Almost over 80% of them were

Fig. 20.5 Earthquake devastation in Dolakha

Fig. 20.6 Earthquake devastation in Charikot

constructed with donor agencies, and distribution of necessity goods was continued till six months after earthquake too. The expert team suggested government to relocate 28 villages from the existing location to safer places. However, the action could not be taken into action due to lack of fund for relocation.

Fig. 20.7 Collapsed building of Charikot bazaar

Table 20.2 Housing pattern with ethnicity

S. no.	Housing pattern	Household with ethnic identity				Percent
		Dalit	Janajati	Other	Total	
1	Bamboo with mud mortar		28	14	42	6.28
2	Stone with mud mortar	42	248	263	553	82.53
3	Brick with mud mortar		16	17	33	4.93
4	Stone with cement mortar		17	19	36	5.37
5	Brick with cement mortar		2	4	6	0.89
	Total	42	311	317	670	100.00
	Percent	6.29	46.41	47.31	100	

Source Field survey 2015

20.4.3 Reconstruction

All the tasks related to post-earthquake reconstruction and rehabilitation are given to National Authority for Reconstruction (NRA), central authority to execute all the projects and program related to reconstruction of structure damaged by earthquake. Many of earthquake survivors (22,750 households out of total of 51,934 households) have been spending cold winter nights, two monsoon with flood in makeshift shelter. However, NRA is preparing to follow its Guidelines on Grant Distribution

Fig. 20.8 Initial rehabilitation in Singati

Rules for private houses to settle the problem. After eighteen months, the survivors are getting the first installment of government aid of NRs 50,000 to rebuild their house. But still the reconstruction work is running at a snail pace. Figure 20.9 shows the reconstructed houses in Manthali as an example.

20.5 Eco-environment

The eco-environment of the whole basin was completely disrupted by the quake. The major quake and subsequent aftershocks have further developed cracks in slopy landscape. The eco-environmental factors like land use and land cover change, landslide, water flow and flora and fauna are presented below:

20.5.1 Land Use and Land Cover Change

The total area of the basin is 2700.81 km^2. The major portion of the land is covered by bush and grass with 935.20 km^2 (34.62%), followed by barren land 755.96 km^2 (27.29%) and forest land 527.55 km^2 (19.53%), and least percentage is covered by water bodies 1.29 km^2 (0.04%), the agricultural land cover 246.99 km^2 (9.14%) and snow 231.81 km^2 (8.58%) (Shrestha 2014). In 1996, the total coverage of the forest in the basin was 31.66%, but in 2014 radical change occurred in the area and

Fig. 20.9 Reconstruction in Manthali

the percentage came down to 19.93% only. The percentage under the land use of the forest has been reduced by almost 9%. Preliminary observation of the area shows that about 100–125 km^2 (3.70–4.62%) forest land has been changed into other land. The major process of change was expansion of rehabilitation land, human settlement, clearing community and government forest for immediate rehabilitation and reconstruction and natural hazards. However, the further demand of fuel wood and timber are other causes for land use changes. It has been peculiarly observed that majority of landslide occurred in the forest area. As stated, above 79% of landslides were fall within the forest area. Satellite image classification shows occurrence of significant number of landslides and alteration in topography and microclimate occurrence in the forest area (Joshi 2015).

20.5.2 Landslides

The earthquake has induced hundreds of dry landslides followed by wet landslides during monsoon, rock falls types and overburden falls. Almost whole TRB was covered by dust and falling stones with sizes of 10 × 8 × 6 ft. Reportedly, there were 4490 number of landslides that were detected covering between 10 and 5000 m^2 (12.9% were mapped as point, 76.4% as line and 10.4% as square). Almost 79% of the total landslide area falls within the forested area polygon (Joshi 2015). The field observation also proved this situation.

The study conducted for the two districts (Dolakha and Ramedhhap) shows that 400 landslides have been found to have occurred, while it was only 32 during the pre-earthquake image. There is only one landslide within the category varying from 1 to 5 ha in size in Ramechhap, whereas the number is almost 20 in northern part (Dolakha side). The number of landslides with more than twenty hectares (68, 43, 56 and 19 ha) is more in Dolakha (ICIMOD 2015). Detail of the important landslides associated with earthquake disaster is presented below:

20.5.2.1 Landslides in Lamabagar Stretch

The road alignment from Singati to Lamabagar (36.5 km) is completely covered by dry landscape blocking the road stretch for 3 months. Even in Lamabagar side, the landslide and rock slide were continuously occurring from upper side like a raining stone to river valley during tremor and after shocks. The area passes through localities like Bhorle, Jamune and Gongar village. A total of eight landslides were identified in the section during the field survey of July 2014. These landslides were identified in almost 3–5 km range. However, density of the damage appeared more came down to less than km after devastating earthquake since within 1 km one can see more damage. About 4 km from the Singati Bazar, an old landslide with an area of 20 × 10 × 5 m exists and the land slide consists of huge boulders. Similarly, at distance of about half km from Suri Dovan another landslide with an approximate area of 10 × 5 × 3 m has been identified. The third major landslide occurred in Sipring Khola on July 2, 2015. This landslide killed one person and injured four persons. The landslide covers an area of about 1.5 km^2. Due to security reasons, persons are not allowed to visit places beyond the Singati bazaar about 10 months from the time of tremor until late February of 2016.

20.5.2.2 Landslides in Gonger Khola

The landslide in the Gongar is triggered after the earthquake. The area from the Gonger up to Lamabagar has been completely damaged. The place is locally called Kabhre Bhir. The narrow road with multiple dry landslide is the main cause for such an occurrence. Only small vehicles can operate on the road from Singati bazaar to Lamabagar’s Kabrebhir (29 km), while 4 km road from Kabrebhir to Gonger is completely covered by dry and wet landslides. Moreover, operating vehicles on the road is a risky affair as boulders and debris continue to fall at the Bhorlebhir area, 6 km from Singati.

20.5.2.3 Landslide in Singati

The huge landslide occurred in Singati killing more than 50 persons at one spot. The head of the lands slide is covered with maize field, and toe is covered with road and bazaar. The structure of the area shows that it is an area nearer to MCT zone where dip and strike are asymmetrical. In the first earthquake, the crack was developed, while the second one caused a total fracture. The triangle shaped area of the landslide is about 500 m base × 300 m height × 3 m depth. About 800 m away, another slide is observed with similarly nature. But its height is almost double of length than this one. Similarly, within the area of 38 km from the Singati to the Lamabagar 40 different types of landslide have been recorded (Figs. 20.3 and 20.4).

20.5.2.4 Landslide in the Namdu

The villages of both sides of Namdu and Busti already show the signs of the ground movement. There are five such landslides triggered by earthquake, and after shocks both dry and wet landslides are equally distributed in either side of the valley.

20.5.2.5 Landslides at Dhole Khola

This is area where materials flow regularly. The area usually drops down at the extent of one to three cm every year. The landslide starts from ridge which is situated approximately at 400 m above from the river Tamakoshi. This slide has become wider in the middle which covers approximately about 500 m and extends to about 300 m in the length. Regular accidents with natural calamities are characteristics of this landslide. However, the earthquake has triggered more than dozen landslides in the area.

Similarly, three small parts of landslide are seen in the opposite part of the Majhigaon. Frequent landslide and continuous material flow occur there, and flowing takes place. According to local people, the land mass especially the khet land is placed on the small and opposite part of the bed rock; the latter earthquake has caused several number of landslides than earlier one.

20.5.2.6 Khimti Bensi Landslide

The major landslide had occurred in the August 12, 2013. The length of the landslide is almost 1.5 km, breadth is 500 m, and depth is 40 m. The landslide swept away all the bridge, and even four human lives were lost. The present earthquake triggered almost half a dozen landslides in the nearby flanks.

20.5.2.7 Landslides at Ranajhor/Sukajhor Khola

The Ranajhor and Sukajhor are not perennial streams and flows only in heavy rainfall during monsoon. The source of Ranajhor is Ghopte Pahiro (landslide) with

2 km length by 1.5 km breadth and 50 m depth which seem to occur as mud flow. But, this landslide is characterized by swampy types of landslide which always seem to occur as mud flows. According to local people, the size of landslide area has been extending within the last five years and frequency of the flow has been raised almost double this year due to earthquake.

20.5.3 River Water

The natural quality of water of Tamakoshi and its tributaries was excellent during pre-monsoon period. The water has been used for domestic and other purposes. But during monsoon season high-turbidity/suspended solids and iron make the river water more turbid and make it unsuitable for domestic purposes. However, following the earthquake the river water of the Tamakoshi changed into turbid for more than three months. The cause of increase in turbidity of water related to numerous landslides in the main and tributaries of Tamakoshi. The landslides that occurred in the upper part are responsible for this (Shrestha 2015).

One of the most significant impacts of the earthquake was decrease in sources of drinking water. Most of the spring and upper sources of water (Gongar, Singati, Gumukhola, Alampu, Charnage, Dolti Sahare, Manthali) get dried, and recharge did not happen even during monsoon. However, some of the springs near Melung, Manthali, Bhatauli are overflowed. The water supply of the municipality (Dolakha) and rural parts get disrupted for three months.

20.5.4 Flora and Fauna

20.5.4.1 Flora

Total forest cover in the study area is 180,336 ha which is equivalent to 48.64%. Out of the total forest land in the basin, about 70,500 ha has been under the community forestry (GIS data and Field Survey) and 29,033 ha has been under the communal holding and managed by 261 units of community Forest User Group. The Community forestry directly benefits altogether about 49,381 households. Of total fuel wood and NTF collected, more than four-fifths of timber (81.3%) is collected from community forest followed by other forests (9.6%), private forest (6.5%) and purchase (92.1%). Community forests overwhelmingly remain the main sources of timber irrespective of caste and economic groups (NTNC 2013). Although there are 45 groups of community forestry in the basin, of these, 24 groups are in the upstream and 15 groups in middle portion and the remaining groups are in the downstream site. The total area of this community forest is 3593 ha with approximately 4177 household. The average community forest per household is 0.70 in middle part, 0.43 in downstream and 0.80 in upstream area. The community forest area is more in the upstream and almost manageable in the middle part and lower in the downstream area. Yet, there is short supply of forest products. The area deficits the timber supply by 25%, fuels wood by 42% and forage grass by 16% (Suwal 2009).

After the April earthquake, most of the houses were destroyed. The community forests from Singati to Lamabagar were more devastated by the earthquake than other. Altogether, 7 different community forests from Namdu Hat danda Gairimudi upward have been badly damaged. The people come with axe and get involved in the felling of *sal* trees for construction of temporary sheds. Moreover, due to crack developed after the earthquake most of forest logs fell down in the river. Similarly, in the ridge the logs were lying on the way Jiri, Singati and Lamabagar from Charikot. According to local people, more than 20 such forests have been damaged due to quake. The pressure on the community and even government forest was raised more than 200% after earthquake. It is estimated that almost 800 MT of fuels wood has been cut annually and it is assumed that 50% is substituted by other energy sources like kerosene and LPG in the study area. The demand for timber and poles for establishment of tents and other construction has put much pressure on the national and community forests.

20.5.4.2 Fauna

The commonly reported mammals of the study area are Barking deer (*Muntiacus muntuik*) Rhesus Monkey (*Macaca mulata*), Jackal (*Canis aureus*), Squirrel (*Funanbulus* sp.) and Langur (*Macacca assamensis*). The area is also inhabited by leopard (*Panther pardus*), squirrel (*Funabulus*) and Dumsi (*Hystrix indica*). The local people also reported that the Himalayan Beer (*Selenarctos thibetanus*) and Sloth Bear (*Melurus ursinus*) are found at higher ground of the upper part. Altogether 22 mammals were reported near Lamabagar and surrounding area. (Norconsult 2006). The permanent residential status of Langurs was noted at Khare, Suridobhan, opposite bank of Bhorle bazar, opposite side of the Tamakoshi at Ratamate. But barking deer is found in the most of the community forests.

The number of wild animals (tiger, jackal, mangoose and wild boar) started to enter to village attacking more domestic animals. The goral which are generally live in remote and rugged topography of high altitude in the mountain area started to be found in nearby settlement area of river valley and low altitude area. Similar actions happen in the places like Gaikhura, Chisapani, of Manthali municipality. A significant number of wild animals and their habitat have been disrupted due to frequent after shock. Similarly, in day also crow and other start to fly and scream as of to warn the incoming tremor. It has been reported throughout the basin that many wild animals (barking deer, kaliz (Himalayan screw) and other) came out from their usual habitat. The frequency of encounters with human is greater than pre-quake period.

20.6 Social Development

The total population affected by the quake of the basin comprises 105,359 inhabitants of 28 VDCs and two municipalities. The total of the earth quake victims is 51,934 in Dolakha and 22,750 have been living in tents. The social development (income, education, livelihood) became more a matter of challenge to local people after earthquake. Government program is merely concentrated in administrative works only.

The social development of the affected area became more vulnerable after quake situation. One of the main problems is slow pace of implementing guidelines and related rules and regulation of the government. People are getting only small amount of relief from the government. According to local people, there is no record of the property and other damage by the earthquake in remote area. Those people neither get aid nor get food from the government, NGO and INGO. Even in case of relief distribution, people get trouble when land and property are not in their own name (Bhedpu VDC).

The suffers (about 30%) are living in land of neighbors. After such a long period of occupancy, they are not in position to pay rent for the land. They come back on their own danger and disturbed places. The vulnerability of this type is more observed in the upper part of the basin as the area itself is in slopy and availability of suitable land for settlement is very poor.

20.6.1 Settlement and Business

The settlements are located in moderate slope and flat places, and they are dense in a level land at the River Valleys. The dense settlements of study area are Singati, Nagdaha, Gumukhola, Nayapool, Kirne, Khimti bensi and Manthali, and these are places for business activities. Old women, children and disabled people have been deprived of basic service for the last one year. People of Lamabagar either have to go to Phalak bazaar of China for goods or to go to Charikot. Even for basic needs such as medicine, they have to walk for three days. The existing health post of Lamabager has dearth of proper human resources and medicine for almost one year.

20.6.2 Post-Quake Socioeconomy

The economic activities of the basin have decreased because of earthquake and poor monsoon. From Table 20.3, it is clear that almost all the sectors of the basin were stagnant in comparison with pre-quake period regarding socioeconomic development. This showed the slowest growth of economic and social for the last two decades. The sectors like construction of Upper Tamskoshi Hydropower Projects

Table 20.3 Selected indicator of socioeconomic profile

Sectors	Before quake	After quake	Change after quake
Agriculture	Normal Production	Almost 25% dropped	Number of food deficit households raised
Forestry	Normal	More damage in CF	More pressure on community forestry
Fishing	Normal	50% dropped	Availability of fish reduced significantly
Mining and quarrying	Fully operating	70% dropped	More risky for mining
Construction	100 times	500 times raising	Concentrated in devastated location
Hotel and restaurant	Fully operating	80% dropped	Charikot and Singati
Retailing business activities	Fully operating	50% dropped	People have no purchasing power
Education	Fully operating	Over 80% in open space	School in open space
Health	Almost constant	Almost constant	Scarcity of medicine
Tourism	Growing in full scale	Cent percent dropped	Completely stopped

Source Field survey 2015

come into halt, the proposed Tamakoshi III hydropower has been rejected, and many other small hydro power investors are diverting their mind to invest in other basins. Tourism-related sector like hotel, restaurant, trekking are the worst hit sectors. The hotels are running at less than 10% occupancy even during peak tourist season (between October and November); the production of agriculture, local mining of slate business, fishing also have dropped down negatively due to frequent tremors. However, the health and social service sectors remain almost constant compare to other activities. The quake has decreased the people's income affecting overall economy of the basin which can be seen from the following Table 20.3.

20.6.3 Food Production

A study conducted jointly by the United Nations World Food Program, Food and Agricultural Organization and United Nations' Development Program said that earthquake survivors have seen a steady increase in food security following the massive shock last year. Still there remain a large number of vulnerable communities where food insecurity persists particularly among Dalit and single female headed households.

The majority of the assets lost or damaged in the earthquake were reportedly tools and infrastructure associated with agricultural livelihoods, which was reflected in lower expectations from agricultural production and higher debts overall. An estimated 78.9% of households reported having debt at the time of the assessment (Shrestha 2015).

20.6.4 Crisis on Labor Force

The post-reconstruction work is hit by labor shortage due to out migration in foreign country to look to the place. According to census, about 6364 persons were absent for the last five years and more. India is the major destination for a large number of job seekers in the basin followed by Arab countries such as Saudi Arabia, Quatar, Kuwait, UAE and Malaysia. Similarly, local laborers have gone to their houses to look after their family and some of them have gone to Kathmandu due to fear of landslide and earthquake after shock (Shrestha 2015).

20.7 Conclusions and Recommendations

The mitigation work of earthquake is a challenge in the country like Nepal where the early preparedness was not practiced; human habitation lies in the hazardous area from geological point of view where infrastructure is not properly developed. The government immediately shows responses on the mitigation of distribution of five thousand and assurance of providing 200,000 to each who suffered for the last one and half years. However, the government has never taken any active prompt mitigation measures (natural hazard zone mapping, warning, monitoring of dangerous areas) in the area. However, some kind of passive mitigation measures specially (warning and public awareness, natural hazard was done by NGOs (NEST) and INGO's(Oxfam)). In the study area, certain mitigation measures of GLOF have been installed in the basin from Rolwaling downwards to Manthali and south too with a view to possible hazard to hydropower and human lives. Similar types of passive mitigation should be developed along the basin for preserving the eco-environmental and proper social development of the Tamaksohi River Basin.

The government was not well equipped with rescue materials. The investigations show the large-scale, deep-seated landslides were due to nearness to epicenter and MCT area. The major landslide area was associated with earthquake, lithological structures, slope and non-geotechnical-friendly infrastructure activities. The analysis also shows that there is a close relationship between high slope and landslide along with tremor of 2015.

The mitigation measures of the post-earthquake in initial stage of the government were noteworthy which was like reduction rehabilitation and reconstruction (3R). However, eco-environmental condition is more seriously hampered and socially more vulnerable. The lack of strong leadership and its command on the line agencies and lack of proper coordination are the main causes for the slow pace of recovery, especially in the reconstruction.

Active faults should be monitored and proper monitoring and evaluation should be carried out every five years to know about the induced change. Building code of conduct should be developed which stood in active zone of fault, alluvial zone and weak geological structure.

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Appendix
Photographs of International Acitivties and Field Investigations

I. International Cooperative Activities

The MOU signing ceremony between IMHE, CAS and TU in 2011 (Photo by IMHE)

Academic visit from IMHE, CAS in TU, September, 2013 (Photo by IMHE)

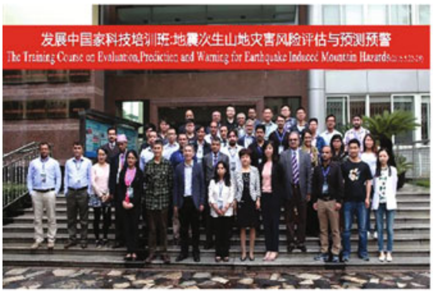
Opening ceremony of the Sino-Nepal Joint Research Center for Geography in TU, April, 2014 (Photo by IMHE)

Opening ceremony of the Sino-Nepal Joint Research Center for Geography in IMHE, CAS, September, 2014 (Photo by IMHE)

Kick-off meeting of the International Cooperation Key Project between IMHE and TU held in IMHE, CAS, January, 2014 (Photo by Wei Zhao)

The training course held by IMHE, CAS in Tribhuvan University, November 2014 (Photo by Wei Zhao)

A. Li et al. (eds.), *Land Cover Change and Its Eco-environmental Responses in Nepal*, Springer Geography, DOI 10.1007/978-981-10-2890-8



The training course on mountain hazards held in IMHE, CAS, May 2016 (Photo by Guisheng Hu)

IMHE-TU joint survey in suburb of Kathmandu (Photo by Wei Zhao)

IMHE-TU joint field investigation in Ramche village, Sindhupalchok District (Photo by Xi Nan)

Interview with village cadres in Dubachour village of Melamchi basin (Photo by Yi Su)

Questionnaire survey in Dubachour village of Melamchi basin (Photo by Yi Su)

Field investigation in Goljung village in Rasuwa Distric (Photo by Xi Nan)

IMHE-TU joint investigation team, March 2016 (Photo by Jianqiang Zhang)

IMHE-TU joint field investigation in Koshi River (Photo by Guisheng Hu)

II. Typical Landscape

A series of snow moutains in the Nepal (Photo by Zhengan Su)

View of high Himalayas (Photo by Jifei Zhang)

Adhikhola basin (Photo by Chhabi Lal Chidi)

Nepal-Madanpur-river valley landform, 2016 (Photo by Jianqiang Zhang)

Sunkoshi River meets Arun River at Chatra, close to Terai Plain (Photo by Bo Kong)

Typical view in Terai plain (Photo by Bo Kong)

III. City and Town

Patan Durbar Square (Photo by Zhengan Su)

Buildings in Kirtipur (Photo by Wei Zhao)

High point view of the Kathmandu valley (Photo by Wei Zhao)

A view of Kathmandu (Photo by Hammad Gilani)

Pokhara city and Phewa Lake (Photo by Hammad Gilani)

Bhimeshwor city in north-eastern Nepal (Dolakha District, photo by Wei Zhao)

A small market town with forest land use and land cover in Bhojpur District (Photo by P. Sharma)

A hill market town (Between Dhankuta and Myaglung, Terhathum District, photo by Puspa Sharma)

IV. Rural Area

Beauty of Karuwa village traditional house in Karuwa, Machhapuchhre VDC, Kaski District (Photo by Prabin Poudel)

Old house with traditional method of Bee Hive in Karuwa, Machhapuchhre VDC, Kaski District (Photo by Prabin Poudel)

Goljung village in Rasuwa District in the Bagmati Zone of northern Nepal (Photo by Jifei Zhang)

Chilime village in Rasuwa District in the Bagmati Zone of northern Nepal (Photo by Wei Zhao)

Rural houses with home gardens amidst *Bari* land terraces in Sankranti Area, Terhathum (Photo by S. Sharma)

A rural village amidst terrace *Bari* land and abandoned agriculture fields in Bhedetar area, Dhankuta (Photo by P. Pradhan)

A primary school sits by a big landslide in Bhirkot village, Dolakha District (Photo by Wei Zhao)

Abandoned house at remote village (Photo by Chhabi Lal Chidi)

V. Livelihoods

Backward living conditions in Melamchi basin (Photo by Yi Su)

The lift style in Melamchi basin of Nepal (Photo by Yi Su)

Couples who cannot even speak in Nepali only Tamang language in Sandal, Machhapuchhre VDC (Photo by Prabin Poudel)

Weaving Doko (as his father's occupation) instead of going school in Chhibang, Machhapuchhre VDC (Photo by Prabin Poudel)

A weekly market or haat bazaar for local rural products in Bhojpur (Photo by P. Pradhan)

Haat bazaar or weekly rural market, Terhathum (Photo by P. Pradhan)

Haat bazaar – an open air market for marketing local needs – Khandbari, Sankhuwasabha (Photo by P. Sharma)

Rudrakchhya – a herbal seed and important exportable product from Sankhuwasabha (Photo by P. Sharma)

Mobile vendor selling cloths, Kathmandu Street (Photo by P. Sharma)

Mobile vendors of flowers, Bhadrakali temple, Kathmandu city (Photo by P. Sharma)

Fruits vendors at Asan, Kathmandu city (Photo by P. Sharma)

Sweet vendors during the festival occasion, Asan, Kathmandu city (Photo by P. Sharma)

VI. Forests

Shorea robusta (Sal) forest in Community forest of Kayarkhola watershed, Chitwan District (Photo by Hammad Gilani)

Agroforestry (terrace agriculture) (Photo by Hammad Gilani)

Pine forest in Champadevi Hill, Kirtipur near to Kathmandu (Photo by Hammad Gilani)

Forest is partly distributed in the north slope of the high mountain in Chilime village, Rasuwa district. (Photo by Jifei Zhang)

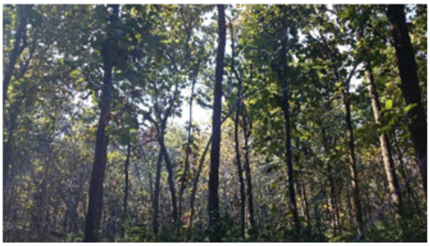
Forest area surrounding settlements, Sankhuwasabha (Photo by P. Sharma)

Forest conservation around Khandbari, the headquarters town of Sankhuwasabha (Photo by P. Sharma)

Thinning forest and secondary growth, Sankhuwasabha (Photo by P. Sharma)

Well forest conservation, Bhojpur (Photo by P. Sharma)

Riverine Forest (Photo by Nabin Kr. Yadav)



Terai Sal forest (Photo by Nabin Kr. Yadav)

VII. Agriculture

Agricultural activity in Melamchi basin of Nepal (Photo by Yi Su)

A sloping farmaland in the Rabiopi Village, Kavrepalanchok District, Bagmati Province (Photo by Zhengan Su)

Couple working on farm land for cultivation in Jimmbir Bari, Machhapuchhre VDC (Photo by Prabin Poudel)

Terraces in the high mountain areas (Photo by Wei Zhao)

Paddy field near the Trishuli River (Photo by Wei Zhao)

Off season vegetable farming – cabbage in Sidhuwa, Dhankuta (Photo by Gita Shrestha)

Tea garden – women picking tea leaves, Laliguras Tea Estate, Dhankuta (Photo by P. Sharma)

Slash and burn, locally known as 'Khoriya' for shifting cultivation practice in the hills of Sankhuwasabha (Photo by G. Shrestha)

Abadoned rainfed terraces at higher altitude and remote areas near to forest area (Photo by Prabin Poudel)

Abandoned village and cultivated land (Photo by Prabin Poudel)

Abandoned steeply slopping cultivated tarrace (Photo by Prabin Poudel)

River tarrace is under crop cultivation and slope land is used for orange farming (Photo by Prabin Poudel)

VIII. Water Resource

Trishuli River section near Trishuli city (Photo by Xi Nan)

Trishuli hydropower cannal (Photo by Xi Nan)

Fish pond of the Community Forest User Groups (Kayarkhola watershed, Chitwan District, photo by Hammad Gilani)

Exploring the hot water source which was lost during flood (Kharapani, Sardikhola VDC, photo by Prabin Poudel)

Wetland in the Terai Plain (Photo by Bo Kong)

Koshi river barrage (Photo by Bo Kong)

Drinking water in Goljung village, Rasuwa District (Photo by Jifei Zhang)

Drinking water in Ramche village, Rasuwa District (Photo by Wei Zhao)

IX. Disasters

Nepal-Debris flow and landslide in Hako, Rasuwa District 2016 (Photo by Jianqiang Zhang)

Nepal-Jure landslide in 2013 (Photo by Jianqiang Zhang)

Nepal-Rockfall induced by earthquake along Trishuli river, Rasuwa District2016 (Photo by Jianqiang Zhang)

Landslide along Lamosangu-Rmechhap Highway, 2013 (Photo by Jianqiang Zhang)

Exposing of rocks due to continues erosion (Photo by Ram Kunwar)

The house few meter away from the landslides (Palunge, Machhapuchhre VDC, photo by Prabin Poudel)

The debris of the catastrophic 2012 flood (Near Jimmir Bari, Machhapuchhre VDC, Photo by Ram Kunwar)

Debris flow investigation in Kukhure Khola (Photo by Guisheng Hu)

Old building destroyed by 4·25 Earthquake in bhaktapur durbar square (Photo by Jifei Zhang)

Destroyed building by landslide induced by 4·25 Earthquake (Photo by Xi Nan)

Damaged building by 4·25 Earthquake (Photo by Jianqiang Zhang)

The Betrawati earthquake camp in Rasuwa Dsitrict (Photo by Jifei Zhang)

The Trishuli earthquake camp (Photo by Xi Nan)

Earthquake rescued in Charikot (Photo by Uttam Sagar Shrestha)