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および地域社会認識の評価：ネパールにおける国立公園管理にむけた統合的 フレーム
ワークの設計)

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in

Environmental Science



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Abstract

The International Union for Conservation of Nature (IUCN) defines the protected area (PAs) as a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the sustainable conservation of nature with associated ecosystem services and cultural values such as national parks, conservation areas, wildlife reserves, sanctuaries and wilderness areas. PAs are vital natural assets that protect diverse ecosystems and heritage sites. They are key to achieving conservation goals, promoting biodiversity, and ensuring its sustainable and equitable use.

According to the IPCC 2023 report, the global landscape is undergoing significant and changes due to anthropogenic activities, which account for 60% of global biodiversity loss and exacerbate climate change impacts. Therefore, it is essential to thoroughly understand various types of land cover, as they play a crucial role in regulating ecological processes, such as carbon sequestration, water filtration, and biodiversity preservation. Additionally, long-term assessments of land cover dynamics offer valuable insights into the complex relationships between environmental changes and human activities. Comprehending these elements may prove instrumental in meticulously monitoring trends, explaining underlying driving factors, and predicting future trajectories of land cover dynamics. Nevertheless, such dynamics are particularly noticeable in mountainous regions, where pressures from human development are consistently increasing due to various factors, including local population needs and tourism development.

Nepal's unique and diverse ecosystems, including forests, grasslands, wetlands, rivers, and glaciers, provide essential ecosystem services that are vital for local livelihoods and global environmental health. However, these ecosystems have undergone considerable changes due to deforestation, land conversion for agriculture, urbanization, and infrastructure development, which are significant drivers of ecosystem degradation. Such loss of forest cover has led to severe consequences, including increased soil erosion, landslides, and habitat loss, which in turn influences the ecological landscape and the socio-economic fabric of communities living around PAs. Recognizing the critical importance of forests, the country witnessed the rise of a movement promoting community engagement in forest protection and management in the 1970s. Nepal is recognized for its community forestry restoration efforts, and nearly two-thirds of its population still relies on forest products for subsistence. This poses significant socio-ecological threats to the country's forest conservation. National parks in Nepal, as tourist destinations, are under high pressure due to the increased demands from domestic, religious,

and international tourists. Therefore, it is essential to understand the interaction between human activities, changes in forest cover, and policies for sustainable environmental management.

This study focuses on Sagarmatha National Park (SNP) and Khaptad National Park (KNP) to assess land use and land cover (LULC) changes using Landsat satellite data from 1991 to 2020 and a questionnaire survey to understand the community perceptions. Monitoring LULC dynamics provides timely information for effective landscape management. This study investigates LULC dynamics in SNP, a popular mountain tourism destination, and KNP, an emerging domestic tourist spot. A random forest image classification algorithm was employed to generate LULC dynamics from Landsat data, and accuracy was assessed using Planet Scope and Google Earth images. Cellular Automata-Artificial Neural Network (CA-ANN) predictions were used to forecast future LULC changes. Tourist and climatic data were also analyzed to explore their impacts on LULC changes. From 1989 to 2021, the SNP experienced an increase in bare land, grassland, shrubland, glacial lakes, and water bodies, but substantial decreases in snow/glacier (140.25 km²) and forest cover (15.36 km²). In KNP, grassland, agriculture, water bodies, and bare land increased, while forest and shrubland decreased by 18.63 km² and 10.48 km², respectively. Forest loss in KNP's buffer zone (19.33 km²) exceeded that of SNP's buffer zone (13.45 km²). Built-up areas increased by 0.80 km² in SNP and 1.11 km² in KNP, indicating escalating tourism and population growth. PlanetScope data of KNP also shows development of new roads in buffer zones that lead towards the boundary of core zone. The increasing pressure on buffer zones of SNP and KNP can impact forests in the core zone; therefore, there is a need to develop a framework to control deforestation in these PAs.

In SNP, mean annual precipitation decreased, while temperature increased from 1994 to 2023. In KNP, mean annual precipitation and temperature shows an increasing trend. Under a business-as-usual scenario (BAU), the estimated forest loss by 2032 is 1.61 km² in SNP and 23.8 km² in KNP by 2030. A significant decline in snow/glaciers is projected for SNP's core zone, with a loss of 22.84 km² expected by 2032. This study provides baseline information on LULC changes in SNP and KNP.

This study also examines the intricate relationship between agriculture, tourism, and forest resources in two contrasting Nepalese national parks: SNP, characterized by high-intensity foreign tourism, and KNP, which attracts domestic religious tourists. Employing a comparative case study design and the Sustainable Tourism Attitude Scale (SUS-TAS), the research investigates the impacts of these sectors on forest cover and community well-being.

Data were collected through household surveys, supplemented by satellite imagery analysis to assess changes in LULC. The findings reveal a significant negative correlation between household tourism and forest cover in both parks. In SNP, increased agricultural productivity is strongly associated with forest loss, indicating that agricultural expansion is encroaching into forest areas. The negative impact of tourism on the SNP is attributed to increased demand for infrastructure and other tourism-related resources. In contrast, KNP shows a significant negative relationship between forest dependency (reliance on forest resources for fuelwood and fodder) and forest cover, highlighting the role of subsistence livelihoods in driving deforestation.

Further analysis, using Ordinary Least Squares (OLS) regression, identified key variables driving forest cover change in each park. In SNP, agricultural productivity and household tourism were significant predictors, whereas in KNP, forest dependency was the primary significant predictor. Other factors, such as tourism satisfaction, gender, and livestock dependence, showed little to no substantial influence on forest cover change in either park.

This study highlights the importance of community-based approaches in ensuring equitable resource distribution, promoting sustainable practices, and fostering ownership and accountability within local communities. The findings suggest that balancing economic development with environmental sustainability requires collaborative efforts, participatory decision-making, and the implementation of policies that address the specific challenges and opportunities within each park's unique context. Building upon these findings, the study introduces the Integrated Land-Use and Community Adaptation Framework (ILCAF) a novel, evidence-driven framework designed to guide sustainable national park development by integrating cross-sectoral strategies, participatory governance, and adaptive land-use management in Nepal's protected areas.

This framework, adaptable to varying tourism levels and ecological contexts, integrates sector-specific indicators and promotes eco-friendly practices. To address deforestation in buffer zones, a community-centric buffer zone management plan and awareness campaign are vital.

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List of Key Abbreviations

SNP	Sagarmatha National Park
KNP	Khaptad National Park
REDD+	Reducing Emissions from Deforestation and Forest Degradation
NDVI	Normalized Difference Vegetation Index
NDSI	Normalized Difference Snow Index
SRTM	Shuttle Radar Topographic Mission
RF	Random Forest
LULC	Land Use Land Cover
GEE	Google Earth Engine
NTB	Nepal Tourist Board
DEM	Digital Elevation Model
IPCC	Intergovernmental Panel on Climate Change
ES	Ecosystem Services
EBC	Everest Base Camp
UNESCO	United Nations Educational, Scientific, and Cultural Organization
PA	Protected areas
CA-ANN	Cellular Automata Artificial Neural Networks
MLP	Multi-layer perceptron
SUS-TAS	Sustainable Tourism Attitude Scale
CFUGs	Community Forest User Groups
ILCAF	Integrated Land-Use and Community Adaptation Framework

Chapter 1. General Introduction

Protected areas (PAs) are important for keeping landscapes and biodiversity safe around the world (Ivanova and Cook, 2020). The International Union for Conservation of Nature (IUCN) defines the protected area as a *clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the sustainable conservation of nature with associated ecosystem services and cultural values* such as national parks, conservation areas, wildlife reserves, sanctuaries and wilderness areas. There are 286,810 designated PAs as of December 2024. These PAs are about 16.44% of the Earth's surface (UNEP-WCMC and IUCN, 2024) and help preserve LULC from changing by setting up boundaries and using different conservation methods. It also restricts various activities by partitioning PAs into distinct zones for the preservation of biodiversity and the maintenance of environmental stability (Watson et al., 2018). Recently, PAs are facing problems like losing habitat, cutting down trees and damaging forests because of the excessive use by humans, which leads to conflicts between people and nature (Chang et al., 2022). So, it's important to know how LULC changes in PAs and how different causes affect it. Many human activities are quickly changing the surface of the Earth. The changes that people have made have a big effect on natural resources and people's health. The most recent IPCC report shows that human activities are to blame about 60% of the loss of biodiversity around the world (IPCC, 2023; Newbold et al., 2015). To effectively manage these changes and reduce their negative effects, it is essential to understand the temporal dynamics of LULC. The change in LULC is important for many ecosystem services on the Earth's surface, like storing carbon, cycling nutrients, and cleaning water. These services are essential preserving healthy ecosystems, which supports biodiversity. Anthropogenic factors have high significance in the causes of LULC change, primarily resulting from human activities such as agricultural expansion, industrialization, urbanization and infrastructure development. In the past the main cause for LULC has been agricultural expansion. The need for more food caused more trees to be cut down and land to be changed around the world (Foley et al., 2005; Chen et al., 2014). While anthropogenic drivers are predominant, natural factors significantly influence LULC changes. Natural factors such as climate changes, natural disasters, and changes in ecosystems. Changes in the weather, like temperature and rainfall, can change the plants species that grow in a certain area. This can cause land cover to change over time (Keenan et al., 2016). Natural disasters, like floods, hurricanes, and wildfires,

can rapidly cause change in the land cover, which can have a big effect on local ecosystems (Cüce, 2023). Long-term evaluation is essential for land use and land cover (LULC) changes for discerning diverse drivers and forecasting future LULC trends, ultimately facilitating sustainable land management (Hansen et al., 2013). In this context, remote sensing and Geographic Information System (GIS) technologies have been instrumental in tracking global Land Use and Land Cover (LULC) changes and various trends, including deforestation, urbanization, and agricultural expansion, which result in habitat fragmentation and a reduction in ecosystem services (Turner et al., 2015; Lambin and Geist, 2008). Monitoring LULC dynamics is crucial in mountainous regions, where population growth and tourism development exert increased pressure on ecosystems (Ingram et al., 2015).

This study combines geospatial data analysis with qualitative data from information gathered from a questionnaire survey that investigates land use and land cover (LULC) changes and reflects the public perceptions in SNP and KNP. It provides a contemporary analysis of LULC change using Landsat data and investigates the various underlying causes of change as perceived by local communities, including their responses to these changes. This comprehensive approach provides a deep understanding of the complex factors and diverse perspectives associated with LULC dynamics to establish a novel framework for protected areas in Nepal.

1.2 Protected Areas of Nepal

PAs were first designated in 1973 with the National Parks and Wildlife Conservation Act (Nepal, 2002). The system aims to protect representative ecosystems, endangered species, and important natural areas. Nepal has 12 national parks, 6 conservation areas, 3 wildlife reserves, and 1 hunting reserve, with unique geography, flora, and fauna. Together they cover 11,805 km² or 8% of the country (Figure 1.1) (DNPWC, 2024a). There are also 12 buffer zones. About 75% of PAs in Nepal involve local people in resource management and benefit sharing. Nepal's national parks system is important for biodiversity and sustainable development. The Department of National Parks and Wildlife Conservation manages these areas (DNPWC, 2024a). Figure 1.1 shows the locations of Nepal's PAs.

- National Parks are Category II protected areas. They are large natural or near-natural areas that preserve ecological processes, species, and ecosystems and allow compatible spiritual, scientific, educational, recreational, and visitor use. In Nepal, the NPW Act (1973) defines them

as “an area set aside for the conservation, management and utilization of flora, fauna and scenery along with the natural environment.

- Conservation Areas are defined under the NPW Act (1973) as “an area to be managed according to an integrated plan for the conservation of the natural environment and balanced utilization of natural resources.” User rights are granted by Local Conservation Area Management Councils (CAMC) to consumer groups representing households in a Conservation Area.

- Wildlife Reserves, defined under the NPW Act (1973) as “an area set aside for the conservation and management of wildlife resources and their habitats,” use fees to regulate community resource use. User rights may be granted to community and Indigenous groups for controlled access (e.g., fishing, collection of fallen wood, wild vegetables, grass).

- Hunting Reserves are areas “set aside for the management of wildlife for allowing hunters to hunt them” (NPW, 1973). They are often high-value ecosystems managed for multi-use and conservation and allow controlled hunting by Nepali and foreign hunters.

1.2.1 Role of Protected Areas of Nepal

Key international conventions and programs, such as the Convention on Biological Diversity (CBD), the World Heritage Convention (WHC), the UN Law of the Sea Convention, and UNESCO's Ramsar Convention on Wetlands, Man and the Biosphere (MAB) Program, are increasingly recognizing the important role of PAs. The World Commission on Protected Areas (WCPA) is also working on a global project that strengthens this commitment. The agreements are necessary for setting up and managing protected areas to preserve the biodiversity and let us use the natural and cultural resources for benefiting the environment (Phillips, 1998) and avoiding causing harm. Nepal's protected areas are very important for protecting biodiversity, preserving the ecosystem, and giving people in the area other means for profiting. They protect a lot of different ecosystems, from tropical forests to alpine zones, as well as endangered species like snow leopards, red pandas, Bengal tigers, and rhinos. These areas are also important for the environment because they manage water resources, store carbon, protect the soil, and places for cultural and religious heritage. Tourism in protected areas is economically important for Nepal. It helps local people make a living by bringing profit from mountain tourism and community-based conservation

projects. But these areas are getting harder to live in because of things like habitat loss, deforestation, conflict between people and animals, and poaching.



Figure 1.1: Locations of various protected areas of Nepal (Source: DNPWC)

1.2.2 National Parks of Nepal

The modern history of PA management in Nepal began in 1973 with the promulgation of the National Parks and Wildlife Conservation Act and the establishment of Chitwan National Park. Chitwan National Park is a UNESCO World Heritage site. It is renowned for its one-horned rhinoceroses, Bengal tigers, and various bird species inhabiting its grasslands and wetlands. In the years immediately after these events, protected area acts and regulations were enforced strictly, often overlooking the role of local communities in managing natural resources. However, with shifts in Nepal's socio-political and economic landscape, management practices have moved toward a more flexible model that more fully acknowledges the contributions of those living and working within PAs. Another major park is SNP, a UNESCO World Heritage Site with Mount Everest's highest peak. The park uniquely blends high-altitude ecosystems, glaciers, and deep

valleys. It is home to iconic wildlife, such as the snow leopard and red panda, alongside the rich cultural heritage of the Sherpa people.

Other significant national parks include Langtang National Park, known for its diverse flora and fauna and scenic trekking routes that lead to the Langtang Valley and the Langtang Lirung Peak. Similarly, Bardiya National Park is situated in the Terai region and is notable for its dense forests and endangered species, such as the Gangetic dolphin and the wild elephant. Additionally, Rara National Park is home to Nepal's largest Rara Lake. It is known for its pristine environment and unique wildlife, making it a crucial conservation area. These national parks are vital for conservation and are essential to supporting local economies through tourism. KNP is known for its tranquil high-altitude meadows, cultural heritage and significance as a local spiritual destination. Nepal's national parks are increasingly integrating sustainable tourism initiatives, which help to maintain environmental integrity and provide economic benefits to local communities through eco-tourism. Table 1.1 lists the national parks of Nepal along with their year of establishment and area.

Table 1.1: Details of National Parks of Nepal (Source: DNPWC annual report 2024)

No.	National Parks	Geographical Region	Core area (km ²)	Core area established year	Buffer area (km ²)	Buffer area established year	Total area (km ²)
1	Chitwan National Park	Terai	952.63	1973	729.37	1996	1682
2	Bardiya National Park	Terai	968	1976	507	1996	1475
3	Langtang National Park	Mountain	1710	1976	420	1998	2130
4	Rara National Park	Mountain	106	1976	198	2006	304
5	Banke National Park	Terai	550	2010	343	2010	893
6	Sagarmatha National Park	Mountain	1148	1976	275	2002	1423
7	Shey Phoksundo National Park	Mountain	3555	1984	1349	1998	4904
8	Shivapuri National Park	Midhills	159	2002	118.61	2016	277.61
9	Makalu Barun National Park	Mountain	1500	1991	830	1999	2330
10	Khaptad National Park	Mountain	225	1984	216	2006	441
11	Shuklaphanta National Park	Terai	305	2017	243.5	2017	548.5
12	Parsa National Park	Terai	627.39	2017	285.3	2017	912.69

1.3 Categorization of National Parks in Nepal

Categorizing national parks helps explain conservation, tourism, and community links. This study uses three factors to group parks in Nepal first one is the area second is the number of tourist arrivals, and revenue. This method labels each park's popularity as high, medium, or low. Park area matters because it shapes ecological diversity, visitor flow, and available activities. But small parks can also earn strong revenue. Infrastructure and distance from cities also matter. These factors change how many tourists come and how much they spend on recreation. Nepal receives international and domestic visitors for many reasons. These include recreation, mountain climbing, and research. To build a single priority score, this study assigns weights to the three factors. That weight is 40% for visitors, 30% for area, and 30% for revenue. That score ranks the parks by popularity. Based on the results, parks fall into high, medium, or low groups, as shown in Table 1.2. Using this scheme, the study selects SNP and KNP. This helps link tourism with conservation and community goals. That choice reflects their popularity levels and contrasting settings.

Table 1.2: Classifications of National Parks according to Area and Revenue Collection in Nepal (Source: DNPWC annual report 2024)

Popularity Level	National Parks	Priority Score	Notable features
High	Chitwan	0.79	Rhinos, tigers, UNESCO World Heritage Site
	Shey Phoksundo	0.34	Shey Phoksundo Lake, snow leopards
	Shivapuri	0.34	Hiking trails
	Makalu Barun	0.29	Alpine flora, mountains
	Sagarmatha	0.2	Mount Everest, Sherpa culture
Medium	Langtang	0.16	Red pandas
	Bardiya	0.15	Tigers, elephants
	Rara	0.08	Rara lake
	Banke	0.06	Tiger and elephant habitat
Low	Khaptad	0.053	Cultural significance, diverse ecosystems
	Parsa	0.04	Dense Forest
	Shuklaphanta	0.028	Diversity of birds

1.4 Overview of Forests in Nepal

Nepal's forests are the most important resources in the country. This resource provides important ecosystem services and provides income for millions of people, especially those who live in rural areas (Lamsal et al., 2018). Table 1.3 shows the drivers of deforestation and underlying causes in Nepal (Chaudhary et al., 2016). There are variety of forests in the country, and they are at different levels. The mid-hills have the most forest, while the Tarai has a lot less (Stainton et al., 1972). Because of these trends, deforestation and forest degradation are big problems. These issues cause disrupt in ecological balance and adversely affect the livelihoods (FAO, 2009; Chaudhary, 2000). These losses are caused by different factors. Direct causes include cutting down trees for fuelwood, timber, and fodder using unsustainable methods; illegal logging; forest fires; and building new infrastructure. Indirect causes are also considered as a reason, such as high population growth and migration (especially to the fertile Tarai plains), overgrazing, weak governance, unclear forest policies, and cross-border timber trade (Shroder, 2016). This combination puts more burden on forests and makes life difficult for people benefiting from them.

Table 1.3: Drivers of deforestation and underlying causes in Nepal
(Source: Chaudhary et al., 2016)

No.	Main Driver of Deforestation	Underlying Causes
1	Forest Dependence	▪ Poverty and lack of alternatives ▪ Limited access to resources ▪ Inefficient resource use
2	Illegal Logging	▪ Weak law enforcement ▪ Poverty ▪ High demand (across borders)
3	Unsustainable Harvesting	▪ Weak law enforcement ▪ Unclear land ownership ▪ Lack of training
4	Forest Fires	▪ Carelessness ▪ Deliberate burning ▪ Poor fire management
5	Land Encroachment	▪ Agricultural expansion ▪ Poverty and land scarcity ▪ Unclear land rights
6	Overgrazing	▪ Too many livestock ▪ Limited fodder alternatives ▪ Poverty
7	Development Projects	▪ Poor planning and coordination ▪ Lack of environmental assessments ▪ New economic opportunities

1.5 Mountain Tourism in Nepal

Mountain tourism is now a big part of tourism around the world. Amerta et al. (2018) say that this needs to be balanced: to protect nature and help local people. In these areas, you can have experiences that you can't have anywhere else. These are variety, remoteness, hard access, fragile nature, and striking beauty (Nepal & Chipeniuk, 2005). Nepal is one of the best places in the world to see mountains. Eight of the ten tallest mountains are in it, including Mount Everest. Every year, thousands of people come to hike, climb, and do eco-tourism. Nepal's economy depends a lot on this sector. The Nepal Tourism Board said that in 2019, just before COVID-19, there were about 1.19 million visitors from other countries (Nepal Tourism Board, 2023). This shows how important tourism is. That shows once more how important tourism is for Nepal's economy and jobs.

National parks are central to mountain tourism. This is because they combine beautiful natural areas with living cultures and support conservation. For example, SNP had more than 60,000 trekkers in 2019, and about 38,000 reached Everest Base Camp one of the world's most popular trekking routes (DNPWC, 2024a). Langtang National Park has received about 30,000 visitors per year in recent years. That shows steady recovery from the 2015 earthquake (Nepal Tourism Board, 2023).

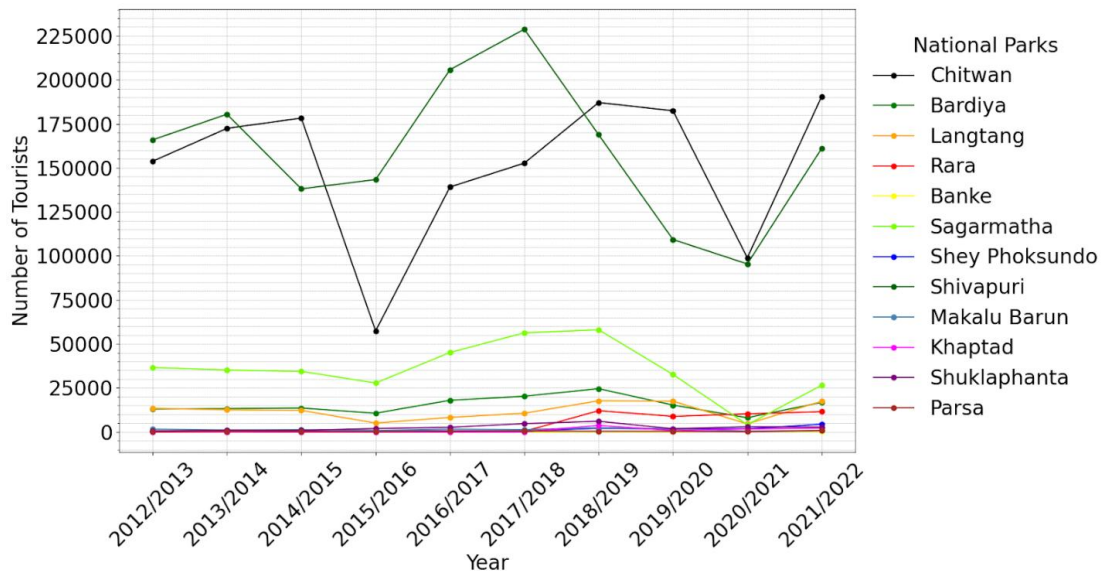


Figure 1.2: Number of foreign tourists in various national parks of Nepal from 2012 to 2023
(Source: DNPWC)

Figure 1.2 shows foreign visitor numbers in Nepal's national parks from 2012 to 2022 (DNPWC, 2024a). KNP is in the far-western region and is harder to reach, so it gets fewer visitors

and less tourist pressure. As a result, its forests and biodiversity are relatively well preserved. But challenges remain, such as illegal poaching and weak infrastructure (S. Bhatta, Devkota, et al., 2023; B. R. Bhattarai et al., 2017).

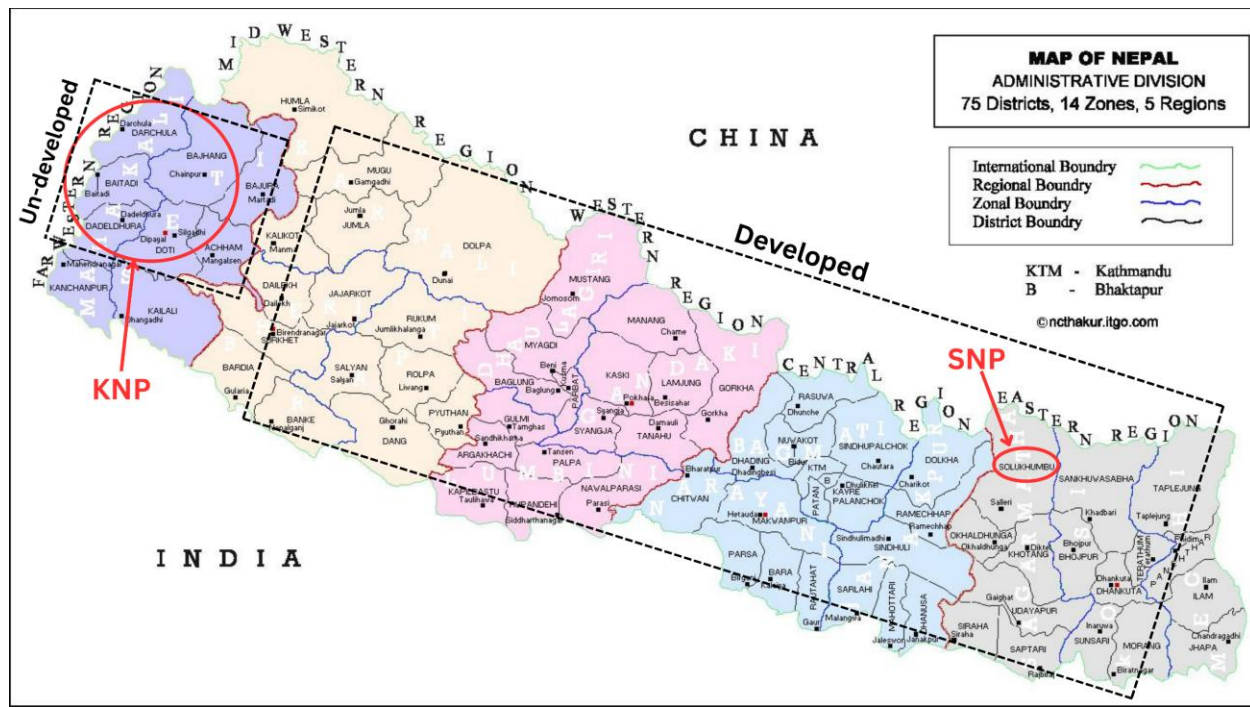


Figure 1.3: Map of Nepal with developed and underdeveloped tourist areas. (Source: Dhakal 2015)

Figure 1.3 shows that the far western and mid-western parts of Nepal are not very developed for tourism. This is a great chance for sustainable mountain tourism to grow (Dhakal, 2015). Nepal's protected areas, local communities, and ecosystems are all very important to mountain tourism and income source, giving people jobs in trekking, hospitality, local trade, and conservation (Shrestha, 2022). Mountain tourism does more than just make money; it gathers people, makes communities stronger, and encourages sharing of ideas and cultures. But the sudden rise in tourism, especially in popular trekking areas, has caused problems for the environment and society, such as deforestation, trash buildup, loss of culture, and increasing number of tourists (Kadayat and Upadhyay, 2024; Kanal and Gosai et al., 2024). Because of these problems, national and local stakeholders are trying to promote sustainable tourism by making it harder to get trekking permits, encouraging eco-friendly practices, improving infrastructure, and running public awareness campaigns.

Putting ecotourism principles first, promoting responsible travel, and respecting local customs and environmental limits are all important for making mountain tourism a fair and sustainable way to grow. Mountain tourism can support the environment and the people who live there by different means, such as by promoting community-based tourism, protecting wildlife, and promoting inclusive governance. To be able to last for a long time, Nepal's mountain tourism industry needs to be able to deal with the problems that tourists from around the world face and plan ahead (Nepal, 2008; Nepal and Chipeniuk, 2005).

1.6 Climate Change in Nepal

Nepal is severally affected by Climate change which affects the people and the environment of the country (Shahi et al., 2022). Nepal is very vulnerable because it has a lot of different altitudes and fragile ecosystems. Since about 1950, the average temperature has increased by about 0.04–0.06 °C every year. This is more than the average for the world (Shivakoti et al., 2015; Anup, 2017). This warming is most pronounced at high elevations, resulting in shifts in biodiversity and the tree line (K.C. and Ghimire, 2015). The rain patterns are also changing. From 1971 to 2005, the total amount of rain increased each year but decrease in the number of days (Baidya et al., 2007). These changes caused more severe events like floods and droughts, which puts rural farmers' livelihoods at risk (Eugenio-Martin and Campos-Soria, 2010). Social conditions increase the risk: being poor, and illustrate, and relying on natural resources make it difficult to adapt (Gurung and Bhandari, 2009). Because of this, Nepal is the fourth most vulnerable country to climate change (CCNN, 2011).

There is a close link between climate and tourism across ecosystems coastal, mountain, and nature-based (K.C. and Thapa Parajuli, 2015). In Nepal, studies focus on mountain regions, where trekking and mountaineering support local livelihoods. This tourism is climate-sensitive, and that makes it vulnerable to changing temperatures, shifting rainfall, and more frequent extreme events.

1.6.1 Impacts of Climate Change on National Parks

National parks support Nepal's ecosystems, communities, and livelihoods. This role is now under threat from climate change. Rising temperatures, erratic rainfall, and new kinds of hazards are harming these parks. Langtang and Sagarmatha are tied to glacial and alpine systems. These warmer conditions are creating more glacier lakes that can burst and cause glacial lake outburst

floods (GLOFs). That risk threatens fragile mountain ecosystems (Byers et al., 2014; Gautam, 2014). Trees are also moving upslope. In Sagarmatha National Park, over the past 200 years, *Abies spectabilis* (East Himalayan fir) shifted upward by about 0.93 m/yr and *Betula utilis* (Himalayan birch) by 0.42 m/yr. This upward shift causes species displacement and habitat fragmentation (Gaire et al., 2017).

These problems also appear in the mid-hills and the Tarai. The greater one-horned rhinoceros (*Rhinoceros unicornis*) in Chitwan National Park faces habitat fragmentation from floods linked to climate change. Increasing droughts and forest fires threaten wildlife in Bardiya and Shuklaphanta National Parks (Pant et al., 2020). In Khaptad National Park, Indigenous medicinal plant species are severely affected by rising temperatures (Kunwar, 2014).

1.6.2 Impacts of Climate Change on Tourism

The tourism industry in Nepal is very important to the country's economy. Climate change has a big effect on this sector. There are already big changes in the climate of the country. The rain pattern is changing, the tree lines are moving, and disasters are happening more often and are more severe. These changes affect both people's jobs and the tourism industry. This is important because farming and hydropower are closely linked to tourism (Sharma, 2009).

The connection between climate and tourism is very important in Nepal. The weather has a big impact on many activities, such as hiking in the mountains, going to see nature, and eco-tourism. Changes in the seasons, strange rain, and extreme events can all have an impact on these activities. The change in weather puts both tourists and people who live there at risk. This can decrease the number of tourists, which is bad for the people who rely on tourism for their income (Anup et al., 2013). Mountain ecosystems are also in danger because of the glaciers melting and the change in snowpack. People come to see these ecosystems because they want to see snow. Nepal's mountainous areas need a plan with several steps to deal with these issues: prevention, strong rescue and recovery systems, and good early-warning systems (K.C., 2017).

1.6.3 Impacts of Climate Change on Agriculture, Livestock, and the Livelihood of Local People

Climate change is bad for Nepal's animals and plants. This puts the jobs of people who depend on farming at risk. Rising temperatures, changing rainfall patterns (with more droughts and floods), and glacial lake outburst floods (GLOFs) all make it harder to grow crops and lower yields (Shrestha et al., 1999). The change in rain patterns affects the irrigation, which makes crops like rice, wheat, and maize less productive (Bhandari, 2013). Extreme weather destroys crops and damages roads, canals, and storage, which affects the economy negatively and makes people less secure about food (Malla, 2008). As the climate changes, animals are more likely to get sick, have less water, and be stressed by the heat (Aryal, 2012). These effects make poverty and inequality, especially for groups that rely on farming and herding that depend on rain. People don't make as much money when there are less crops and animals. That makes a lot of families move or use short-term, unsustainable ways to deal with things, which puts their health at even more risk in the long run.

1.7 Land Use and Land Cover Change in Mountainous Regions of Nepal

Nepal has different species of plants, and animals. There are a lot of changes happening to the land use and land cover (LULC) in this country. These changes, to the farmland, infrastructure, are mostly caused by people (Rai et al., 2023). Illegal logging and the growth of farms have caused the loss of forest cover, which threatens biodiversity and ecosystem services (Verma et al., 2021; Lamsal et al., 2018). It's also becoming clearer that climate change is happening, as glaciers are melting and rainfall patterns are changing which affects the ecosystem negatively (Shrestha et al., 2010). These changes can make landslides and floods more likely to happen, especially in the mountains (Tiwari & Dhakal, 2023). These problems show that we need to manage land better so that it fits with the SDGs (Sustainable Development Goals).

It is important to monitor the LULC in the mountain regions. These places are like "water towers" for downstream regions and host different kinds of plants and animals that influence local and regional climate patterns. However, activities such as deforestation, intensive farming, and urban expansion exert significant pressure on these ecosystems (Li et al., 2023; Newbold et al., 2015). These pressures adversely impact the environment and society, disrupting ecological

balance (Sharma et al., 2009; Shrestha et al., 2022). Studies in the Himalayas reveal that alterations in land use and land cover are driven by unsustainable practices, population increase, and tourism expansion (Tiwari, 2000; Verma et al., 2021). Paudel et al. (2016) found that as farmland grows, forests shrink, which is bad for biodiversity and the local climate. Adding more places for tourists to stay can change LULC (Bhatta & Chan, 2023). These changes break up habitats, reduce biodiversity, and make ecosystem services less useful (Sharma et al., 2022). LULC also affects the climate by changing how energy, water, and greenhouse gases move between land and air (Sleeter et al., 2018). It's important to know how LULC and management work together to understand how they affect the climate and find beneficial methods to deal with it (Dewan & Yamaguchi, 2009).

1.7.1 Role of Remote Sensing in LULC Monitoring

The LULC changes are mainly caused by various anthropogenic activities. These drivers include population growth, demand for farmland, and new infrastructure (Foley et al., 2005; IPCC, 2023). Satellite remote sensing and geographic information systems (GIS) give clear information about LULC change. These tools can show a change in forest cover from farm expansion and illegal logging, which threatens biodiversity and ecosystem services (Verma et al., 2021; Lamsal et al., 2018). This is why monitoring LULC is crucial for environmental management and conservation plans that support sustainable development (Hansen et al., 2013). Conventional field methods have limits in area, timing, cost, and effort. The growth of remote sensing has changed LULC monitoring by allowing high-spatial and high-temporal satellite analysis (Turner et al., 2015).

Different sensors record distinct spectral signals from Earth's surface. These signals help identify and classify LULC types. Satellites cover large areas and revisit regularly. This lets us track LULC from local to global scales over long periods and reduces limits of ground surveys. Advances such as high-resolution multispectral sensors and Synthetic Aperture Radar (SAR) have greatly improved classification accuracy and detail (Wulder et al., 2016; Zhu et al., 2019).

Cloud platforms like Google Earth Engine (GEE) further improve processing and analysis of very large remote sensing datasets (Phan et al., 2020). This enables efficient multi-temporal analysis and faster detection of LULC change patterns. In Nepal, long Landsat records help in tracking change in forests, farmland, settlements, and other classes over decades (Paudel et al., 2016; Shrestha et al., 2010). These studies reported the decline in forest and snow/glacier cover,

and rapid urban growth in major cities (Wang et al., 2020). The use of advanced methods, including machine learning, has further improved LULC classification accuracy and efficiency (Paudel et al., 2016).

1.8. Research Gaps and Rationale of Study

There are major gaps in Nepal's LULC investigations, considering the use of remote sensing. Previous studies often focus on national trends and overlook detailed analysis of specific regions and ecosystems. These studies also do not fully explain the interplay among the main drivers of change climate change, population dynamics and tourism development. There hasn't been enough study of that integrate LULC with community perceptions. The long-term impacts of community forestry on LULC and the links between local forest cover change and stakeholders' decisions are still not well studied. There is also limited research that uses satellites to connect LULC change with its causes and to predict what will happen in the future in an integrated design. While some studies examine LULC in SNP, there is very limited comparable research for KNP. This study fills these gaps by doing a detailed analysis of LULC change in the core and buffer zones of SNP and KNP. This research uses the ground-truth data, climate data, tourism statistics, socio-economic data and local community perceptions. The study examines inputs for decadal (ten-year) LULC changes, identify causes, and assess climate effects in two parks with different ecosystems and popularity. The results describe the reason of the change, such as natural processes, human activities and policy actions. The research provides a framework for protected areas in Nepal. The framework focuses on sustainable mountain tourism and on balancing local community needs with conservation goals. These findings will help SNP and KNP plan and manage conservation so that development and preservation work together.

1.9 Research Objectives

This study provides a new framework for Nepal's protected areas system based on LULC dynamics and community perceptions. Enhancing the understanding of LULC dynamics in SNP and KNP provides better managements applications, with emphasis on the impact of mountain tourism on surrounding ecosystems. These two parks were selected for their differing levels of tourism activity and landscape characteristics, offering a comparative analysis of tourism's impacts. This study integrates various data sources using remote sensing, field surveys, questionnaire

surveys and advanced analytical techniques (machine learning, CA-ANN modelling, GIS) to comprehensively understand LULC change, predict future scenarios, and propose sustainable mountain tourism strategies. This research provides valuable insight into developing a new framework for sustainable mountain tourism strategies for SNP and KNP. The specific objectives are:

1. To analyze LULC dynamics in the core and buffer zones of SNP and KNP from 1990 to 2020 using satellite data.
2. To Assess change patterns and trends in LULC and forecast predictions, considering drivers such as mountain tourism, climate change, and anthropogenic activities.
3. To evaluate the key drivers of LULC changes through community surveys to understand local perceptions.
4. To develop a new framework to balance conservation objectives and the socio-economic needs of local communities.

1.10 Research Questions

1. What are the spatio-temporal patterns of LULC changes in the core and buffer zones of SNP and KNP over the past 30 years?
2. How have mountain tourism, climate change, and human activities influenced LULC patterns and trends over the years, and what are the projected future changes under a business-as-usual scenario?
3. What are the community's perceptions on the drivers, causes, and impacts of LULC changes?
4. How the LULC change analysis and community perceptions be used to develop a new framework that balances conservation objectives and the socio-economic needs of local communities in protected areas?

1.11 Why a Framework Is Needed for the Protected Areas?

Protected areas in Nepal are getting harder to manage. This is because ecological change, socio-economic pressure, and climate variability are happening at the same time. Conventional conservation methods that focus only on biodiversity protection or land-use rules are not enough

to meet this challenge. Rapid development, growing tourism demand and local livelihood needs put strong pressure on land use. These pressures cause habitat fragmentation, resource degradation, and ecosystem imbalance. Climate change makes this sever by accelerating the melting in glacier, changing downstream water flow and increasing natural disasters.

These linked pressures call for a wider, more flexible and more coordinated strategy. This strategy must support ecological sustainability, community well-being and socio-economic progress at the same time. There integration across policies and plans is less. That means weak links between land-use maps, community perceptions, climate forecasts, and tourism strategies. This gap leads to bad informed decisions, reactive policies, and outcomes that are not aligned to the conservation goals or community needs.

Decision-makers, planners, and stakeholders need a strong framework based on LULC and community input. This framework should bring together geospatial analysis of land-use and land-cover change, predictive modeling, community perceptions, and climate-impact assessments into one clear decision-support system. That system can identify priority conservation areas, forecast risks, promote environmentally friendly tourism, and align policy with the ground conditions. This study offers an Integrated Land-Use and Community Adaptation Framework (ILCAF) to fill that gap a scalable model for Nepal's protected areas that builds resilience, supports sustainability, and enables adaptive governance.

1.12 Significance of the Study

The study illustrates the LULC dynamics in protected areas and the fundamental for designing sustainable conservation and development strategies, particularly in ecologically fragile mountainous regions like Nepal. Despite the country's extensive network of national parks and conservation areas, there is lack in linking spatial land-use patterns to socio-economic realities and climate change impacts. This study addresses these gaps by integrating multi-decadal remote sensing analysis, climate data, and community perceptions, which give a comprehensive approach to understanding the landscape transformations and their underlying causes.

The significance of this study lies in its comparative approach between two contrasting national parks SNP a globally famous tourism destination and KNP a low-tourism, remote park with diverse ecological and socio-cultural backgrounds. This dual-site analysis enables the identification of diverse patterns of LULC change, anthropogenic pressures, and adaptive

responses, offering valuable visions into how tourism intensity, accessibility, and governance shape conservation outcomes.

This study employs advanced geospatial modelling (Random Forest and CA-ANN) combined with community-based surveys (SUS-TAS and OLS analysis) creating a robust methodological framework that bridges environmental science and social research. The outcomes provide not only historical trends and future projections of land cover change but also reveal the perceptions, attitudes, and priorities of local stakeholder's essential components for effective protected area management.

By generating these multidimensional insights this research directly contributes to the development of the ILCAF a novel and evidence-based model that can guide future protected area governance across Nepal. The findings of the study will inform policymakers, conservation managers and development planners in balancing biodiversity conservation with sustainable tourism and community livelihoods, ultimately strengthening Nepal's capacity to meet national conservation goals and international biodiversity commitments.

1.13 Thesis outline

Chapter 1: This chapter provides an overview of the study. It shows about how land use and tourism in the mountains are related in Nepal, how LULC has changed in the mountains, and how remote sensing can help keep monitor those changes and shows about climate change and how it affects forests, national parks, mountain tourism, and other things. These subjects come together to give a clear picture of how to manage land and grow tourism in the mountains of Nepal. the chapter displays the research questions impotency.

Chapter 2: This chapter gives a general idea of the study areas in Nepal SNP and KNP. It explains the different types of land use and land cover, lists the parks' different types of terrain, and shows their location. The chapter describes the used datasets, the research methods, and the steps that were used to clean the data. Finally, it sums up the fieldwork that was done to validate the results.

Chapter 3: This chapter shows the results of LULC change in SNP and KNP to set a baseline. It talks about how the core and buffer zones changed from (SNP: 1989–2021; KNP: 1991–2020) and also makes predictions about how land will be used in the future. The results show that the

forest cover in the buffer zones of both parks has changed, as have the barren land and grassland areas nearby.

Chapter 4: This chapter reflects the people view in SNP and KNP about farming, livestock, and the community. The SUS-TAS-based was utilized a questionnaire and employed OLS regression for data analysis to investigate the interconnections among tourism, agriculture, and forestry.

Chapter 5: This chapter relies on the previous one to create a new framework that balances the conservation goals of SNP and KNP with the socioeconomic needs of the people who occupy the area. It looks at where existing studies agree and where they don't, and it uses those findings to help national parks grow in a way that is good for the environment.

Chapter 6: This chapter summarizes the main findings of the research in SNP and KNP. It also talks about the study's limits and makes suggestions for future work.

These chapters are useful scientific contributions to the existing knowledge related to land use/land cover change and mountain tourism in SNP and KNP. However, this study also has some limitations that should be addressed in future research.

Chapter 2. Study Area and Methodology

2.1 Study Area

There are five different types of Protected Areas in Nepal: National Parks, Buffer Zones, Wildlife Reserves, Hunting Reserves and Conservation Areas. These protected areas cover a wide range of the country's landscapes, from high mountains to mid-hill regions to lowland areas. These areas will cover 23.39% of the country's total land area by 2024. They will help protect ecosystems and biodiversity in their natural state, and they will make the country the eighth Asian country with the most protected areas.

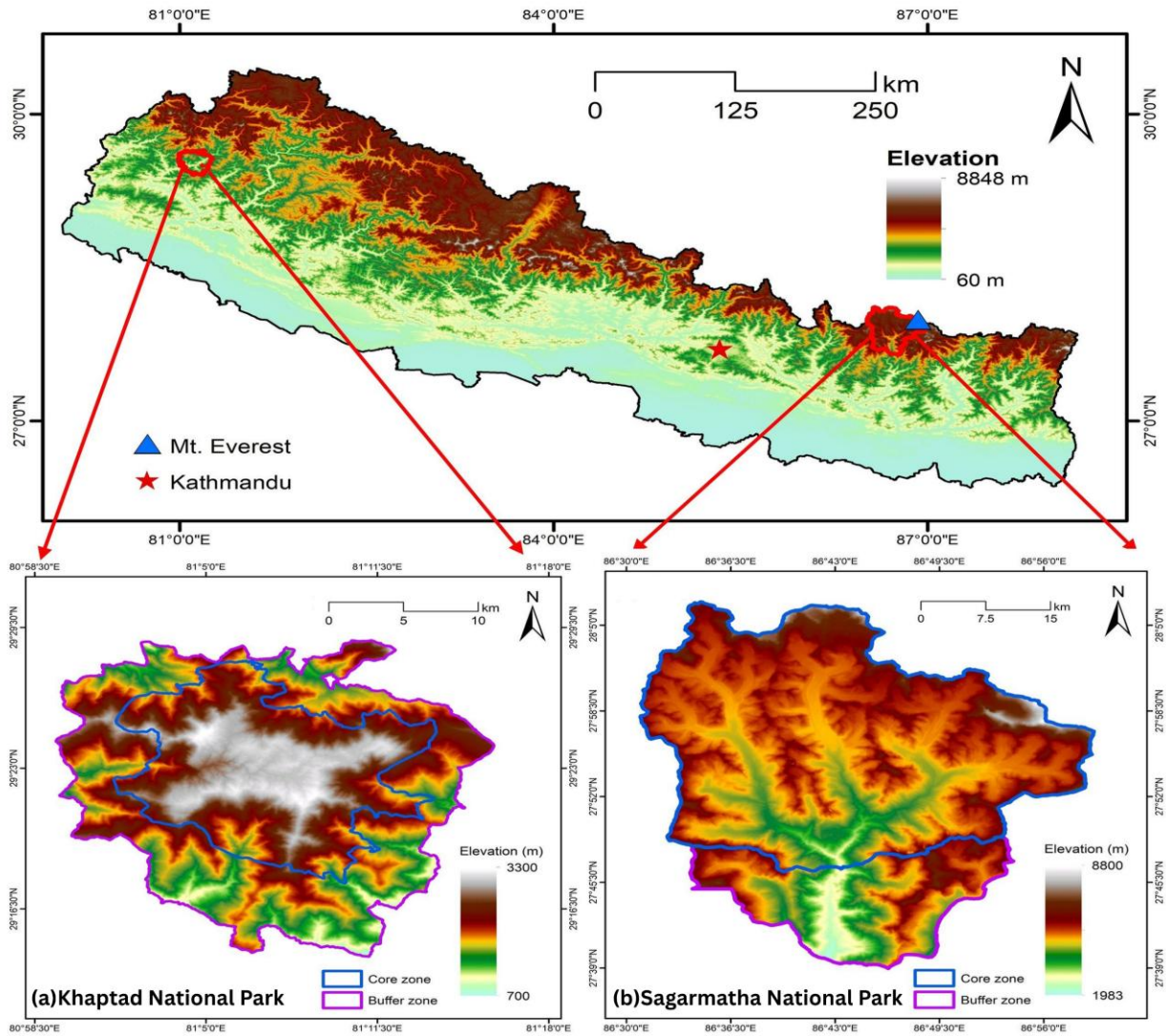


Figure 2.1: Study areas located in KNP and SNP, Nepal.

Figure 1.1 in Chapter 1 has more information about Nepal's protected areas. The study area includes two national parks in Nepal: SNP and KNP. The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data in Figure 2.1 shows where SNP and KNP are and how their elevations change. The reason for choosing these two parks is that their ecosystems and effects on tourism are very different, which makes them great places to study how LULC changes in different situations. SNP is a well-developed and popular tourist destination located at high elevations. It sees a lot of tourist activity. KNP, on the other hand, is in a remote part of western Nepal, has moderate elevations, and gets only a small amount of tourism. It is still not very developed.

2.1.1 Sagarmatha National Park (SNP)

The Great Himalaya massif is where SNP is located, in the northeastern part of Nepal's Solukhumbu district. The latitude and longitude are between 27°45' and 28°07'N and 86°28' and 87°07'E, which is about 140 km east of Kathmandu. The park, which is home to Mount Everest, is about 1,148 km² of rough land that is useful for ecological and geographical research. It was built in 1976 and named a UNESCO World Heritage Site in 1979. SNP is about 140 km east of Kathmandu, which is the capital of Nepal (NTNC, 2018). The park covers the upper catchment area of the Dudhkoshi and Bhotekhoshi rivers. This area has a lot of different geomorphological features, such as rough terrain, deep river gorges, glaciers, glacial lakes, and mountain system gorges. SNP has tall, young mountains and glaciers that are geologically new. The sharp terrain erodes slowly and quickly. The Glaciers made up of U-shaped valleys in the upper park areas, and rivers made up of the narrow V-shaped valleys in the lower buffer zone. The Glaciers, rivers, and fluvio-glacial activity withdrawals left behind the soils in SNPBZ. The changing climate with elevation impacting on soil formation by affecting factors like temperature, precipitation, and decomposition rates (Bajracharya et al., 2009). The park's geography might be changed from the geomorphological processes, like erosion and mass movements like rockslides, shape. These processes might be dangerous for the people living there and affects the water conditions of the areas (Posch et al., 2015). However, the park's elevation changed a lot, from 2,300 m in Surke to 8,848 m at the top of Mount Everest, which is the highest peak on the Earth. This steep slope makes the different ecological zones and habitats in the park areas. A buffer zone of 275 km² was

established around the southern boundary in 2002 to help in reducing the biotic pressure and conserve the park areas (DNPWC, 2024a).

2.1.1.1 Climate of Sagarmatha National Park (SNP)

In SNP the climate changes have a big impact, because of its high elevation. The park has most of the rain falls in between July and September and also has various negative impacts by monsoon weather. The average amount of rainfall about 1,000 mm, which has a big effect on water supply of the park areas. On the other hand, in the winter the temperature goes down gets very cold, especially at higher elevations, where the plants and animals have to faces the harsh conditions. The best times for people to go to the park are usually from March to May and from September to November, when the weather is nicer (Nepal Hiking Team, 2024). SNP The Himalayas are beautiful, and the different heights make the weather in the area different. At lower elevations, the climate is humid subtropical, but at higher elevations, it is cold and dry. From June to August, the lower areas get a lot of rain. It is usually below freezing from December to February, which is when the winters are cold and dry. Spring (March to May) is still chilly, but there are some days when the sun shines. The sun goes away completely in the fall, from September to November. The best times to go to the park are from March to May and from October to November. In the summer, the weather is usually cool and wet, and in the winter, it is cold and dry (DNPWC, 2024a).

2.1.1.2 Vegetation and Wildlife of SNP

SNP has a lot of different climate zones, which means that there are different types of vegetation belts and ecosystems. At lower elevations, temperate and subalpine forests are common. Pine (*Pinus*) and hemlock (*Tsuga*) are the most common trees in these forests. As the elevation rises, the vegetation changes to include groups of fir (*Abies*), juniper (*Juniperus*), birch (*Betula*), and different types of rhododendron (*Rhododendron*) (DNPWC, 2020a). The plants change to alpine communities above 4,000 m, elevation in the park. The highest peaks are usually over 5,000 m, this consists of tough alpine herbs, shrubs, mosses, and lichens. Various variety of plants that support a wide variety of animals, including more than 118 bird species and many mammals. The park also has many different habitats that are home to important species like red pandas (*Ailurus fulgens*), snow leopards (*Panthera uncia*), musk deer (*Moschus*), and Himalayan tahr (*Hemitragus*

jemlahicus) (DNPWC, 2020a). SNP itself is a place that helps to protect park's biodiversity because it has unique habitats and different weather patterns. The park is a home to different types of endangered and rare species, which is why it needs a focus of ecological and conservation studies. There are many different types of situations that support a wide variety of species, especially birds. Some of these species includes the pheasant, snow cock, and blood pheasant. So, it's very important to have an eye on and estimating changes in species, populations and habitats can give conservationists important information they can use to protect the ecological integrity of the parks.

2.1.1.3 Population and Ethnic Groups of SNP

According to the 2021 Census of Nepal stated that in SNP the total population of the people living there are 158,041. The Sherpa community also living there, and their Tibetan roots have a major impact on the culture. In the park there are about 6,000 Sherpas currently living in 20 nearby villages, like Namche Bazaar, Kunde, Khumjung, Thyangboche, and Pang (Ranjit, 2022; Sun and Watanabe, 2021). During the high peak of the tourist season, many of Sherpas from these villages move along the trekking trails for a short time. In addition, with the tourism, they also make an existing income by doing the farming and raising the livestock as major task for their daily necessities. The Sherpa people solely depends on farming and agriculture for their living, as well as on tourism. A high influx of tourism in the country is also an important part for generating locals' economy. Thousands of hikers and climbers come to see the beautiful natural beauty and cultural sites. But increase in tourists also brings problems, such as how to deal with trash and damage to the environment.

2.1.2 Khaptad National Park (KNP)

The KNP is located in Nepal's remote western region, it includes parts of the Doti, Achham, Bajhang, and Bajura districts (MoFSC, 2014). The latitude and longitude are between 29°14' and 29°28'N and between 81°02' and 81°11'E. The park opened in 1984 and covers 225 km². Its average height is about 3,000 meters. It is the only national park in the area that is in the middle of the mountains. This means that it has a unique and necessary ecosystem that is important for both preserving biodiversity and cultural heritage (Dhami et al., 2024). The park is important for the environment because it has 567 plant species, including well-known ones like pine, hemlock,

and different types of rhododendron flowers. KNP is also home to a lot of medicinal plants, with about 224 different kinds (Kunwar and Duwadee, 2003). The ecosystem is home to about 270 different kinds of animals, including birds like the Impheyan pheasant, partridges, flycatchers, bulbuls, cuckoos, eagles, Peregrine falcons, and white-rumped vultures. This rich diversity of life is great for birdwatchers and researchers alike.

2.1.2.1 Climate of Khaptad National Park

The climate of KNP shows seasonal variations, with clear monsoon, summer, autumn, and winter periods. The monsoon season brings the most rain of all, with falling in July and August. These amounts of rain are very important for the park's ecosystems (Dhami et al., 2024; Upadhyaya, 2024). In the summer, temperatures range from 0 to 20 degrees Celsius. In the winter, they are much colder.

2.1.2.2 Vegetation and Wildlife of KNP

The grasslands, known locally as "Patans," are a prominent feature of the park's landscape; they consist of 22 patches of pastureland that provide grazing field for livestock, vital for the local economy. These grasslands showcase an impressive variety of over 135 flower species that bloom in summer and late spring, reinforcing the area's rich biodiversity. Diverse altitudinal gradients of KNP lead to varying ecosystems within the park. At lower elevations (1,000–2,000 m), subtropical vegetation is predominant, with species like Montane Sal (*Shorea robusta*), Pine (*Pinus roxburghii*), and Alder (*Alnus nepalensis*). As one rises, temperate vegetation becomes more common, including a mix of lower temperate broad-leaved species such as *Lindera neesiana* and *Cinnamomum tamala*; temperate evergreen species, including Spruce, Fir, Hemlock, and Oak; and upper temperate broad-leaved species like *Aesculus indica* and various species of Birch and *Rhododendron* (Kunwar and Duwadee, 2003).

The park's landscape includes several Land Use classes in the core and designated buffer zones. These land classes include forests, shrublands, agricultural areas, water bodies, grasslands, and built-up regions. Forests dominate the region, covering over 90% of the core zone and nearly 52% of the buffer zone. In contrast, the buffer zone is characterized by agricultural land, shrubland, and grassland, while shrubland and grassland are significant land use classes in the core area. The soil types in KNP are diverse, including alluvial, brown forest, podzol, and mountain soils. Alluvial

soils, known for their mineral-rich composition and fertility, are deposited by rivers and streams and are found in areas where continuous water flows. Podzol soils are common in coniferous forest regions, characterized by their acidic nature and leached topsoil. Brown forest soil, rich in organic matter from plant decomposition, is prevalent in densely vegetated locales. In contrast, mountain soil is typically found in steep terrains, exhibiting distinct characteristics due to the challenging topography (Thapamagar et al., 2019).

2.1.2.3 Population and Ethnic Groups of KNP

According to the 2021 Census of Nepal, KNP has a population of 761,291. KNP is not only ecologically significant but also culturally rich. It attracts numerous devotees to the sacred Khaptad Baba Asharam, where Hindu pilgrims gather for meditation and spiritual healing. The annual Ganga Dashahara festival is trendy, drawing visitors across the region (DNPWC, 2024). The local population primarily comprises indigenous ethnic groups, including the Khas, Brahmins, Chhetris, and Dalits. Economic activities within the buffer zone largely revolve around agriculture and livestock grazing, with significant reliance on the collection and trade of medicinal plants. The thriving religious tourism related to KNP's sacred sites further contributes to the local economy. This region has significant local tourism potential due to various temples dedicated to Hindu gods and goddesses. These temples draw both national and international visitors for pilgrimage and festivities during special occasions. People from all over the world come to these temples for religious pilgrimages and celebrations on special occasions (Badal, 2024b).

2.1.2.4 Challenges Faced by Tourism in KNP

Sudurpaschim province has received less exposure and attention from the tourism authorities and the government of Nepal. (S. Bhatta, Devkota, et al., 2023). In the new system of government, the federal government needs to focus on developing the areas. The study also aimed to explore how important religious sites are for tourism, focusing on Khaptad. It examined the socio-economic conditions of the area and identified the factors contributing to the region's underdevelopment. Challenges include insufficient infrastructure, a lack of quality hotels and homestays, limited marketing and promotion, poor tourism planning and development, minimal government involvement, and weak coordination among local organizations (S. Shrestha and Balayar, 2023).

2.1.3 Population Trends in the SNP and KNP Region

The population trends in the SNP and KNP regions from 1971 to 2021 show distinct patterns. In SNP (Figure 2.2a), the Solukhumbu district's population increased to 105,324 in 1971 but fell to 97,200 by 1991. From 2001, it plateaued, peaking at 105,886 in 2011, before declining slightly to 104,851 by 2021. This recent decline may be due to migration, economic changes, and the impacts of COVID-19 on local tourism. Tourists primarily visit for trekking, mountaineering, viewing wildlife, and local culture (S. Bhatta, Neupane, et al., 2023; Neupane et al., 2022).

In contrast, KNP, saw robust and consistent population growth during the same time period (Figure 2.2b). KNP's population grew rapidly from about 468,247 in 1971 to almost 799,294 by 2011. It then showed a minor decline to 761,291 by 2021 across four districts that encompassed KNP. This sustained demographic growth in KNP reflects favourable economic conditions, increased migration, and successful regional development initiatives. The population in KNP relies heavily on agriculture, forestry, and livestock, which underscores the connection between local livelihoods and population trends in the area.

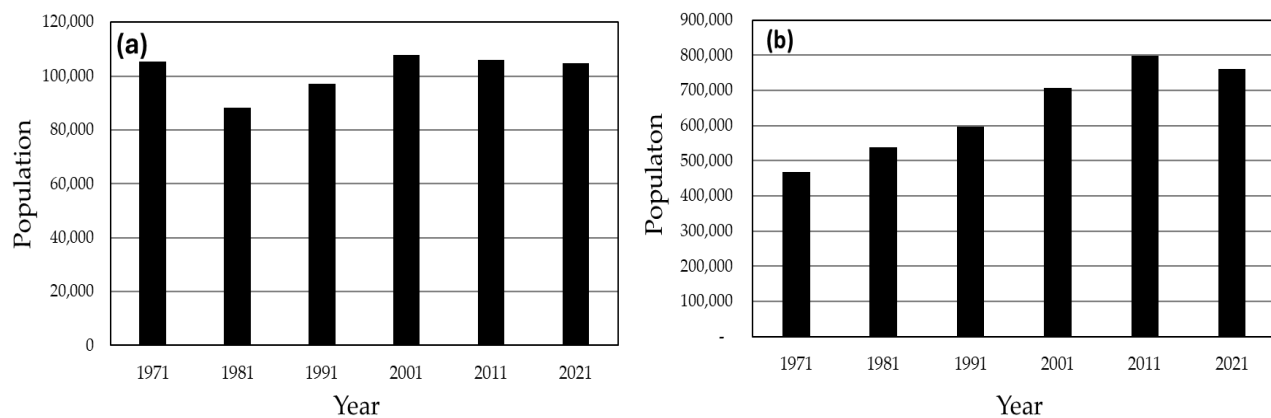


Figure 2.2: Population trends in National Parks located in districts. (a) SNP and (b) KNP.

2.1.4 Tourist Trends in SNP and KNP

The tourism statistics for SNP from 1993 to 2023 demonstrate a substantial upward trend, with annual visitors consistently numbering in the tens of thousands (Figure 2.3a). The Ministry of Culture, Tourism, and Civil Aviation (MCTCA) began recording separate data on tourists visiting national parks and wildlife conservation areas in 1993. From 1993 to 1999, the number of tourists in SNP steadily grew to 26,788, followed by a slight decline in 2000 and a drastic

decline in 2002, nearly half the number from 1999. This decline was partly due to the political turmoil at the time, including the Royal Palace massacre in Nepal and the 9/11 terrorist attack in the United States. However, tourism arrivals began to recover from 2003 through 2013, with subsequent declines in 2014 and 2015, presumably due to the earthquake that struck Nepal. The number has steadily increased since then, reaching 58,030 visitors in 2019. This shows that SNP remains very popular among trekkers and mountaineers drawn to Mount Everest. The data also illustrates periodic fluctuations, with a most dramatic decline in 2020 due to the COVID-19 pandemic, which reduced visitors to 2,461 before rebounding to 52,499 by 2023 (Figure 2.3a).

On the other side, Figure 2.3b, shows significantly lower foreign tourists in KNP from 1993 to 2023, with the highest number recorded being 80 in 2023. KNP receives relatively few foreign visitors compared to other national parks in Nepal, mainly due to its remote location and limited infrastructure (Ranjit, 2022). But domestic tourism is very important in the area, especially during religious festivals like Ganga Dashahara, when Hindu pilgrims come to the Khaptad Baba Ashram. KNP had 865 domestic tourists in the first seven months of the fiscal year 2023/24 (<https://myrepublica.nagariknetwork.com/news/883-tourists-visit-khaptad-in-seven-months-of-current-fy>). The park had 2,891 visitors in the last fiscal year, most of whom came from the Bajura, Achham, Bajhang, and Doti districts nearby. People come to see religious and natural sites like Tribeni Dham, Nagdhunga, Khaptad Swami's Ashram, and the park's 22 meadows. The Ganga Dashahara Fair in June and the Jatra (Yatra) festival in Jestha on Janai Purnima are the busiest times for pilgrimage tourism. Thousands of pilgrims come to Khaptad's holy sites during these times (Badal, 2024b). There is a buffer zone around the park that gives people in the area access to a variety of natural resources.

The divergent trends between SNP and KNP underscore how varying tourism pressures impact environmental and social conditions within these parks. While the SNP faces environmental challenges related to solid waste and ecological degradation due to large international visitors, KNP's domestic pilgrimage tourism also strains local ecosystems and cultural integrity (Upadhyaya et al., 2020). Increased domestic tourism demand for infrastructure—such as trails, lodges, homestays, and facilities—may lead to deforestation and habitat disturbance, as Bhatta et al. (2023) noted, who highlighted the need to develop sustainable homestay facilities to support tourism. Both SNP and KNP illustrate the environmental risks of unchecked tourism, including insufficient environmental awareness, limited understanding of mountain ecosystems, and a lack

of foresight regarding the long-term impacts on environmental sustainability and the tourism sector (Manandhar et al., 2017).

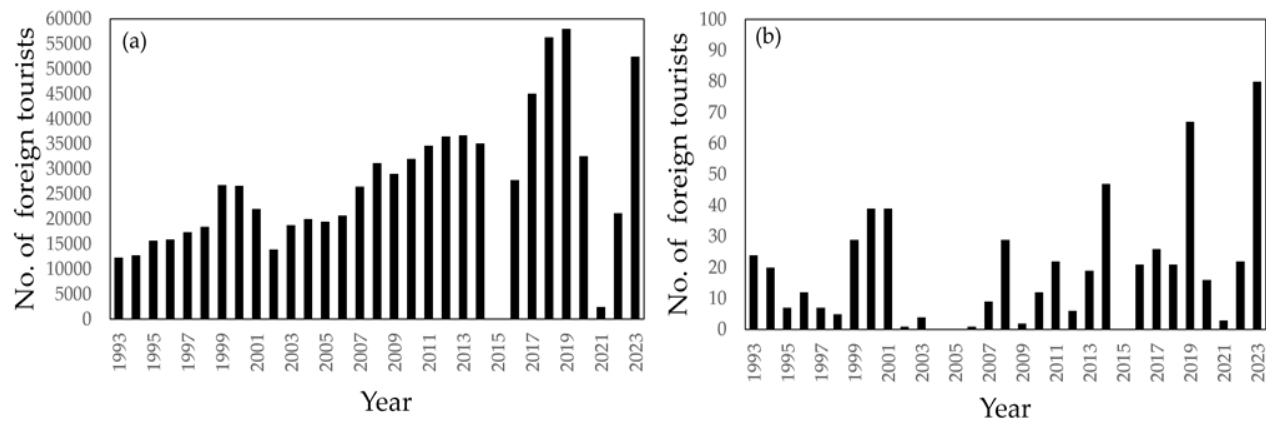


Figure 2.3: Annual number of foreign tourists visiting (a) SNP and (b) KNP (data source: MTCTCA). It should be noted that the scales of the Y-axis are different.

2.2 Methodology

This research consists of an in-depth case study to gain insights into the interrelationships between the tourism, local communities, the climate change, the national park, and the aspects that influence these factors and challenges. This study has the multidimensional nature which consist of a range of methods, including remote sensing analysis, extensive fieldwork, questionnaire surveys, semi-structured interviews, and participant observation.

2.2.1 Land Use/Land Cover Mapping

Land use refers to how humans utilize land, focusing on its economic purposes. For example, is the land being used for commercial buildings like stores, factories, and residential? Or is it designated for recreation or farming? Land cover, on the other hand, is what the Earth's surface is made of, like grass, trees, water, bare ground, asphalt, soil, and buildings made by people. LULC change means changing the type of cover that is on top of the land. There are many reasons why this might happen, such as more farming, cutting down trees, building cities, or changing how people farm. These changes can have an effect on the health of the environment, biodiversity, soil quality, water runoff, and greenhouse gas emissions.

Table 2.1: LULC classes summary

No.	LULC classes	Definitions/descriptions
1	FOREST	Patches of forest with mixed tree species may include needle-leaved Closed Trees, needle-leaved Woodland, and Broadleaved Closed Trees.
2	SHRUBLAND	Mostly made up of shrubs and short trees, it may include Broadleaved Closed Shrubland, Broadleaved Open Shrubland, Mixed Open Shrubland, and Dwarf closed shrubland
3	AGRICULTURE	Area of crop production
4	BARE LAND	Bare Rock, Gravels, Stones, or Boulders
5	WATER	Rivers, creeks, water channels
6	GRASSLAND	Mostly closed to open herbaceous vegetation
7	BUILT-UP AREA	Built-up areas and settlements
8	SNOW/GLACIER	Snow, perennial (> 9 months) ice in movement. Typical elongated shapes.
9	KHARKA	Alpine pastureland, used as grazing places for livestock
10	GLACIER LAKE	Perennial (> 9 months) standing water bodies associated with glaciers.

To manage land well, you need to know both land use and land cover. It aids in strategizing and determining forthcoming advancements (Das, 2014). Because the study area is in the mountains, satellite data is very important for cutting down on the amount of fieldwork and costs. A LULC classification scheme was formulated utilizing supplementary information and existing literature (Bajracharya et al., 2009; Uddin et al., 2015). In the study area, Table 2.1 shows the LULC classes and what they mean.

2.2.2 Data Acquisition

Remote sensing methods have become an important way to measure changes in LULC over time, space, and quantity. Multi-temporal remote sensing data facilitates the analysis of change dynamics over time. Remote sensing is a good way to study the accurate spatial patterns of landscapes because sensors can go back and take observations many times. This gives a new view of the landscape, showing how things have changed over time and space. This data thus enables a comprehensive comparison with economic and demographic information (Uddin et al., 2015). The Landsat satellite has been in use since 1972 and provides a continuous global record of the Earth's land surface. It is one of the most important sources of remote sensing data.

2.2.2.1 Landsat Imageries

The Landsat program is the best satellite remote sensing project for looking at land. This group of satellites has given the world standardized multispectral images with a moderate spatial resolution (Green, 2006). Landsat has three unique features that set it apart: first, its archived data goes back to 1972, which allows for in-depth analyses over many decades; second, images are collected all over the world every 16 days; and third, the images are currently free to use with no restrictions (Miller et al., 2013). Satellite remote sensing has shown significant promise in delineating landscape patterns across diverse spatial scales and in monitoring landscape dynamics through the detection of alterations in these patterns. When combined with socioeconomic data, historical land use and land cover (LULC) change data derived from remote sensing are frequently used as inputs for LULC models (Hu, 2004; Masser, 2001). The reliability of the results from LULC change modelling is influenced by the chosen modelling method. It is also significantly dependent on the accuracy of LULC change mapping derived from remote sensing and the quality of socioeconomic data.

Table 2.2. List of Landsat images used for the SNP and KNP region

Sagarmatha National Park		Khaptad National Park	
Sensor	Acquisition date	Sensor	Acquisition date
Landsat 5	09-Nov-89	Landsat 5	13-Dec-91
Landsat 5	25-Dec-00	Landsat 5	01-Jan-99
Landsat 5	21-Dec-10	Landsat 5	14-Oct-10
Landsat 8	01-Jan-21	Landsat 8	25-Oct-20

In this study, Landsat images from different sensors, including Landsat 5 (TM) and Landsat 8 (OLI), were downloaded from the United States Geological Survey (USGS). The Google Earth Engine (GEE) web-based computing platform was utilized for image acquisition and preprocessing tasks. Landsat primary data was used for LULC classification and prediction (Wulder et al., 2019). This work conducted a multi-temporal LULC analysis of SNP and KNP using Landsat imagery. Considering the quality of available images, data from Landsat 5 and Landsat 8 were selected. The Thematic Mapper (TM) sensor on Landsat 5 allows for the continuation of multispectral imaging at a resolution of 30 m, similar to that of the Landsat 8

Operational Land Imager (OLI). This provides the opportunity for interannual earth observation time-series analysis, allowing for more stable and accurate predictions than those derived from single-date imagery (Brandt and Maner, 2024). Table 2.2 provides detailed information related to the Landsat data acquired for LULC classification in SNP and KNP.

2.2.3 Google Earth Engine

Google Earth Engine were used as a cloud computing platform to acquire and pre-process all of the images. Google Earth Engine is a planetary-scale web platform that improves Earth science data analysis. This cloud-based architecture effortlessly connects a vast satellite imagery and geographic metadata collection with advanced analysis techniques. Using this platform, one may detect changes, track trends, and quantify variances throughout the Earth's surface with unprecedented precision. Google Earth Engine addresses significant social problems such as deforestation, drought, disaster response, disease prediction, food security, water management, climate monitoring, and environmental preservation (Gorelick et al., 2017). It stands out as a comprehensive solution that serves not just remote sensing experts but also a wider audience without a specific technical understanding of supercomputing or large-scale cloud computing resources.

The platform is available for non-commercial usage after account registration and has evolved significantly since its inception in 2010, developing as a powerful tool for broad geospatial analysis (Zurqani et al., 2018). In this study utilized Landsat Level-2 Surface Reflectance (SR) products: Landsat-5 (TM/ETM+) processed with LEDAPS (Schmidt et al., 2013) and Landsat-8 (OLI; also relevant to 9) processed with LaSRC (Vermote et al., 2016). The study used all of the images at a spatial resolution of 30 m and reprojected them to WGS 84 / UTM (SNP: Zone 45N; KNP: Zone 44N) to meet the geoprocessing standard. The images were selected between October and January, taking into account the weather at the time, which had the least amount of snow and clouds (Table 2.2). The Landsat images were pre-processed at level 2 (surface reflectance) and have been undergone for the atmospheric correction. The CFMask method's QA_PIXEL feature was used to get rid of clouds and their shadows, which helped to reduce image bias (Foga et al., 2017). Figures 2.4 and 2.5 show the false color combination of Landsat images of SNP and KNP in red, green, and blue (RGB). This false-color composite with the SWIR-NIR-Red band gives the user a lot of information and color contrast that helps them find and tell apart different features on the ground.

Also, the Landsat data was chosen because it had high-quality satellite images (clear and almost free of clouds). The images were picked between October and January, when there was the least amount of snow and clouds, and there was about a 10-year gap between them.

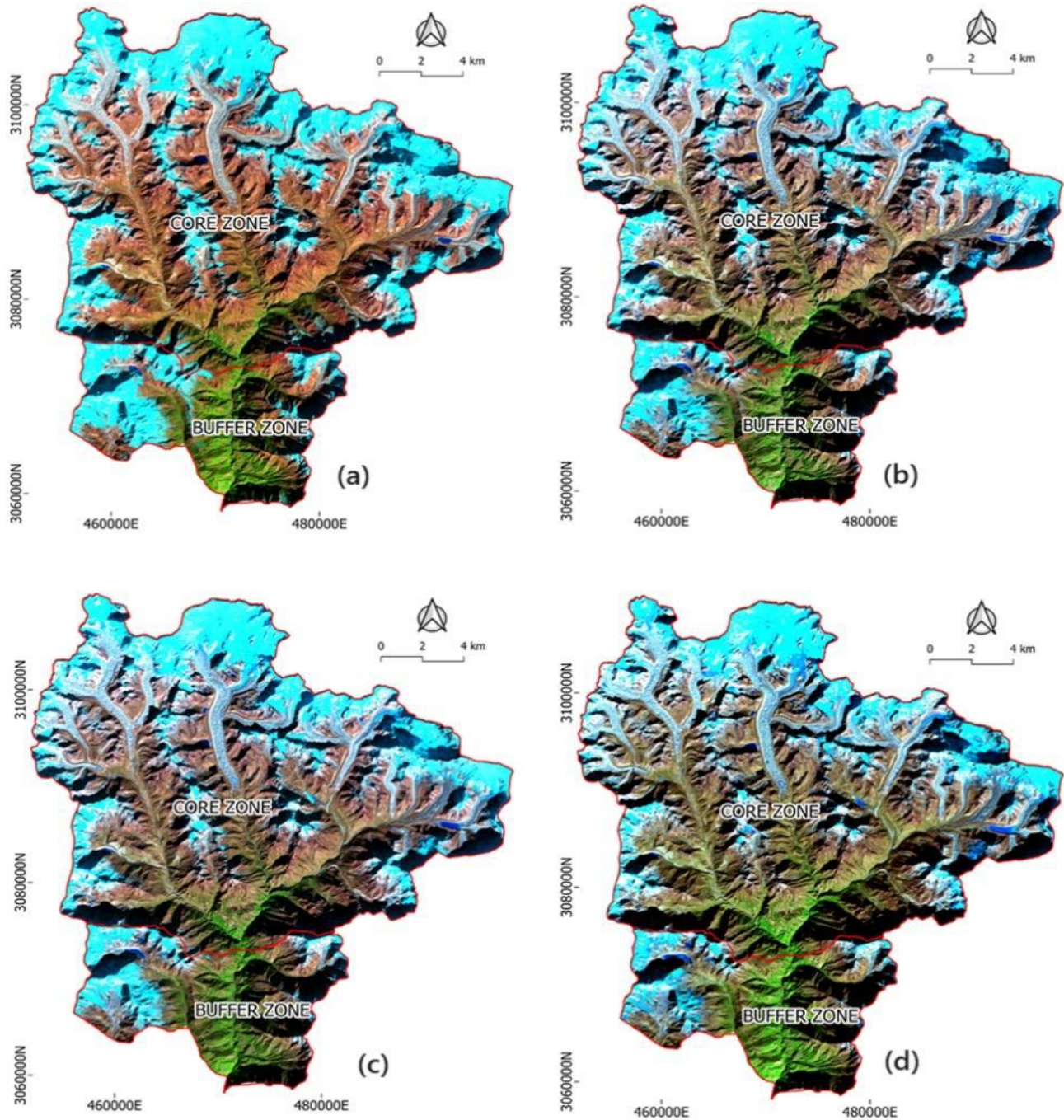


Figure 2.4: Landsat images for the years (a) 1989, Landsat 5, (b) 2000, Landsat 5 (c) 2010, Landsat 5, (d) 2021, Landsat 8 used for LULC classification of SNP, visualized in SWIR-NIR-Red band composite.

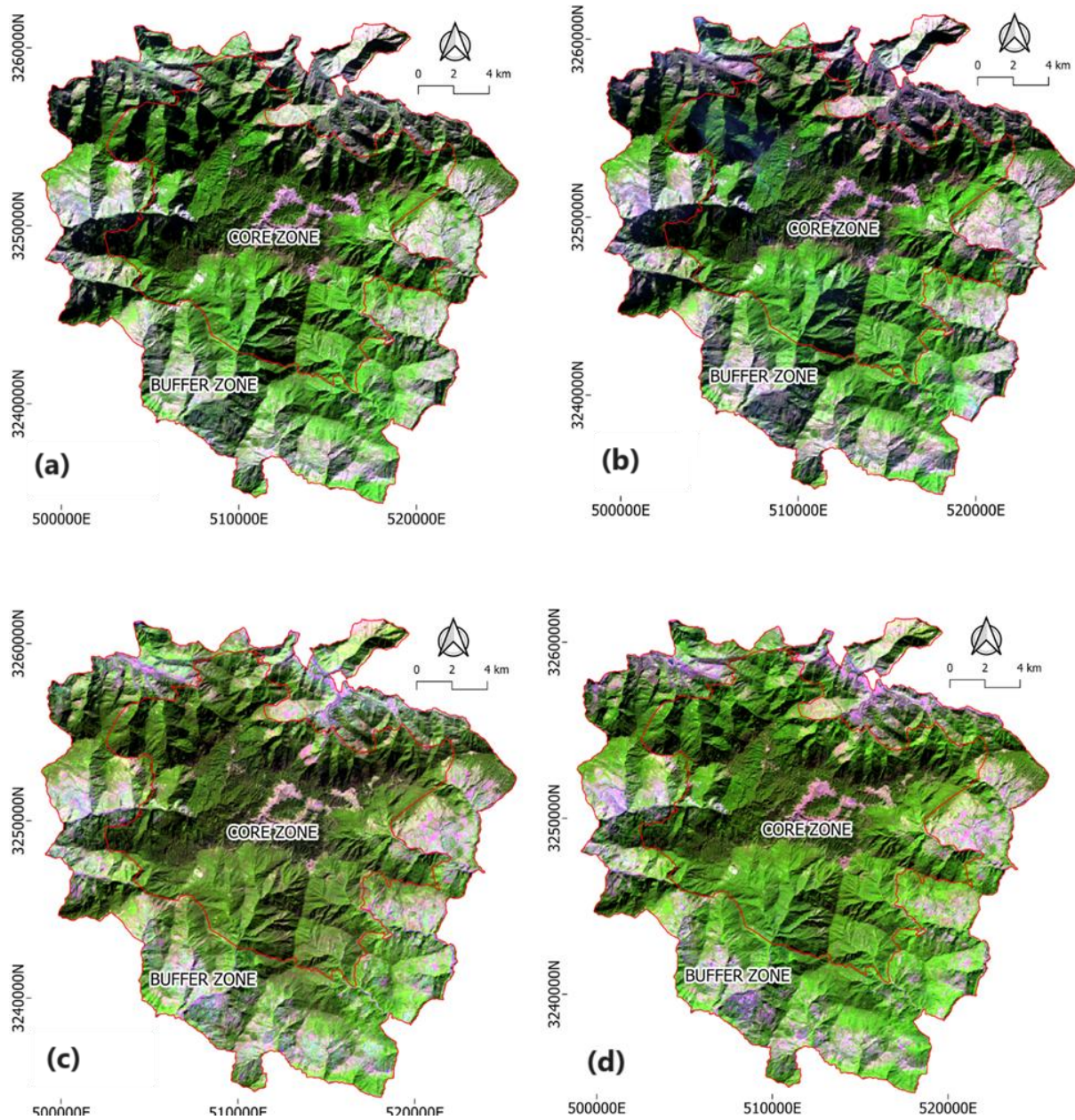


Figure 2.5: Landsat images for the years (a) 1999, Landsat 5, (b) 1991, Landsat 5, (c) 2010, Landsat 5, (d) 2020, Landsat 8 used for LULC classification of KNP, visualized in SWIR-NIR-Red band composite.

2.2.4 LULC Classification

The process of classifying LULC was done with the help of QGIS software. This study used the method shown in Figure 2.6. There were 7 classes in KNP: forest, shrubland, agriculture, bare

land, water, grassland, and built-up area. In SNP, three new types were added to the LULC classification: snow/glacier, glacier lake, and kharka. Kharka is a type of pastureland that is often found in the Himalayas (Sarkar et al., 2024). Training areas were delineated through the visual analysis of Landsat data and, when accessible, high-resolution imagery from Planet and Google Earth. The training data were chosen for each observation year (1989, 2000, 2010, and 2021 in SNP; and 1990, 1999, 2010, and 2020 in KNP) in the study area. However, some of these were at the same place the whole time, so there was no change. The data sets were chosen because they had high-quality images that weren't covered by clouds. The study used the random forest algorithm in QGIS to do the classification, and added the DZetsaka plugin (Karasiak, 2016). To train the samples and make LULC maps, a random forest algorithm was used. Random forest is a type of ensemble classifier that uses a lot of decision trees built from randomly chosen predictors from a small part of the training data. The final classification or prediction is based on the majority vote of the individual trees (Adugna et al., 2022). This non-parametric algorithm has been widely known for accurately distinguishing LULC types based on satellite images (Kulkarni and Lowe, 2016). Random forests are an ensemble algorithm that use multiple decision trees to overcome overfitting and provide the information about each predictor variable in classification (Manorathna, 2021).

The input data for classification are six bands of Landsat 5 and 8, comprising Blue, Green, d, Near-Infrared, Shortwave Infrared 1, and Shortwave Infrared 2. Four other additional input layers were included in SNP, i.e., normalized difference vegetation index (NDVI), normalized difference snow index (NDSI), elevation, and slope, considering the coverage of snow/glacier and the extreme topography condition in the Himalayas. The classification results were used to identify LULC change by overlaying the four multi-year LULC classification results in SNP and KNP, respectively. The LULC change was presented in a LULC change matrix for analysis. The accuracy of LULC maps was evaluated using validation data randomly distributed in the study area, generated by the AcATaMa (Accuracy Assessment of Thematic Maps) plugin on QGIS. The stratified random sampling ensured that the sample size of each class corresponds to its area with a random distribution. The validation data ranged between 395–397 points, interpreted visually on Landsat and high-resolution images, likewise obtaining the training samples. Confusion matrices were then constructed to calculate producers, users, and overall accuracy.

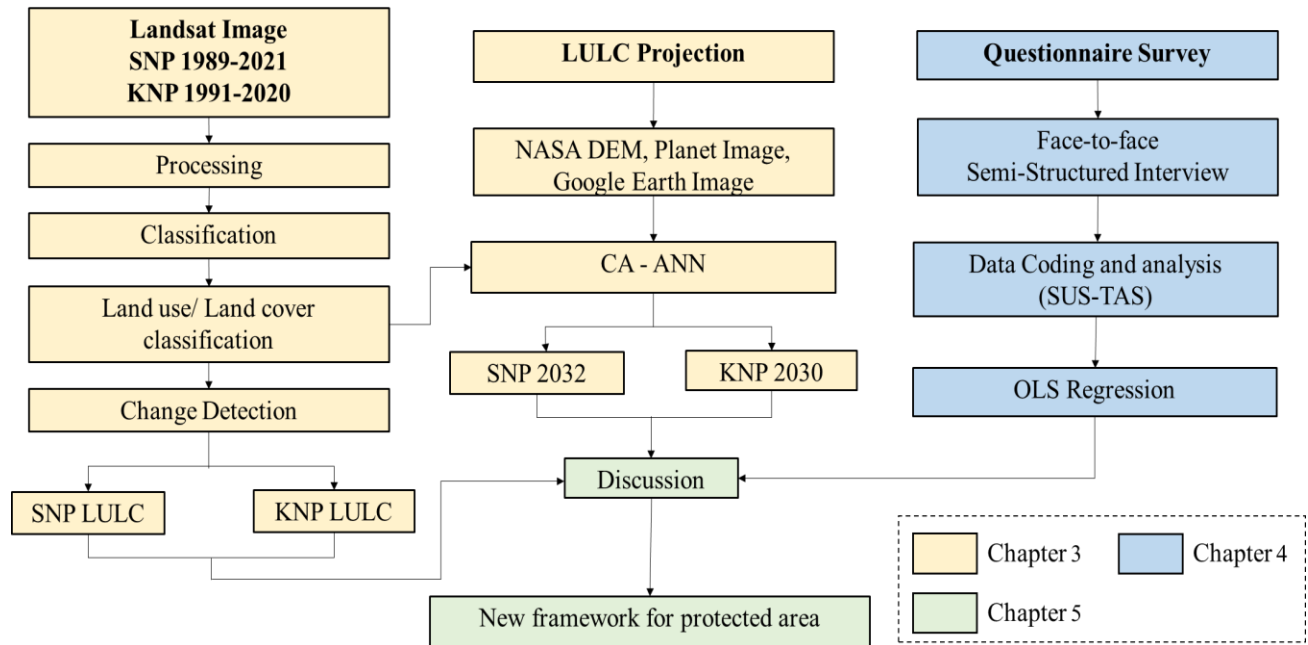


Figure 2.6: The flow chart describes the detailed methodology used in the study

2.2.5 LULC Change Matrices Analysis

Digital change detection using satellite images identifies changes in an object or phenomenon by observing it over different times. This process quantifies temporal effects through multi-temporal datasets (Kavanagh et al., 2004). Accurate and timely detection of land-use or land-cover changes is essential for understanding human interactions with Earth's features and supports better policy decisions (C. Li, 2014). LULC maps were analyzed by calculating the area for each observation year in the corresponding study area, i.e., SNP and KNP. After that, the LULC change matrices were produced to monitor the decadal LULC change and the difference between the first and last periods. These matrices visually demonstrate the changes consist of various land use classes between the specified years (Shalaby and Tateishi, 2007). Through this analysis, specific alterations within the LULC classes over the studied periods can be effectively identified and examined comprehensively in detail. The comparison matrices give the valuable insights into the dynamics of LULC changes and provide a basis for understanding the trends and patterns of land use in their respective regions.

2.2.6 LULC Future Prediction

The prediction of LULC in SNP and KNP was intended to understand the protected areas' environmental impact and sustainable development. This study used the MOLUSCE (Modules of Land Use Change Evaluation) plugin in QGIS to perform prediction, taking two last LULC maps of the study area (2010 and 2021 for SNP, and 2010 and 2020 for KNP) (NextGIS, 2014). The analysis incorporated various change parameters, including elevation, slope, proximity to roads, and distance from the river. Figures 2.7 and 2.8 have been extensively utilized as determinants in LULC prediction (Leta et al., 2021). NASADEM data, a refined version of SRTM digital elevation data (Buckley, 2020), was used to get the slope from the elevation data source. The distance to road and river data was obtained from a Euclidean distance calculation based on road and river vector data. Elevation data is crucial in LULC change as lower elevations experience more rapid changes due to their suitability for human activity (Muhammad et al., 2022). The slope gradient is related to soil quality, erosion, and accessibility, with steep slopes posing higher risks of soil erosion and may not be suitable for specific land uses (Ceddia et al., 2009; El Kateb et al., 2013; Nabiollahi et al., 2018). Distance to roads has an effect on accessibility and connectivity, which causes different land use patterns near major roads than in more remote areas (Liu et al., 2020). Distance to roads affects accessibility and connectivity, leading to distinct land use patterns near significant roads compared to more remote areas (Liu et al., 2020). Likewise, the distance to the river is associated with water availability, soil moisture, and flood risks, where areas near rivers are suitable for cropland. In contrast, the farther areas are more appropriate for conservation or development (Ren et al., 2022).

Multi-layer perceptron (MLP), one of the artificial neural networks (ANN) methods, was used to study the transitional potential of LULC. Several parameters were defined for the processing, including neighbourhood = 1, iterations = 1000, hidden layer = 10, momentum value = 0.05, and learning rate = 0.05. The algorithm iterated the learning process until it obtained the best prediction. After that, the Cellular Automata (CA) method simulated the trained algorithm to produce LULC predictions. The CA method works by following certain rules that determine how cells in a spatio-temporal grid change over time. So, transition probabilities in the CA method aren't randomly chosen using random numbers (Fischer et al., 2017). If the chance is higher than the random number, the states of cells change (Santé et al., 2010). The 2032 and 2030 LULC maps for SNP

and KNP, respectively, were the final LULC projections. This was because the two LULC maps used as inputs were from different times.

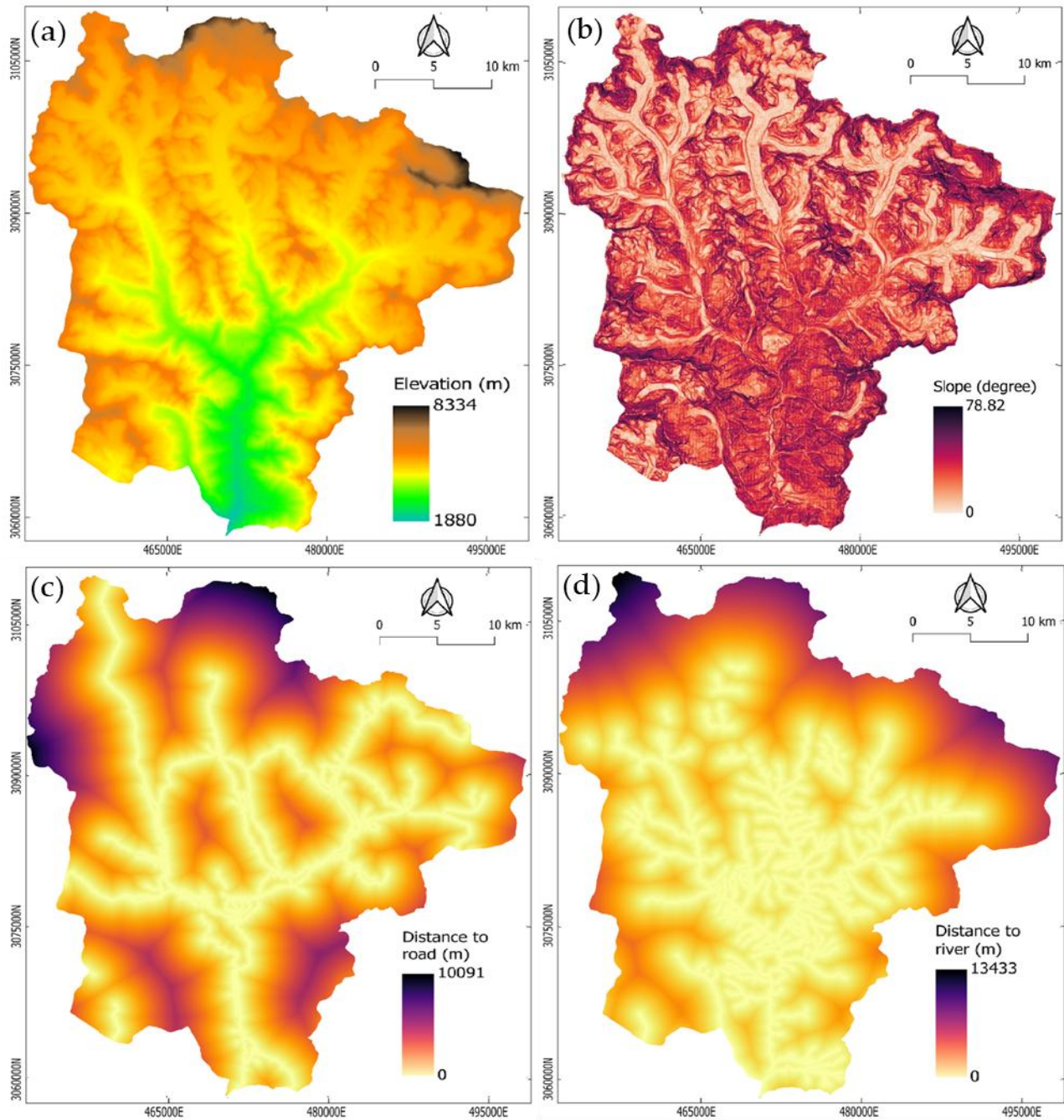


Figure 2.7: Variables used for LULC prediction in SNP: (a) elevation, (b) slope, (c) distance to road, and (d) distance to river.

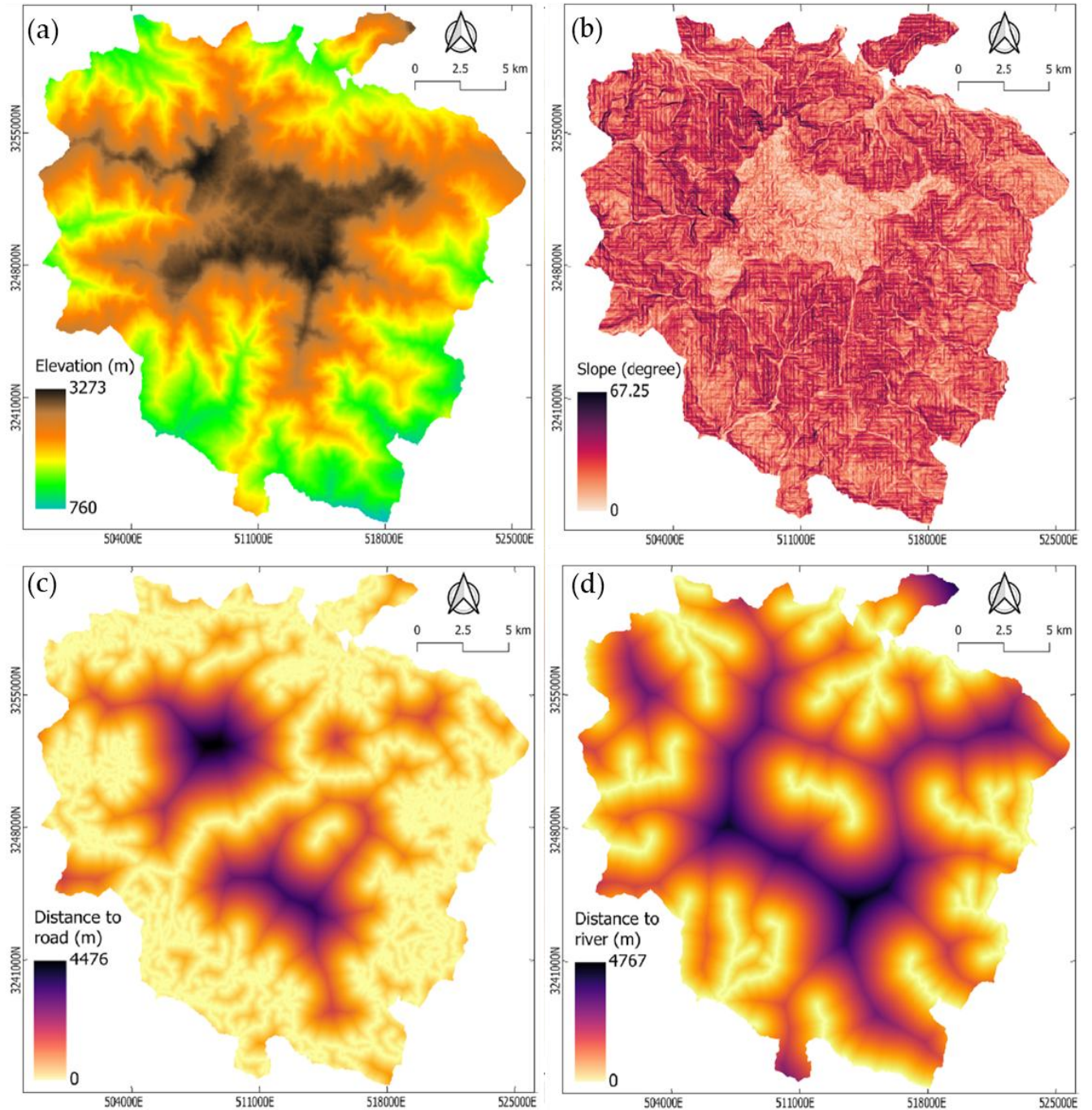


Figure 2.8: Variables used for LULC prediction in KNP: (a) elevation, (b) slope, (c) distance to road, and (d) distance to river.

2.2.7 Survey Data Collection

The research conducted a questionnaire survey in both SNP and KNP. The overall theoretical framework used for data collection and further evaluation is based on the concept of

the Sustainable Tourism Attitude Scale (SUS-TAS) (Choi and Sirakaya, 2005). The framework helps ascertain the perception of local communities around sustainable tourism development and the impact of tourism on factors like forest cover, the impact of forest dependencies, and overall tourism satisfaction in the regions. The rationale for using the SUS-TAS framework is based on its successful application in sustainable tourism development for mountains and their communities (Jeelani et al., 2023; Yu et al., 2022; Obradović and Stojanović, 2022; Ulkhaq et al., 2019). The research conducted a primary survey to analyse the perceptions of locals towards tourism within the communities. Apart from asking about the community perceptions of tourism, the research also has impacted the forest cover in the regions, whether they were satisfied with tourism development in the national parks, and questions about agriculture and livestock to understand how these factors have impacted forest cover. The data was collected from both the national parks buffer and core zones. The reason for surveying both areas was to examine how tourism-related activities affected zones with different levels of community involvement and exposure to tourism-related activities. This was evident based on the information available during initial stakeholder discussions

The survey asked questions about various parts of life in the National Park districts and how people depend on each other. The full questionnaire survey used for this study is shown in Annexure A6. Figure 2.9 displays the field photographs obtained during the fieldwork, questionnaire survey, and discussions with local residents (Table 2.3). Annexure A7 has more pictures. The following strategy was used to carry out the questionnaire survey:

- ✓ It started by asking participants about their demographic details, such as sex and official roles. Participants provides their detailed agricultural practices, including the crops they cultivated and the livestock they raised, specifying the types and quantities of livestock involved.
- ✓ The questionnaire also explored participants' engagement in various trades and enterprises, including farming and trading forest products, agricultural goods, and livestock.
- ✓ Financial aspects were analysed through inquiries about annual income, while changes in agricultural patterns over the past decade and agricultural productivity were probed.
- ✓ Preferences for cooking and heating fuels within households were examined, alongside involvement in tourism services and related training opportunities.

- ✓ Preferred cooking and heating fuels within households were examined, and the frequency and sources of forest product collection were further discussed.
- ✓ Community perceptions of climate change impacts on livelihoods, agriculture, and livestock were also assessed to identify potential adaptation needs and challenges.
- ✓ Opinions to scrutinized changes in forest areas over the past three decades and the reasons behind these changes, collectively providing a comprehensive understanding of community perspectives on various facets of life within the National Park districts.

The resident survey employed a mix of question formats to capture local people's perceptions and experiences regarding tourism development. To galvanize these perceptions, the survey used ordinal categorical scales to understand the perceived impacts of tourism on land use/forest cover and agricultural productivity. Participants could indicate whether they observed increases, decreases, or no change in these aspects. Similarly, resident satisfaction with tourism development was assessed using an ordinal scale ranging from highly satisfied to dissatisfied, facilitating a nuanced understanding of community sentiments. The research harnessed Binary yes/no questions to determine community dependence on forests and the availability of training opportunities for tourism participation, ensuring clear-cut responses to these critical inquiries. Additionally, the survey included questions concerning livestock ownership, enabling insights into the role of livestock within the community. This comprehensive approach contributed to a holistic depiction of resident perspectives on various aspects of tourism development and its potential effects on both the community and the environment.



Figure 2.9: Field photograph collected during the questionnaire survey in KNP

Table 2.3: Questions asked during the questionnaire survey.

Question Asked	The rationale of the question	Scale and Rationale	Question Type
Has Household tourism impacted LULC/Forests?	Assess resident perception of tourism's impact on land use/forest cover	Yes (If they think there is an impact)/No (If there is no impact)	ordinal categorical question
Has agricultural productivity increased	Understand if agricultural productivity increased in the region	Increased (If they think agriculture productivity has increased), Decreased (If they think agriculture production has decreased), No change (If they think there is no change)	ordinal categorical question
Is the community satisfied with tourism development	Measure resident satisfaction with current tourism development practices	highly satisfied (if the perception of tourism development is high), satisfied (if the perception is satisfied), Neutral (If there are no deviating perceptions, or dissatisfied (if the perception of tourism development has gone down)	ordinal categorical question
Is there a dependency on forests by the community	Determine the level of community dependence on forest resources	Yes (If they think there is an impact)/No (If there is no impact)	Binary responses
Has the forest changed/LULC changed	Gather objective data on actual forest cover changes	Increased (If they think agriculture forest change has increased), Decreased (If they think forest change has increased), No change (If they think there is no change)	ordinal categorical question
Are there any training opportunities for tourism development	Assess the availability of training opportunities for residents to participate in tourism	Yes (If training was available)/No (If there is training)	Binary responses
What is the impact of climate change?	Understand if climate change directly or indirectly impacts the park or the surrounding areas.	Yes/No/Unsure	Binary responses
Dependence of livestock	Understand if they have ownership and dependence on livestock	Yes (If they own)/No (If they do not)	Binary responses

2.2.8 Statistical Assessment

The research employed a survey to capture community perceptions on various issues, particularly how development of tourism and agriculture-related parameters (dependent variable) affected forest cover (independent variable). Following data collection, an Ordinary Least Squares (OLS) regression analysis was conducted to assess the statistical significance of these perceptions. While OLS was a common technique used, it is essential to consider potential limitations due to the use of ordinal data in some survey questions. Building on prior research that examined perceptions, this study aimed to quantify the impact of several factors. The research had strategically selected relevant variables based on their importance to the study. Interpretation of the results combined a comprehensive analysis of the statistical findings with insights gleaned from the subsequent field visit. The field visit aimed to gather qualitative data that could provide context and nuance to the statistical findings. Henceforth, the research ensured that the final analysis would have the explanatory prowess and provide a comprehensive picture of the impacts of forests while considering key activities like tourism. A detailed description is provided in Chapter 4 gives a full explanation of the statistical measures.

2.2.9 Methodological Approach for the Development of ILCAF Framework

The Integrated Land-Use and Community Adaptation Framework was developed using a thorough, multi-method approach that was based on both geospatial data and socio-cultural facts. The framework was created through a step-by-step process that combined LULC mapping based on remote sensing, climate trend analysis, socio-economic surveys, and statistical modeling. At first, Google Earth Engine (GEE) was used to get and process high-resolution satellite data from Landsat 5 and 8. It is possible to use the random forest algorithm in QGIS to make strong LULC classifications. These classifications find the changes in time and space in both SNP and KNP's core and buffer zones. Climate data variables, specifically trends in temperature and precipitation, were integrated to contextualize observed landscape alterations and to comprehend stressors such as glacial retreat and shifts in vegetation. Next, a structured questionnaire survey based on the Sustainable Tourism Attitude Scale (SUS-TAS) was conducted in both SNP and KNP to gather community opinions on forest dependency, the effects of tourism, and adaptive behaviours. The study used Ordinary Least Squares (OLS) regression to understand the relationship between socio-

economic variables and changes in LULC. The structure of ILCAF was based on this triangulated data, which is evident from satellites, climate records, and local knowledge. In the end, the framework was not created in a vacuum; it was created in response to real-world problems, such as deforestation caused by tourism in SNP and agricultural encroachment in KNP. It shows how land use, conservation, and community resilience are all connected.

Chapter 3. Analyzing Land Use/Land Cover Dynamics in Core and Buffer Zones of SNP and KNP

3.1 Introduction

Millions of people visit the mountains annually. There are many things to do there, such as hiking, skiing, climbing mountains, and watching wildlife. Mountain tourism has grown because more people are interested in eco-friendly travel and new experiences (Bourdeau, 2009). It gives people in the area jobs and money. Building up the tourism infrastructure, such as hotels, restaurants, and transportation networks, makes life better for people who live in the area. However, earlier research has indicated that heightened mountain tourism leads to environmental degradation, promoting deforestation, forest degradation, soil erosion, waste generation, habitat destruction, and biodiversity loss (Ives and Messerli, 2003; Nepal and Chipeniuk, 2005). The increasing influx of international tourists and their recreational pursuits may jeopardize the sustainability of energy resources, land utilization, and trekking trails (Nepal, 2008; Rimal et al., 2019; Uddin et al., 2015). Natural and human-made factors are changing the world, causing 60% of biodiversity loss and making climate change worse. To manage land in a way that is good for the environment and to provide ecosystem services, it is important to understand how land cover changes (Intergovernmental Panel on Climate Change, 2023; Newbold et al., 2015). In mountainous areas, changes in land use and land cover (LULC) are caused by both natural and human-made factors, and this is becoming a bigger problem around the world (Elmahdy et al., 2020; Taati et al., 2015). In numerous mountainous areas globally, anthropogenic influences induce more pronounced LULC alterations than natural factors, attributed to swift population growth and the disparity between human advancement and environmental governance (Garrard et al., 2016; Guarderas et al., 2022). Natural and anthropogenic factors substantially influence LULC; consequently, evaluating alterations in LULC is imperative (Chaudhary, 2000). Also, knowing how LULC changes is important for keeping an eye on changes in the environment and managing natural resources (M. K. Tiwari and Saxena, 2011).

Satellite data is becoming more popular for studies of LULC change because it is free and there are well-established methods for using it (Mtui et al., 2017). Prior research has shown that machine learning algorithms, including random forest and support vector machine (SVM), can

facilitate LULC classification, thereby improving the accuracy and reliability of data analysis (Paudel et al., 2016; B. M. Shrestha et al., 2010). The Google Earth Engine (GEE) has also recently become a powerful cloud-based platform for processing geospatial data. It lets you find changes over time using different remote sensing data sources (Acharya, 2023; N. T. Sherpa, 2020). This platform makes it easy to analyze large datasets, which lets you keep track of and evaluate changes in LULC over time.

Mountain tourism has grown in Nepal over the last few decades. Approximately one-fourth of all international tourists go to mountain destinations in Nepal. This means that mountain tourism is a major source of income for local communities (Nepal, 2003). According to the World Bank (2024), tourism made up about 6.7% of Nepal's GDP. The Tarai (lowland) region is more affected by LULC changes than the middle and high mountain regions of Nepal (P. Khanal, 2022). The changes in LULC are caused by more than one thing. A growing population causes deforestation and the conversion of forests to farmland in mountainous areas. It also causes soil erosion on sloping terraces (B. M. Shrestha et al., 2010). Tourism in mountainous regions necessitates increased food and goods, resulting in agricultural expansion and alterations in land use and land cover (Paudel et al., 2016). The establishment of tourism-related infrastructure, regarded as the foundation for the enhancement of economic activity, also influences LULC (D. B. Rai, 2017).

This research examines the spatiotemporal patterns of land use and land cover (LULC) changes in SNP and KNP, utilizing Landsat satellite data from 1990 to 2020. Even though the LULC study of SNP and KNP is important, only a few studies have looked at how the different drivers affect it. These parks were chosen because they have different types of tourist attractions and landscapes. The main goal of this study was to find the main causes, effects, and drivers of changes in LULC.

This study concentrated on delineating LULC classes within the core and buffer zones, examining patterns and trends of change, forecasting future LULC scenarios based on existing practices, and assessing the influence of diverse drivers. In SNP, the construction of tourism infrastructure to accommodate an increasing influx of visitors has resulted in considerable deforestation and habitat fragmentation (Sherpa, 2020). Although prior studies investigated LULC changes in SNP from 1992 to 2011, a revision is required. This study utilizes Landsat data from 1990 to 2020 to address the existing data deficiency for KNP and offer updated insights for SNP, thereby enhancing the comprehension of effective management strategies.

3.2 Materials and Methods

Figure 3.1 showing the methodology used for LULC classification and future projections. The diagram illustrates the use of multi-temporal Landsat imagery, high-resolution Google Earth and Planet images, and secondary socio-economic and climatic data. Image pre-processing, random forest classification, and post-classification change detection are applied to generate LULC maps and quantify LULCC dynamics for SNP and KNP. These outputs are then integrated with topographic and proximity-based drivers in a CA-ANN framework to simulate future LULC scenarios.

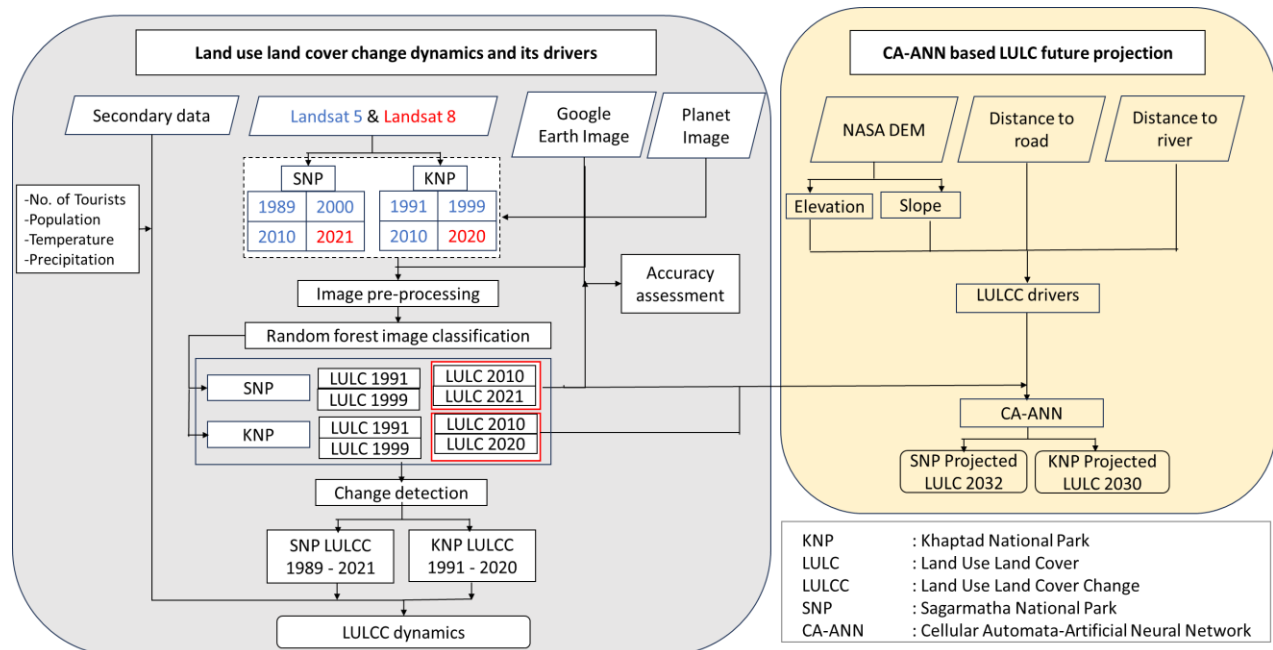


Figure 3.1: Flowchart of the methodology used for LULC classification and future projections

3.2.1 Demography and Climate of Study Areas

The 2021 Census of Nepal says that SNP has 158,041 people and KNP has 761,291 people. (Figure 2.2). From 1971 to 2011, both parks saw steady population growth, but since then, there has been a small drop (Central Bureau of Statistics, 2021). This study is affected by a variety of climates because of the different altitudes. The air temperature in the SNP's lower zone ranges from 10 to 20 degrees Celsius in the summer (June to September) and can drop to -10 degrees Celsius in the winter. The weather is usually cool and sunny in the Khaptad area, which includes

the KNP, in the spring, summer, and fall. The best times to visit are in the spring (March to May) and fall (October to November), when the air is between 10°C and 20°C.

3.2.2 LULC classification

The study used Landsat 5 and 8 in this study because the Landsat images were of good quality. The Google Earth Engine for analysing cloud computing to get Landsat data and prepare it for use. The Landsat images utilized in this study underwent pre-processing at level 2 (surface reflectance). The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) was used to pre-process Landsat 5 data, and the Land Surface Reflectance Code (LaSRC) was used to pre-process Landsat 8 data (Schmidt et al., 2013; Vermote et al., 2016). The CFMask method used the QA_PIXEL feature to reduce image bias by getting rid of clouds and their shadows (Foga et al., 2017). The DZetsaka plugin helped QGIS's random forest algorithm make LULC maps (Karasiak, 2016). Figure 3.2 shows the flowchart for the LULC classification method.

The SNP LULC classification has 10 classes: forest, shrubland, agriculture, bare land, water, grassland (mostly closed to open herbaceous vegetation), built-up area, snow/glacier, kharka (pastureland), and glacier lake. There were seven KNP classes: forest, shrubland, agriculture, bare land, water, grassland (mostly closed to open herbaceous vegetation), and built-up areas. The study found training areas by looking at pictures from Landsat, PlanetScope, and Google Earth. Data for training were chosen for each year of observation. Random forest algorithms enable considerable precision in the processing of data samples and the generation of LULC classifications. The Random Forest algorithm employs numerous decision trees to guarantee elevated classification precision, as confirmed through stratified random sampling and the Accuracy Assessment of Thematic Maps (AcATaMa) plugin in QGIS (Avcı et al., 2023; Amgoth et al., 2023). Four-year LULC classifications were superimposed to detect alterations, depicted in a change matrix for examination.

3.2.3 LULC Data Analysis

This study examined at the classified LULC maps by figuring out the area for each observation year in the core and buffer zones of SNP and KNP. After that, LULC change matrices were made to keep track of the changes in LULC over the course of ten years and the differences between the

first and last periods. These matrices show how the size of different land-use classes has changed over time (Shalaby and Tateishi, 2007). This analysis allowed us to thoroughly identify and examine specific changes in LULC classes throughout the study period.

3.2.4 Climate Data

This study analyzed precipitation data from the Climate Hazards Group (CHIRPS version 2.0) with a spatial resolution of about 5 km to look at precipitation patterns from 1994 to 2023. This study got fifth-generation ECMWF atmospheric reanalysis (ERA5) data for air temperature at 2 m above the Earth's surface from the climate data store (CDS) with a spatial resolution of about 29 km (Funk et al., 2014). A 5-km grid was made to get data on both study areas' air temperature and precipitation. Using Python, data were extracted and gridded to a resolution of 5 km for both study areas. To analyze the climatic pattern of the study area, the annual mean precipitation and air temperature were computed for the period from 1994 to 2023. Sen's slope, the Mann-Kendall test, and linear regression (Cohen, 2013; Fischer et al., 2017; Leta et al., 2021; Santé et al., 2010) were employed to examine trends, considering the recognized effects of global climate change on land use, snow/ice, water resources, and vegetation patterns (Avtar et al., 2022; Hegglin and Huggel, 2008).

3.2.5 LULC Prediction

This study utilized the Modules of Land Use Change Evaluation (MOLUSCE) plugin in QGIS to forecast LULC (Amgoth et al., 2023) for SNP and KNP, employing the most recent LULC maps of the study areas (2010 and 2021 for SNP and 2010 and 2020 for KNP). The analysis incorporated four variables: elevation, slope, distance to the road (inclusive of trekking trails), and distance to the river. These variables have been extensively utilized as determinants in LULC prediction (Leta et al., 2021). This study used NASADEM elevation data (which came from SRTM) to figure out the slope and used the Euclidean distances from vector data to figure out the distances between roads and rivers. Figure 3.2 shows the flowchart for the method used to predict LULC.

3.2.6 Detection of Development of New Roads Using High-resolution data

PlanetScope surface-reflectance imagery (≈ 3 m, 4 bands) was used to detect the construction of new roads in the KNP. Cloud-free data from KNP was downloaded from October to January. The PlanetScope data was reprojected to WGS 84 / UTM (SNP: Zone 45N; KNP: Zone 44N), snapped them to a 3 m grid, co-registered them to the Landsat reference, and masked out clouds and shadows with vendor QA layers. A DEM-based terrain-shadow mask was also applied. Simple spectral and terrain predictors such as NDVI, visible-band brightness, slope, and distances to settlements and streams were used to find constructions of new roads.

3.3 Results

3.3.1 LULC of core and buffer zones of SNP

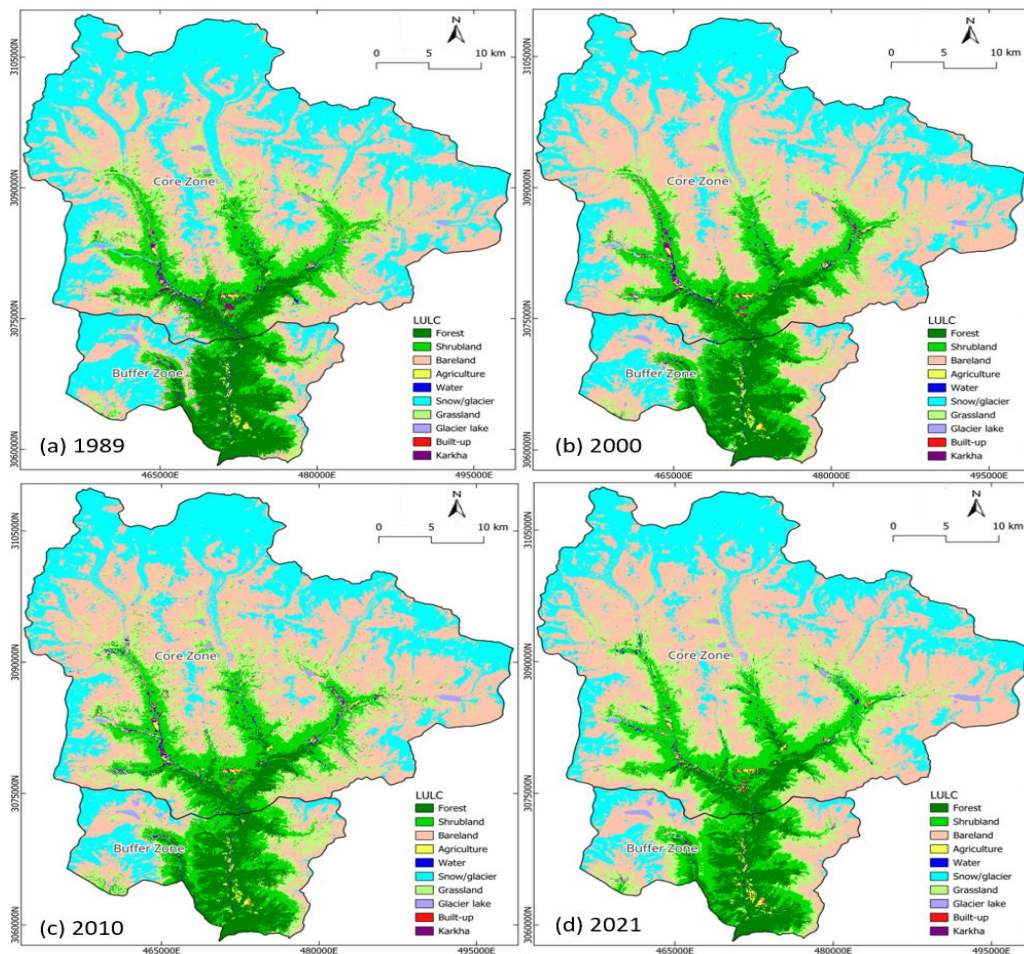


Figure 3.3: Land use/land cover maps of (a) 1989, (b) 2000, (c) 2010, and (d) 2021 in SNP.

This study processed LULC classification using Landsat data for SNP for 1989, 2000, 2010, and 2021 (Figure 3.3). Visual interpretation indicates that snow/glaciers, forest, shrubland, and bare land were the predominant land cover types. A comparison of these maps reveals a consistent decline in the extent of snow/glacier and forest cover, essential components of the SNP ecosystem. Simultaneously, agricultural and built-up areas have increased significantly over this period.

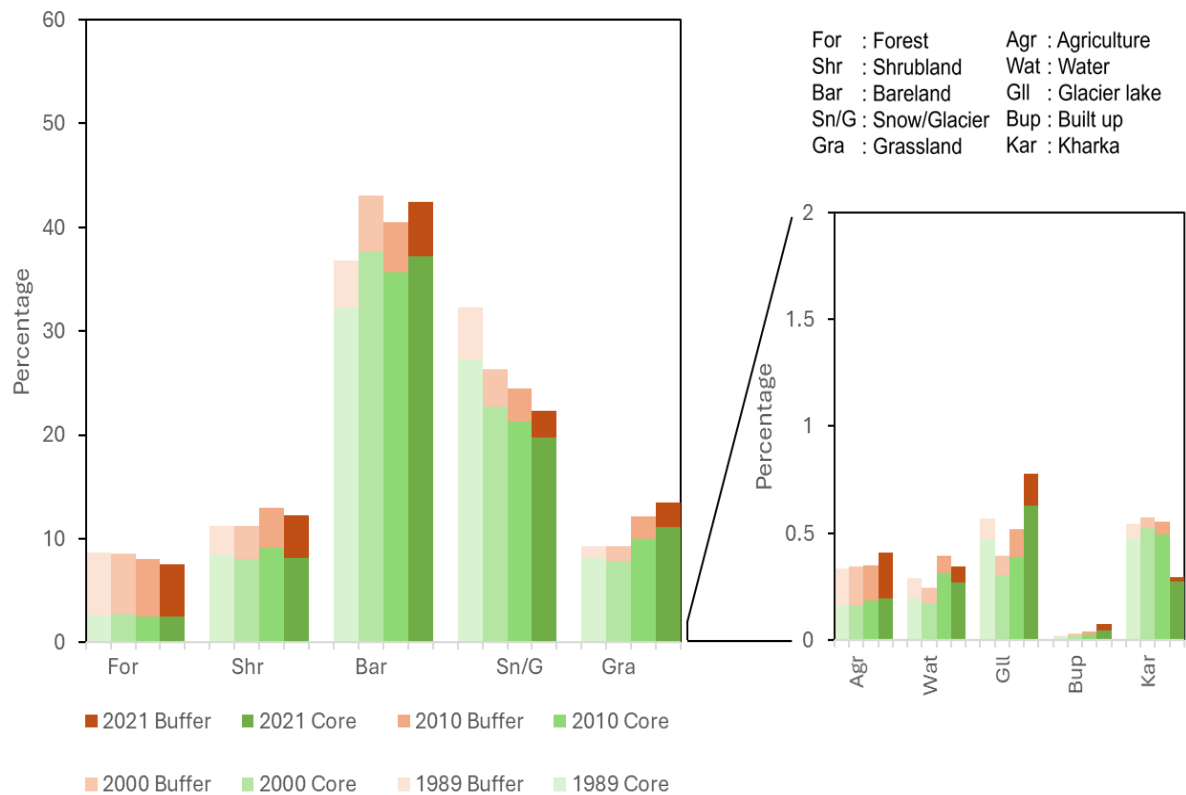


Figure 3.4: Land use/land cover change patterns in SNP (1989–2021)

Figure 3.4 clearly shows how the patterns of land use and land cover (LULC) have changed over the years (1989–2021) in SNP's core and buffer zones. The forest area in the core zone is more stable than in the buffer zone. From 1989 to 2021, the forest area in the core zone lost 13.45 km². The shrubland in the core zone has stayed mostly the same, but the shrubland in the buffer zone has slowly grown, adding 19.18 km² in 2021.

SNP saw a lot of changes in LULC from 1989 to 2021. There was an increase of 68.84 km² (4.87%) in the core zone and 11.11 km² (0.79%) in the buffer zone of bareland. The core zone has grown a lot because the snow and glaciers are melting, which exposes the ground below. The core zone lost 106.23 km² (7.52%) of its snow and glacier area, leaving 278.69 km². During the same

time, the snow and glacier area in the buffer zone shrank by 34.01 km² (2.41%), leaving a total area of 36.44 km². The area of glacier lakes grew by 2.23 km² in the core zone, bringing the total to 8.88 km². In the buffer zone, it grew by 0.80 km², bringing the total to 2.14 km². Every year, the core zone's grassland gets bigger. It grew by 42.97 km² (3.08%) to 157.56 km² between 1989 and 2021. In the buffer zone, it grew by 16.51 km² (1.17%) to 33.45 km² during the same time. Both zones saw growth in agriculture and built-up areas. From 1989 to 2010, the Kharka area in both zones stayed pretty stable.

3.3.2 LULC of Core and Buffer Zones of KNP

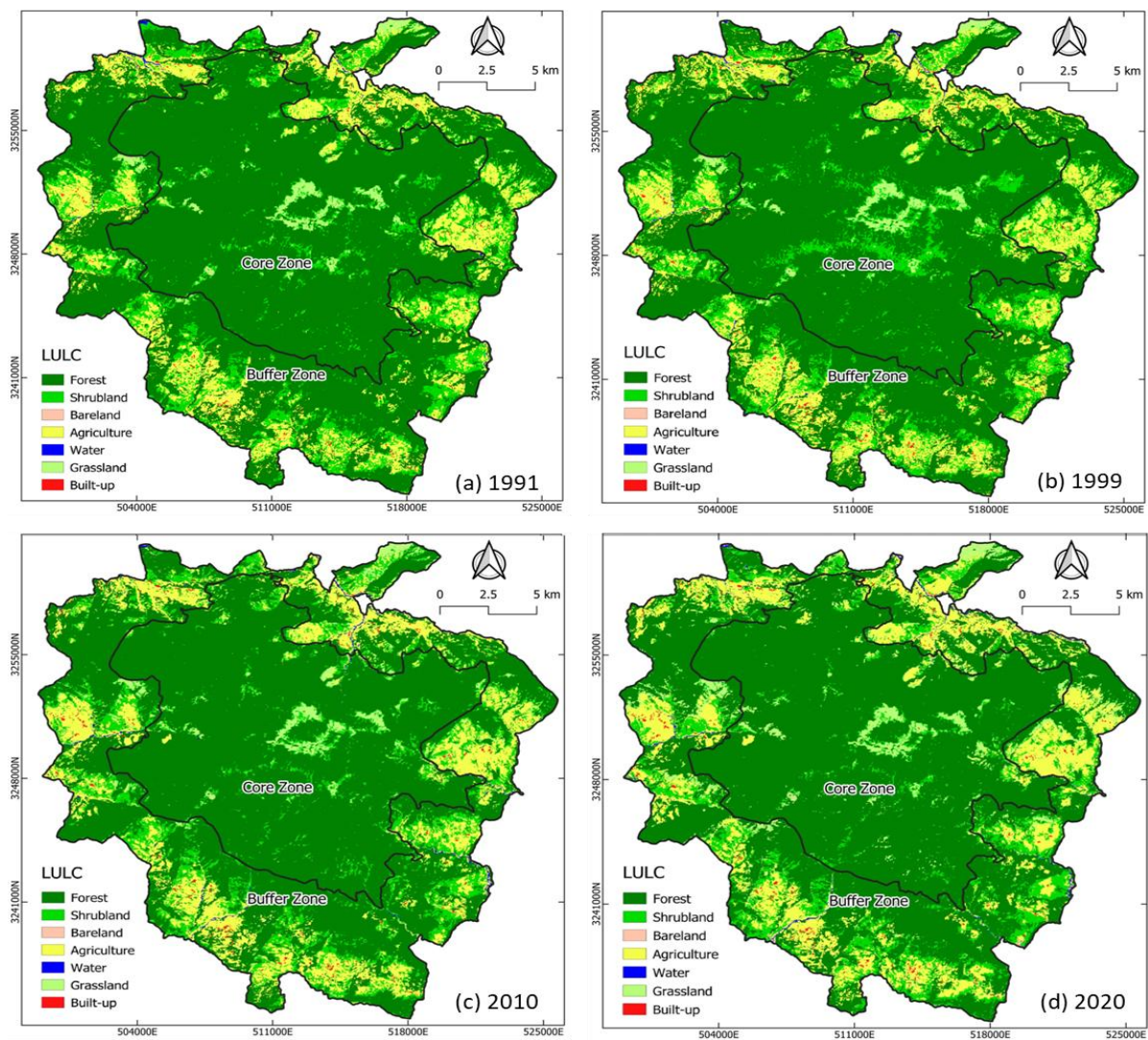


Figure 3.5: Land use/land cover maps of (a) 1991, (b) 1999, (c) 2010, and (d) 2020 in KNP.

In KNP, three types of land use and land cover (LULC) have been the most common: forest, shrubland, and agriculture. Figure 3.6 shows that the forest area shrank by 18.63 km² between 1991 and 2020, leaving an area of 439.21 km² (69.35% of the total area). From 1991 to 2020, Shrublands also shrank a lot, losing 4.11 km² in the core zone and 6.36 km² in the buffer zone. This left 11.63 km² in the core zone and 56.4 km² in the buffer zone. On the other hand, the buffer zone's agricultural land grew by a significant 8.09 km², bringing the total to 87.09 km². Grassland also grew a lot in the core zone, by 14.33 km², bringing the total area to 18.93 km² by 2020.

Although bare land covers a relatively small area compared to other LULC types, it increased by 0.75 km² in the buffer zone from 1991, reaching 0.8 km² in 2020 (Figure 3.6). The water area also increased, with a total rise of 0.02 km² in the core zone and 1.43 km² in the buffer zone. This growth in water bodies could be attributed to melting snow caused by climate change. The built-up area in the study site also increased, though not significantly. In the core zone, the built-up area expanded by only 0.02 km², while in the buffer zone, it grew by 1.09 km² during the period from 1991 to 2020.

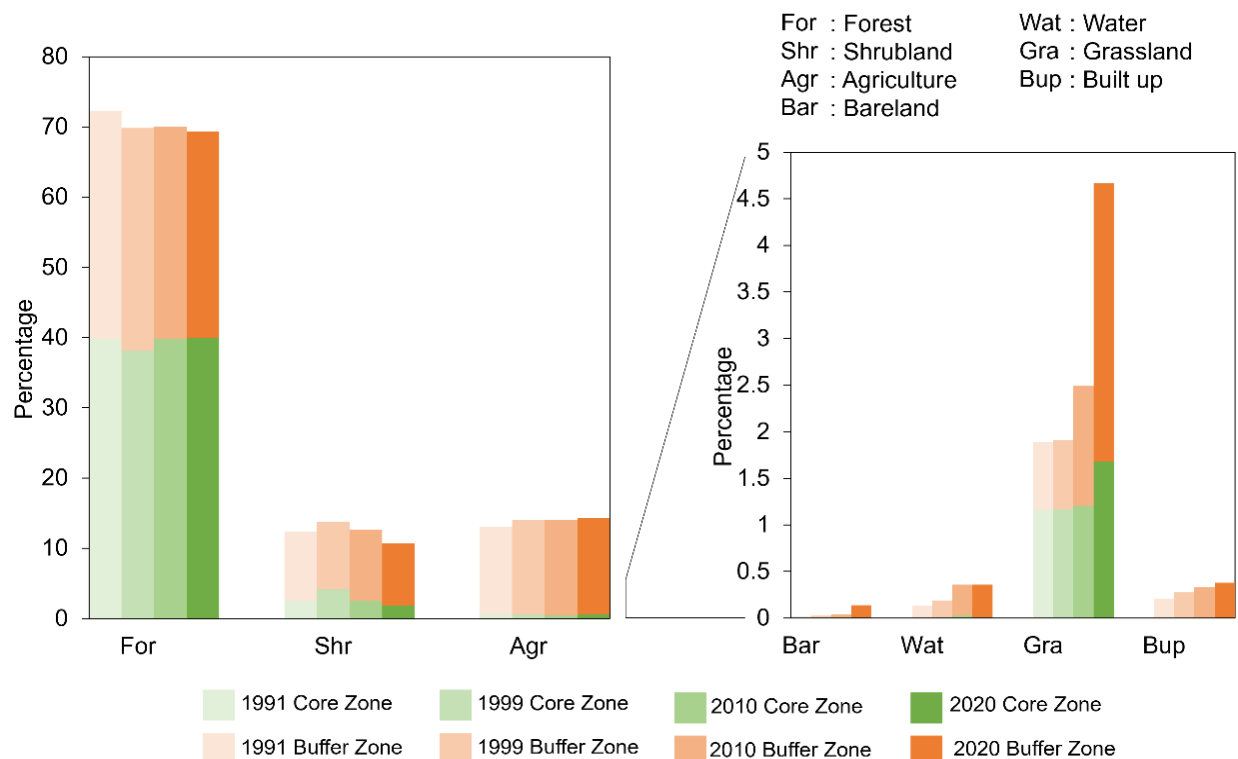


Figure 3.6: Land use/land cover change patterns in the KNP (1991–2020).

3.3.3 Accuracy Assessment

Stratified random sampling was used to check the accuracy of about 480–605 validation samples from high-resolution Google Earth images. This was done to see how well the classified LULC types matched the actual land cover class. An evaluation of accuracy was conducted for each study period. Table 3.1 shows how accurate the LULC classification was overall and for each year. The LULC classification for SNP and KNP was generally accurate, with an average accuracy of about 84.5% over all study periods (Table 3.1). The KNP data's overall accuracy was between 84.9% and 86.6%. Even though the topography of both KNP and SNP is dynamic and undulating, and the slope aspects need to be made clearer, the accuracy of all the images stayed the same (annexure A1-A4). This consistency shows that the classification model is very accurate.

Table 3.1: Overall land use land cover classification accuracy and Kappa coefficients of (a) SNP and (b) KNP.

Year	Overall accuracy	Kappa coefficient
(a) SNP		
1989	82.12	0.794
2000	83.40	0.806
2010	83.47	0.806
2021	84.87	0.825
(b) KNP		
1991	85.52	0.767
1999	85.02	0.772
2010	84.92	0.773
2020	86.86	0.794

Some LULC classes, on the other hand, had lower user accuracy. This was especially true for SNP, where the shrubland and grassland classes had lower accuracy. The wrong classification of some SNP classes was mostly caused by the fact that the satellite data was collected on different days and in different weather conditions, which change the spectral reflectance of the data. All classes showed good user accuracy, which was within acceptable ranges. These accuracy assessment results provide useful information about how reliable LULC classification is, which supports using the classified data for more research.

3.3.4 Spatio-Temporal Analysis of LULC

(a) LULCC matrix of SNP for the whole area													
Area (km ²)	2021												
1989	Classes	For	Shr	Bar	Agr	Wat	Sn/Gl	Gra	Gll	Bup	Khar	Total	Loss
	For	95.87	21.28	0.02	0.96	0.13	0	3.65	0	0.09	0	122	26.11
	Shr	7.24	121	4.29	0.6	0.67	0	23.47	0.02	0.09	1.32	158.7	37.7
	Bar	0.93	14.54	431.3	0.47	1.8	0	70.74	2.1	0	0.21	522.1	90.79
	Agr	0.4	0.72	0	2.71	0.02	0	0.13	0	0.53	0.22	4.73	2.02
	Wat	0.79	0.98	0.31	0.1	1.22	0.01	0.63	0.01	0	0.04	4.07	2.85
	Sn/G	0	1.88	126.5	0.11	0.68	315.7	7.39	4.11	0	0.06	456.4	140.3
	Gra	0.86	8.56	37.91	0.31	0.19	0	83.75	0.07	0	0.11	131.8	48.02
	Gll	0	0.07	1.82	0.01	0.05	0.48	0.86	4.71	0	0	8	3.29
	Bup	0	0.01	0	0.02	0	0	0	0	0.21	0.01	0.25	0.04
	Khar	0.55	3.87	0.03	0.47	0.08	0	0.48	0	0.12	2.11	7.71	5.6
	Total	106.6	172.9	602.1	5.75	4.84	316.2	191.1	11.02	1.05	4.08	1416	
	Gain	10.77	51.89	170.8	3.04	3.62	0.48	107.4	6.31	0.84	1.97		
(b) LULCC matrix of SNP for the core area													
Area (km ²)	2021												
1989	Classes	For	Shr	Bar	Agr	Wat	Sn/Gl	Gra	Gll	Bup	Khar	Total	Loss
	For	27.92	6.41	0.01	0.01	0.03	0	2.31	0	0.02	0.04	36.75	8.82
	Shr	4.7	88.64	3.82	0.46	0.55	0	20.45	0.01	0.09	1.26	120	31.34
	Bar	0.51	7.59	387	0.28	1.56	0	57.53	1.9	0	0.17	456.6	69.53
	Agr	0.03	0.4	0	1.2	0	0	0.12	0	0.24	0.22	2.22	1.02
	Wat	0.47	0.7	0.25	0.04	0.8	0.01	0.45	0.01	0	0.03	2.77	1.97
	Sn/G	0	0.79	99.23	0.05	0.59	278.3	2.75	3.21	0	0.04	384.9	106.2
	Gra	0.7	7.14	33.33	0.21	0.19	0	72.87	0.06	0	0.09	114.6	41.72
	Gll	0	0.03	1.72	0	0.04	0.43	0.75	3.69	0	0	6.65	2.96
	Bup	0	0.01	0	0.01	0	0	0	0	0.18	0.01	0.21	0.04
	Khar	0.5	3.22	0.01	0.47	0.07	0	0.33	0	0.12	2	6.71	4.71
	Total	34.84	114.9	525.4	2.73	3.83	278.7	157.6	8.88	0.65	3.86	1131	
	Gain	6.91	26.29	138.4	1.53	3.03	0.44	84.69	5.18	0.47	1.86		
(c) LULCC matrix of SNP for the buffer area													
Area (km ²)	2021												
1989	Classes	For	Shr	Bar	Agr	Wat	Sn/Gl	Gra	Gll	Bup	Khar	Total	Loss
	For	67.8	14.83	0	0.94	0.09	0	1.34	0	0.07	0.02	85.1	17.3
	Shr	2.54	32.34	0.47	0.14	0.12	0	3.01	0	0.01	0.06	38.69	6.35
	Bar	0.41	6.94	42.4	0.19	0.24	0	13.17	0.21	0	0.04	63.59	21.19
	Agr	0.37	0.31	0	1.5	0.02	0	0	0	0.29	0	2.5	0.99
	Wat	0.32	0.27	0.05	0.05	0.41	0	0.18	0	0	0	1.29	0.88
	Sn/G	0.16	1.09	27.1	0.06	0.09	36.39	4.64	0.91	0	0.02	70.45	34.01
	Gra	0	1.41	4.54	0.09	0.01	0	10.85	0.01	0	0.03	16.94	6.09
	Gll	0	0.04	0.1	0.01	0.02	0.05	0.12	1.02	0	0	1.35	0.33
	Bup	0	0	0	0.01	0	0	0	0	0.03	0	0.04	0.01
	Khar	0.05	0.64	0.02	0	0.01	0	0.14	0	0	0.11	0.99	0.87
	Total	71.65	57.87	74.71	3.01	0.99	36.44	33.45	2.14	0.4	0.28	281	
	Gain	3.85	25.53	32.3	1.5	0.91	0.05	22.6	1.13	0.37	0.16		

Figure 3.7: LULC change matrices of SNP for (a) the entire area, (b) core zone, and (c) buffer zone. (The color gradient shows the level of change in the area of the LULC class). Land

use/land cover classes: For = Forest, Shr = Shrubland, Bar = Bare land, Agr = Agriculture, Wat = Water, Sn/G = Snow/Glacier, Gra = Grassland, Gll = Glacier Lake, Bup = Built up, Kar = Kharka.

(a) LULCC matrix of KNP for the whole area										
Area (km ²)	2020									
	Classes	For	Shr	Bar	Agr	Wat	Gra	Bup	Total	Loss
1989	For	420	16.55	0.14	14.54	0.58	5.95	0.09	457.84	37.84
	Shr	13.83	38.99	0.05	16.35	0.07	9.12	0.11	78.5	39.51
	Bar	0	0.01	0.06	0.01	0	0.02	0	0.1	0.03
	Agr	5.1	11.08	0.47	58.55	1.29	5.29	0.98	82.76	24.21
	Wat	0.05	0.02	0.03	0.33	0.34	0.06	0	0.83	0.48
	Gra	0.24	1.37	0.11	1.11	0	9.12	0.01	11.97	2.85
	Bup	0	0.01	0	0.06	0	0	1.21	1.29	0.08
	Total	439.21	68.03	0.87	90.93	2.28	29.57	2.4	633.28	
	Gain	19.22	29.03	0.81	32.38	1.94	20.45	1.19		
(b) LULCC matrix of KNP for the core zone										
Area (km ²)	2020									
	Classes	For	Shr	Bar	Agr	Wat	Gra	Bup	Total	Loss
1989	For	246.36	3.58	0	0.75	0.02	1.3	0	252.01	5.65
	Shr	5.78	6.32	0	0.82	0	2.81	0	15.74	9.42
	Bar	0	0	0.04	0	0	0.01	0	0.05	0.01
	Agr	0.41	0.69	0	1.99	0.02	0.64	0	3.76	1.77
	Wat	0	0	0	0.02	0.01	0	0	0.03	0.02
	Gra	0.17	1.04	0.03	0.25	0	5.88	0.01	7.37	1.49
	Bup	0	0	0	0	0	0	0	0	0
	Total	252.72	11.63	0.08	3.83	0.05	10.64	0.02	278.96	
	Gain	6.36	5.31	0.04	1.85	0.04	4.76	0.02		
(c) LULCC matrix of KNP for the buffer zone										
Area (km ²)	2020									
	Classes	For	Shr	Bar	Agr	Wat	Gra	Bup	Total	Loss
1989	For	173.64	12.97	0.14	13.78	0.56	4.66	0.09	205.83	32.19
	Shr	8.04	32.67	0.05	15.52	0.06	6.31	0.1	62.76	30.09
	Bar	0	0.01	0.03	0.01	0	0.01	0	0.05	0.03
	Agr	4.7	10.39	0.47	56.56	1.27	4.65	0.98	79	22.44
	Wat	0.05	0.02	0.03	0.31	0.34	0.06	0	0.8	0.46
	Gra	0.07	0.33	0.08	0.86	0	3.24	0.01	4.59	1.35
	Bup	0	0.01	0	0.06	0	0	1.21	1.29	0.08
	Total	186.5	56.4	0.8	87.09	2.23	18.93	2.38	354.32	
	Gain	12.86	23.72	0.77	30.53	1.9	15.69	1.17		

Figure 3.8: LULC change matrices of KNP for (a) the entire area, (b) core zone, and (c) buffer zone. (The color gradient shows the level of change in the area of the LULC class). Land use/land cover classes: For = Forest, Shr = Shrubland, Bar = Bare land, Agr = Agriculture, Wat = Water, Gra = Grassland, Bup = Built up.

Figure 3.7 show the most notable change in the SNP occurred in snow/glacier areas, leading to an increase in bare land (126.46 km²). When examined based on their respective zones, −99.23 km² of snow/glacier transformation occurred in the core zone, while −27.10 km² occurred in the buffer zone. Snow/glacier areas were converted to grassland (close to open herbaceous vegetation), totaling 2.75 km² (core zone) and 4.64 km² (buffer zone).

Figure 3.8 shows the LULC change matrices for KNP: the entire area (a), the core zone (b), and the buffer zone (c). As discussed earlier, the LULC types in KNP were relatively stable throughout the observation period, except for a significant increase in grassland area. It can be observed in Figures 3.5 and 3.6 that the shrubland area in 2020 covered 16.55 km², which resulted from deforestation. This led to an overall decrease in forest area from 1991 to 2020. Most forest-to-shrubland conversions occurred in the buffer zone, totalling 12.97 km². Other substantial changes in the buffer zone include forest-to-agriculture conversion covering 13.78 km² and shrubland-to-agriculture conversion covering 15.52 km².

3.3.5 Trend analysis of Climate Change in SNP and KNP

Figure 3.10 illustrates the annual mean precipitation and air temperature trends from 1994 to 2023 in SNP. Mann–Kendall (MK) test and linear regression show a non-significant decreasing trend of precipitation and a significant increasing temperature trend. These methods were selected to characterize climate tendencies relevant to mountain protected areas, where temperature and precipitation shifts can influence land use dynamics, snow/ice processes, water availability, and vegetation patterns under ongoing global climate change.

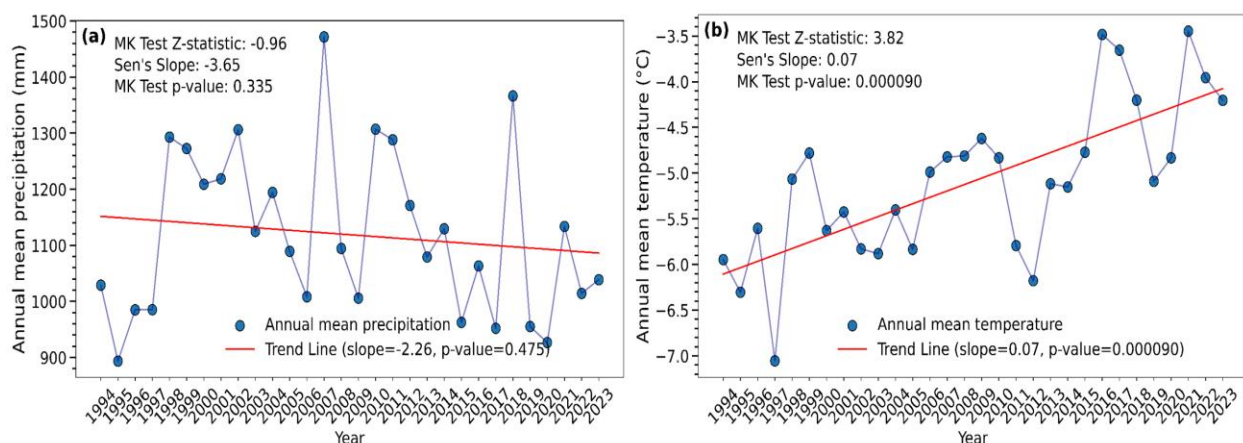


Figure 3.10: Trends in (a) annual mean precipitation and (b) annual mean air temperature in the SNP from 1994 to 2023. Data of CHIRPS (Index of /products/CHIRPS-2.0 (ucsb.edu)) for precipitation and of 5-km grids from ERA5 (Climate Data Store (copernicus.eu)) for air temperature were used.

Although the MK test ($p = 0.335$) and linear regression ($p = 0.476$) do not indicate statistical significance at the 95% confidence level, the negative slopes (-3.65 and -2.26) highlight a gradual reduction in rainfall over the last three decades a trend that could become significant under extreme climate scenarios. On the other hand, the annual mean temperature increased by $0.07\text{ }^{\circ}\text{C}$, and the trend was statistically significant ($p = 0.00009$).

Figure 3.11 depicts precipitation and temperature trends for KNP over the same period. Here, both precipitation and temperature show positive trends, supported by positive Z-values and slope estimates. Sen's slope (2.41) and linear regression slope (3.67) for precipitation reflect a moderate upward trend, while temperature exhibits a consistent rise of $+0.05\text{ }^{\circ}\text{C yr}^{-1}$. These results indicate a statistically meaningful warming trend and a potential intensification of the hydrological cycle.

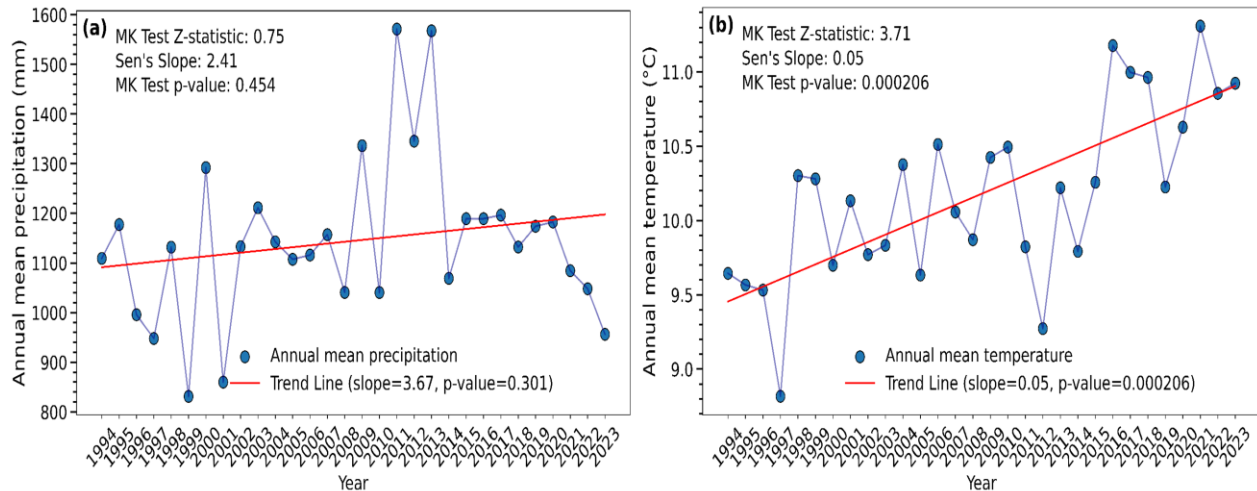


Figure 3.11: Trends in (a) annual mean precipitation and (b) annual mean air temperature in the KNP from 1994 to 2023. Data of CHIRPS (Index of /products/CHIRPS-2.0 (ucsb.edu)) for precipitation and of 5-km grids from ERA5 (Climate Data Store (copernicus.eu)) for air temperature were used.

3.3.5.1 Implications of Climate Trends on Forests, Livestock, and Agriculture

The warming trend of about $+0.07\text{ }^{\circ}\text{C yr}^{-1}$ in Sagarmatha National Park (SNP), along with a decrease in precipitation in one direction, means that forest ecosystems are becoming more

stressed by moisture. As the temperature rises, species must move up the slope to find suitable climatic niches. However, in the steep Himalayan terrain, there isn't much room for them to live, so the forest may shrink. Seedlings and young trees are especially sensitive to lower soil moisture levels, which can slow down the growth of new trees, make the forest structure less dense, and encourage drought-tolerant shrubs over trees with closed canopies. Additionally, warmer and drier periods increase the likelihood of disturbances like fires or pest outbreaks, which can further harm the health of forests (Lamsal et al., 2017b).

These stresses in the forest affect the livestock systems. As the health and cover of forests get worse, the amount of fodder available goes down, which limits the amount of grazing that can be done. At the same time, warming puts stress on livestock's bodies, making them eat less, reproduce less, and work less when it's hot. In marginal areas, pasture productivity may drop when there isn't enough moisture, which means that herders will have to cut back on their herds or move them to different grazing areas. Climate change makes the problem worse by changing how much water is available, which can make it harder for animals to find places to drink (Thakur and Karki, 2018).

Farming in the buffer zones around SNP is also at risk. Warmer temperatures may speed up the phenology of crops, which could shorten important growth stages like grain filling. More importantly, the fact that precipitation is becoming less predictable—delayed monsoons, mid-season droughts, or heavy rain—can hurt crops, wash away soil on steep terraces, or mess up planting schedules. Smallholder farmers in Nepal are already dealing with crop stress, yield variability, and a higher risk of extreme weather (P. Shrestha et al., 2024; Thakur and Karki, 2018). Terraces that are on the edge or at a high elevation may become less useful, which could lead to their abandonment or conversion to less demanding uses. So, in SNP, the changes in temperature and precipitation are not just predictions; they are real threats to the health of forests, the productivity of livestock, and the viability of farming. The warming trend in Khaptad National Park (KNP) is about the same strength as in SNP (about +0.05 °C per year), but the precipitation signal is slightly positive. This small amount of moisture may help relieve some stress compared to drier systems, but the forests here are still at risk from changes in the timing of precipitation, soil moisture variability, and disturbance regimes. Even if the rain is better, regeneration could still be stopped by rains that come and go or soil erosion that gets worse. Warm stress still makes

trees more likely to get pests and damage their edges, and repeated disturbances can change the types of trees in a forest over time.

The small amount of rain in KNP may make livestock systems a little less strict than in SNP. But warmer weather still stresses animals, especially during dry spells or heat waves. If the productivity of the pasture doesn't keep up, grazing pressure may increase in lower areas, forcing herders to change the size or movement of their herds. Water shortages and disease pressure are still big problems, especially when it's warm and wet, which is when pathogens tend to spread. Farmers in the agricultural fringes near KNP might benefit from more rain, but only if it falls in a consistent pattern. Warm stress during sensitive crop phases, unpredictable rainfall patterns, and extreme events still threaten yield stability. Crops may mature too quickly or get damaged by heat, soil erosion may make steeper terraces less productive, and marginal plots at higher elevations may slowly lose productivity. In Nepal, crop yields are already sensitive to even small changes in the weather, and farmers often change their planting schedules or grow a wider variety of crops in response (P. Shrestha et al., 2024).

In conclusion, KNP may have a slight advantage when it comes to moisture trends, but the warming in both parks puts similar stress on forests, livestock, and agriculture. The effects will be different in each park depending on the terrain, how reliable the precipitation is, and how people choose to adapt.

3.3.6 LULC Prediction

This study projected LULC for the next decade by introducing four variables: elevation, slope, distance to roads, and distance to rivers. The relationships between these parameters were quantified using Pearson's correlation (Cohen, 2013). As shown in Table 3.2, the correlations among all variables used for LULC prediction ranged from -0.101 to 0.679, indicating weak-to-moderate associations.

Table 3.2: Matrices of Pearson's correlation values between spatial variables used for LULC prediction in (a) SNP and (b) KNP.

SNP	Elevation	Slope	Distance to road	Distance to river
Elevation		0.124	0.422	0.679
Slope			0.102	0.071
Distance to road				0.355
Distance to river				

KNP	Elevation	Slope	Distance to road	Distance to river
Elevation		0.031	0.566	0.457
Slope			0.056	-0.101
Distance to road				0.431
Distance to the river				

Moderate correlation values were found among the three parameters: elevation, distance to river, and distance to road. The researcher assumed no collinearity among variables with correlation coefficients > 0.7 (Avtar et al., 2022).

The ANN learning process systematically determined various parameters until optimal accuracy was achieved. The obtained accuracy scores were 0.031 for SNP and 0.770 for KNP, with lower values indicating higher precision of the constructed model. Figure 3.12 depicts a visual representation of the ANN training process for (a) SNP and (b) KNP. Subsequently, the CA method is employed to make predictions using the knowledge gained from the ANN learning process.

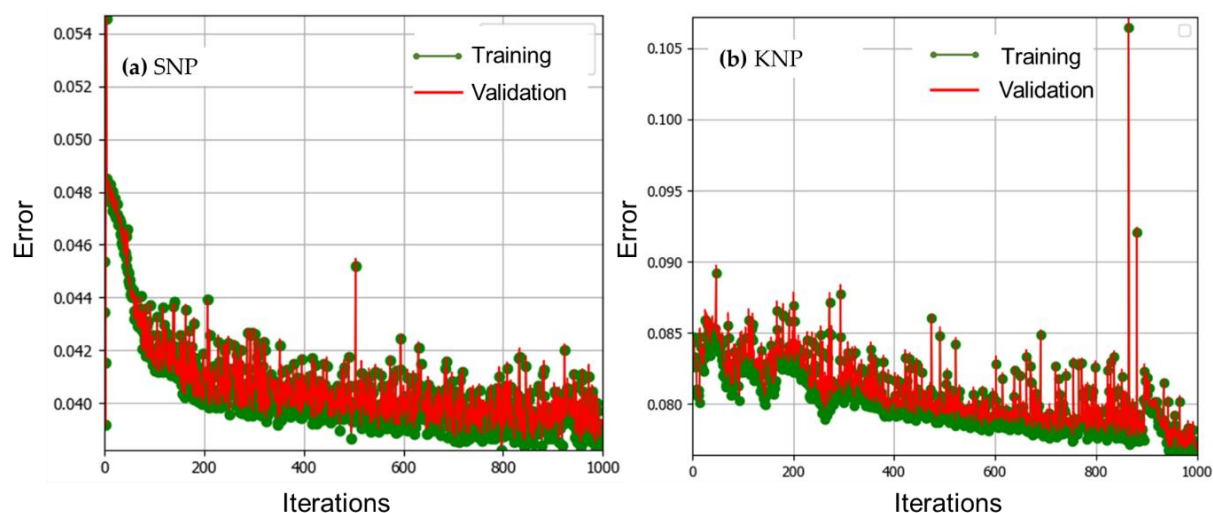


Figure 3.12: Neural network learning curves for training LULC prediction in (a) SNP and (b) KNP.

The projected LULC map of the SNP for the year 2032 and area changes from 1989 to 2032 are presented in Figures 3.13a and 3.13b, respectively. The findings revealed a significant increase in bare land areas within the core zone, primarily due to snow and glacier melting. There will be a decrease in the area of snow/glaciers in the core zone of 22.84km^2 (2.04%) from 2021 to 2032. The reduction in snow/glaciers has been reported in a previous study (Hegglin and Huggel, 2008).

It is anticipated that the areas currently covered by snow/glaciers will be converted to other land use categories, including bare land, grassland, agricultural land, water bodies, and glacier lakes. A continued decline in forest cover is also projected, particularly in the buffer zone, with shrubland partially replacing deforested areas. Moreover, agricultural areas in the core and buffer zones are expected to expand by 2032.

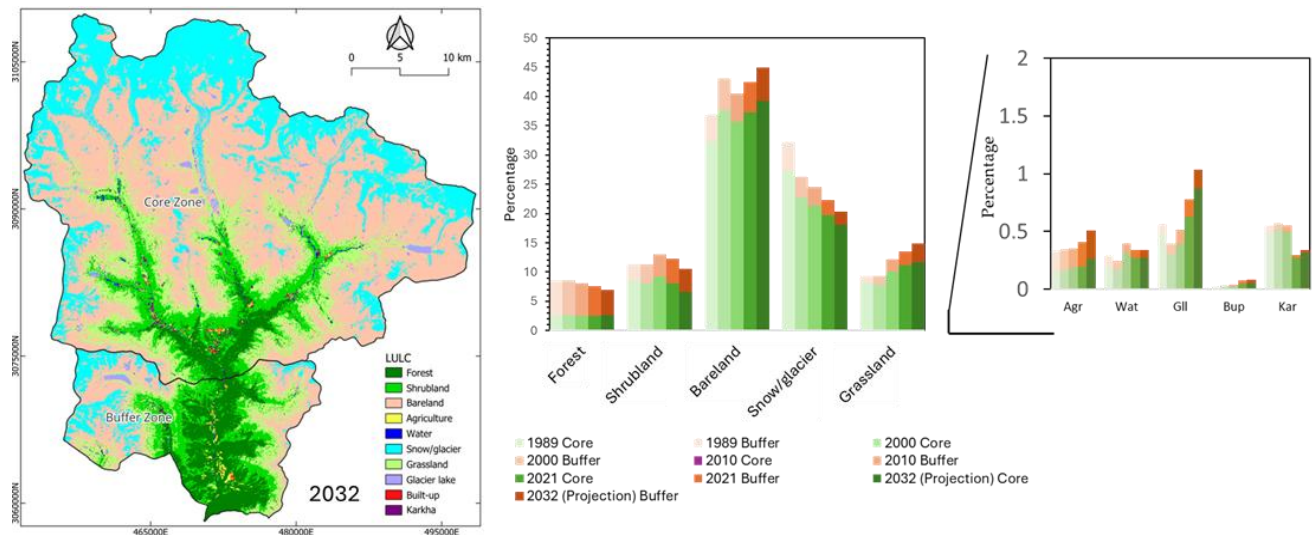


Figure 3.13: (a) Projected LULC for SNP in 2032 and (b) changes in area from 1989 to 2032.

The LULC prediction of KNP indicated a significant decrease in forest area, particularly within the buffer zone (Figure 3.14a). The loss of forest area is expected to be replaced by agriculture areas, shrublands, and grasslands. Figure 3.14b shows an expansion in grassland, mostly in the buffer zone. The forest area in 2030 is projected to decrease by 5.37 km² in the core zone and by 18.43 km² in the buffer zone.

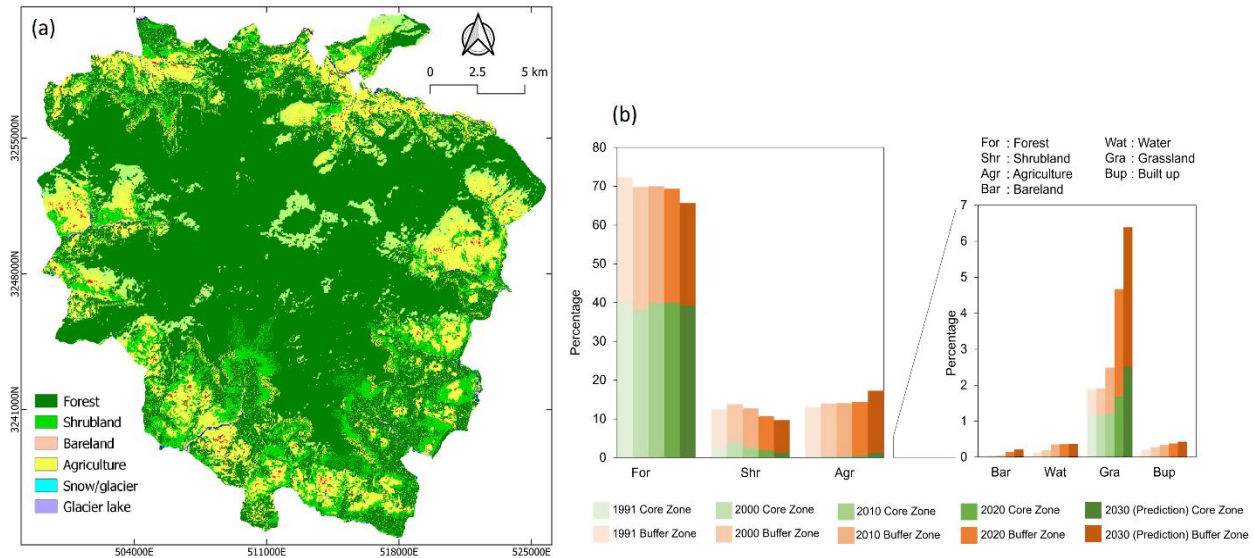


Figure 3.14: (a) Projected LULC for KNP in 2030 and (b) changes in area from 1991 to 2030.

3.3.7 Road detection results from Planet imagery

PlanetScope satellite data acquired in 2016 and 2021 were first processed in ENVI software for radiometric normalization and contrast enhancement and then interpreted in ArcGIS Pro software using digitizing tool. Visual image-interpretation techniques were applied to identify development of new roads. The Normalized Difference Vegetation Index (NDVI) is a widely used indicator of vegetation conditions typically reflect more near-infrared (NIR) radiation and absorb more red radiation. Accordingly, NDVI images were generated for both dates and interpreted to support road-change detection, as new road construction is expected to reduce vegetation cover and therefore decrease NDVI values along road corridors. Figure 3.15 presents NDVI maps of the Bajhang area for 2016 and 2021, illustrating localized reductions in NDVI associated with vegetation clearance related to road development.

$$NDVI = (NIR + Red) / (NIR - Red)$$

Bajhang district, shows construction of new roads (Figure. 3.15). Newly visible switch backed segments and short spur connections are mostly found along mid-slope traverses. These segments and connections come together to form longer, more connected corridors that improve the connection between ridge-top routes and valley-side access paths.

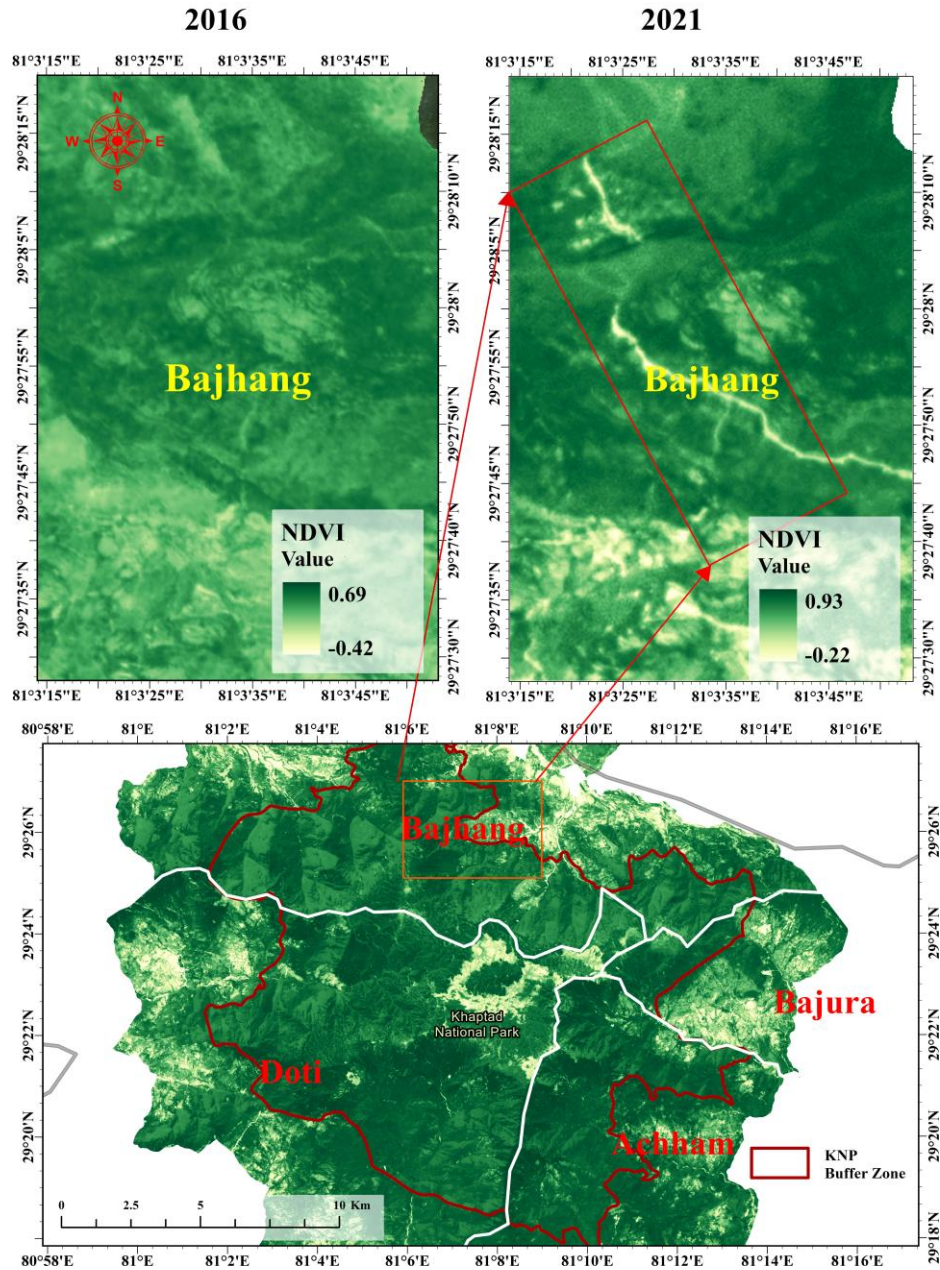


Figure 3.15. Road detection and densification in Bajhang (2016–2021) from PlanetScope imagery

Figure. 3.16 illustrates the construction and extension of new roads in Bajura by comparing Planet data of 2021 and 2016. These features are mostly found on the eastern side and near major slope breaks above the valley floor. This shows that the local path system is becoming more connected.

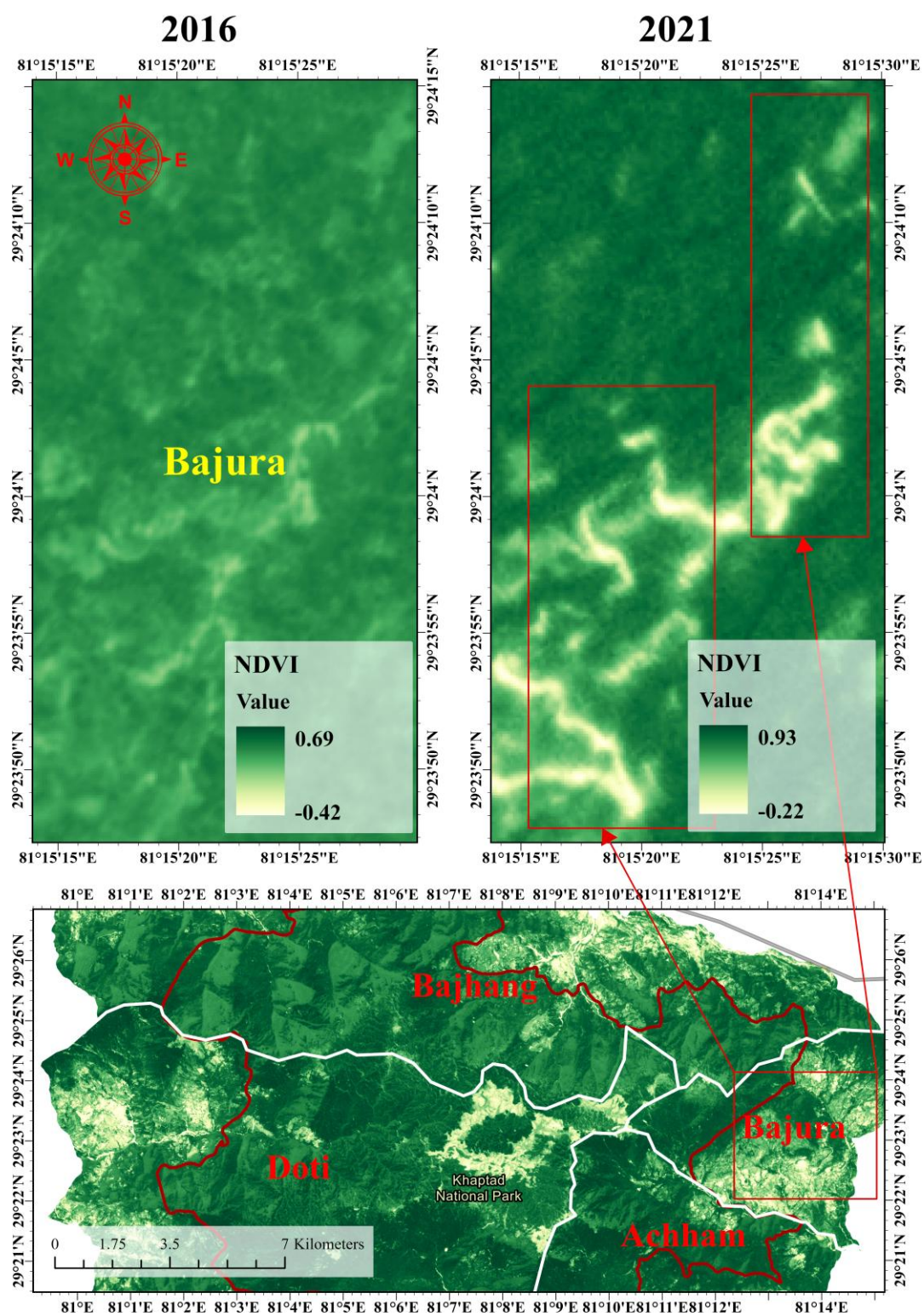


Figure 3.16. Road detection and densification in Bajura (2016–2021) from PlanetScope imagery

PlanetScope-based mapping shows an increase in road density and network continuity across the Bajhang–Bajura corridor from 2016 to 2021. The ENVI workflow made it easier to tell the difference between linear features, and on-screen digitizing in ArcGIS Pro picked up both new switchbacks and paths that seemed to be getting wider. The polyline layer that comes out of this shows network growth in a way that can be overlaid with management zones and then checked in the field.

3.4 Discussion

This Chapter revealed spatiotemporal variations in LULC in SNP and KNP. It highlights the complex interplay between natural and anthropogenic drivers impacting these mountain ecosystems. The contrasting LULC dynamics in SNP and KNP demonstrate the need for integrated approaches to manage mountain tourism and the ecological sustainability of the study sites. The findings from this study highlight the importance of combining historical LULC analysis with CA-ANN-based projections, which provide a forward-looking view of land cover changes under the pressures of tourism and climate shifts. This holistic approach distinguishes this study by addressing both immediate and future landscape dynamics in ecologically sensitive mountain regions, offering actionable insights for policymakers.

3.4.1. Comparative Analysis of Methodology and Results

A comparative analysis of methodologies and results is necessary to justify the selection of the hybrid Random Forest–CA-ANN framework and to demonstrate that it is suitable for complex mountain landscapes such as SNP and KNP. By comparing performance and assumptions against commonly used methodologies (e.g., MLC, SVM, post-classification change detection, and Markov models), the study clarifies why certain methods may produce lower accuracy or higher uncertainty under high spectral variability and strong spatial heterogeneity.

3.4.1.1. Methodological Advantages of Using Random Forest for LULC Analysis.

This Chapter employed a hybrid approach of random forest classification and CA-ANN modelling, yielding an enhanced LULC classification and future projections for both SNP and

KNP. To elucidate the strengths of this methodology, this chapter examines advantages related to various established LULC techniques documented in the literature, including MLC, SVM, post-classification change detection, and Markov chain models. MLC is a popular supervised classification method that performs well in simple landscapes but assumes that the data are normally distributed. Nonetheless, research utilizing MLC in intricate terrains, such as mountainous areas as exemplified in this study, frequently indicates diminished classification accuracies owing to challenges in capturing significant spectral variability and diverse land cover types (Attarchi et al., 2014).

This random forest method used in this chapter got an overall classification accuracy of about 84.5%, which is better than the usual MLC results, which are between 60% and 70% in similar environments (Y. Chen, 2023). This enhancement illustrates the efficacy of the random forest's nonparametric framework in managing intricate landscapes and diverse spectral attributes proficiently. SVM, on the other hand, is another strong machine learning algorithm used for LULC classification. It is known for being very accurate when working with complicated, high-dimensional data. SVM has shown accuracy levels of 75% to 80% in other LULC studies (Balha et al., 2020). In this study, random forest classification surpassed these accuracy levels, primarily due to optimized parameter tuning for high-altitude environments. This demonstrates the advantages of random forests, which necessitate less computational tuning while yielding comparable results with diminished complexity. Post-classification change detection is a common way to find changes. It involves classifying images from different times separately and then comparing the results. Nonetheless, it is susceptible to cumulative classification errors, particularly in intricate landscapes (Peiman, 2021).

Using CA-ANN modeling, this chapter addressed cumulative errors, yielding a more complete picture of how LULC changes over time. This was especially clear when it came to accurately spotting slow changes in land cover, like when bare land increased, and forested areas decreased. Markov chain models are also often used to predict how LULC will change based on transition probabilities from past data. CA-ANN works well for simple time predictions, but do not take into account spatial context and do not accurately show the complex spatial interactions that happen in mountainous areas. In contrast, the CA-ANN method improves the accuracy of predictions by taking into account spatial dependencies and nonlinear relationships. This added spatial complexity is important for making accurate future LULC projections.

For instance, this research predicted that by 2032, there would be a loss of forest in Khaptad's buffer zones and a reduction in snow and glaciers in Sagarmatha. Conventional methods of LULC analysis frequently employ linear integration of socioeconomic and environmental variables, which may neglect intricate interactions between factors like tourism and climate variables. This method takes advantage of CA-ANN's ability to combine these factors in a nonlinear way, which gives a better understanding of how they affect changes in LULC. This integration allowed us to accurately measure how climate change and tourism growth affect forest and glacier areas. This is especially useful for developing long-term management plans for environmentally sensitive areas. Deep learning models such as CNNs have shown promise in high-resolution LULC studies, but they require substantial training data and computing power, which may not always be available in remote or resource-constrained settings (Wang et al., 2023).

3.4.2 Land Use and Land Cover Dynamics in SNP

The changes in LULC in the last section could be bad for the environment and the economy. The changes make it easy to see the differences between the core and buffer zones of each park. SNP is a high-altitude park that is at risk from ecological threats. Its main land use and land cover (LULC) classes are snow/glacier, forest, shrubland, and bare land. The core area, which is mostly covered in snow and glaciers, is an important part of the SNP ecosystem (Bajracharya et al., 2009). But this area has been getting smaller and smaller, mostly because of climate change (Bhatta, et al., 2023). From 1994 to 2023, the study of climate patterns in (SNP) showed that temperatures rose and rainfall fell. Bhattarai et al. (2023) found similar results for the years 1990–2021, which suggests that snow is melting (Leng et al., 2023).

The reduction in snow and forest cover is chiefly attributable to climatic influences, including increasing temperatures and substantial precipitation (Sherpa et al., 2023). The increasing mean annual, maximum, and minimum temperatures in the Everest region, along with less rain, are strongly linked to less net snow accumulation and continue to cause glaciers to melt (Chand and Watanabe, 2019). The number of glacial lakes in the core area has been going up because the air temperature has been going up (Chand and Watanabe, 2019; Khadka et al., 2014a). Also, when glaciers melt, they expose rocks and bare soil, which can help grasses and shrubs grow (Leng et al., 2023). This could be one reason why the SNP has more grasslands now.

The buffer zone is different because it has more farmland and less forest cover (Bajracharya et al., 2009). This pattern shows how population growth, rising demand for agricultural goods, and the growth of tourism-related infrastructure all affect each other (Ghimire and Jha, 2024). Tourists who visit national parks to engage in activities that can cause changes, particularly the LULC change. For example, tourism development can expand built-up areas, which can lead to deforestation and habitat fragmentation (Badal, 2024a). Badal, 2024 showed that an increase in tourism puts more stress on natural resources (Badal, 2024a; Nepal, 2003). This may be one of the main reasons why the buffer zone has less forest cover and more farmland. Many residents in the SNP area have converted their homes into cottages and shops to make room for the growing number of tourists. This has changed the way that built-up areas are growing, which has had an effect on LULC change (Chetri and Gurung, 2004). Families in buffer zone areas have broken up, which has made it necessary to build new homes and hotels and expand farmland. This expansion into forested areas happens because there is not much land in the Himalayas that can be used for farming or building (Bhattarai et al., 2023). Overall, there have been more areas of bare land and grassland in buffer zones, which is in line with what other studies have found (Chetri and Gurung, 2004; Garrard et al., 2016; Ragettli et al., 2018).

This comparison also strengthens the credibility of the findings of this research work by showing that the chosen approach improves classification reliability and spatially explicit prediction, and it helps by positioning the study's contribution within the broader LULC literature while informing methodological choices for future protected-area monitoring and planning.

3.4.3 Land Use and Land Cover Dynamics in KNP

KNP has LULC patterns that are more stable than SNP's, with forest, shrubland, and agriculture being the most common types. The core zone of KNP, which is the most pristine area and has strict protection, has seen an increase in forest area since it first started to decline in 1999. By 2020, it had grown to 252.76 km² (39.90%), probably because of good conservation efforts and natural regrowth. The core zone is losing shrubland and gaining grassland. According to Soliva et al. (2003), this may be because people in the area graze their livestock seasonally. The core zone shows LULC is mostly stable, but small changes need to be looked into more closely. The buffer zone of KNP, on the other hand, lost a lot of forest area (18.43 km² or 2.997%), which was mostly replaced by farmland and shrubland. Population growth and rising agricultural needs are the main

reasons for this (Baral et al., 2012; Bhattarai et al., 2023). The rise in agricultural land indicates that more regions are being transformed for farming to support the expanding population. The growth of grasslands is connected to more cattle grazing because the people who live there depend on livestock for their income and use grasslands as pasture. The growth of farming, especially in the buffer zone, makes people worried about possible land-use pressures that could disrupt the park's ecological balance (Soliva et al., 2003).

The park's buffer zone includes 12.97 km² of land that has been changed from forest to shrubland. There are also some other important changes in the buffer zone. For example, 13.78 km² of forest was turned into farmland, and 15.52 km² of shrubland was turned into farmland. The most common change was from forest to agricultural land, with about 9.09 km² of forest area changed in the buffer zone. The grassland area grew the most between 2010 and 2020, increasing by 10.78 km² at a rate of 1.08 km² per year (Figure 3.4). The rise in water bodies indicates the effects of climate change, possibly due to melting snow, resulting in elevated water coverage in the area (Dixit et al., 2021). Furthermore, community-based questionnaire survey of chapter 4 also supports an increase in temperature. More than 93% respondents reported an increase in temperatures compared to previous years in SNP, while 72.41% respondents reported a decrease in precipitation. However, 94.66% of respondents reported higher temperatures than in previous years in KNP, while 67.22% reported a higher increase in precipitation. These results are based on questionnaire surveys conducted among 145 respondents in SNP and 110 respondents in KNP, as presented in Annexure A5. Population growth and a greater reliance on tourism-related income have led to the expansion of built-up areas, which has led to more construction and development (Badal, 2024b). The number of tourists in KNP is going up because of religious tourism, even though there are fewer tourists in KNP than in SNP (Badal, 2024a). It has become a popular destination for locals since COVID-19 (Bhatta, 2023; Neupane et al., 2023). This has also given people in the buffer zone a chance to make a living by setting up homestays for tourists from other countries (Shrestha et al., 2023). This has also led to more demand for farm goods, since tourists from other countries like local food and organic food, which has led to more farmland. This has led to the encroachment of forests and their transformation into agricultural land (Font and Tribe, 2000; Khanal and Shrestha, 2019). Increasing grassland and water areas in the buffer zone may also be indirectly linked to deforestation associated with land-use change. These factors show that even places where tourism isn't very high can still be affected by changes in the environment.

3.4.4 LULC Future Projections in SNP and KNP

The changes in LULC that are happening all the time in both parks, especially in snow/glacier and forest cover, mean that there is a need to take action to control them. These changes have been connected to human activity and climate change. Projections of LULC based on the CA-ANN method give us an idea of what might happen in the future. The SNP projections suggest a potential rise in barren land within the core zone (Figure 3.13), chiefly attributable to ongoing snow and glacier melt, which transforms snow and glacier regions into desolate terrain (Sarwar and Mahmood, 2024; H. Zhu et al., 2024).

Overall, forest cover is expected to go down (Figure 3.14), and it could be turned into shrubland or farmland because of population growth, tourism pressure, and possible changes in how land is used (Del Pozo et al., 2024). These predicted changes shown in (Figure 3.13) predicts how important it is to protect the park's unique high-altitude ecosystems through sustainable tourism management and strategies for adapting to climate change. The possibility of cascading hazards from glacier melt underscores the necessity of risk mitigation (Biswas and Kumar, 2024; Chand and Watanabe, 2019; Selawaty et al., 2024). The melting of snow and glaciers makes the Himalayas less beautiful, which could reduce the number of visitors to national parks and disrupt the livelihoods of people who live there (Bajracharya et al., 2009; P. Khanal, 2022).

KNP's projected LULC (Figure 3.14) indicates that forest cover in the buffer zone will continue to go down, and it could be replaced by agriculture, shrublands, and grasslands. This projection is in line with current trends and shows how population growth, the rising demand for agricultural land, and the growing impact of domestic and religious tourism are all working together (Bhatta, Neupane, et al., 2023; Font and Tribe, 2000; Khanal and Shrestha, 2019; Shrestha and Balayar, 2023b). The growing number of tourists looking for new places to visit may make these pressures even worse, which could lead to more land being converted for infrastructure development and agricultural expansion (Bhatta, Neupane, et al., 2023; Font and Tribe, 2000; Khanal and Shrestha, 2019; Shrestha and Balayar, 2023b). These forecasts highlight the pressing necessity for mitigation strategies and enhanced tourism management to safeguard vital ecosystems.

3.4.5 Integrated sustainability and management strategies

The changes in land use and land cover (LULC) that were seen in SNP and KNP are the result of many different factors working together, such as tourism, climate change, and traditional land use practices, as shown in Chapter 3 (Figure 3.4, Figure 3.6, Figure 3.10, and Figure 3.11). These results from this chapter show that there is a need for integrated strategies that protect the environment while also improving people's quality of life. Tourism in other mountain areas, like the European Alps, the Andes, and the Himalayas, has also caused big changes in land use and land cover (LULC), which has hurt fragile ecosystems (Huddart et al., 2020; Ives and Messerli, 2003b; Rimal et al., 2019). More hotels, ski resorts, and transportation networks for tourists have broken up habitats and caused biodiversity loss (S. Bhatta, Devkota, et al., 2023). In SNP and KNP, unregulated tourism has worsened deforestation, soil erosion, and vegetation degradation, just like environmental pressures seen in the Andes, where even small amounts of tourism growth can upset fragile ecological balances (S. Bhatta, Neupane, et al., 2023; A. Byers, 2005).

Bhutan is a different case; its controlled tourism model limits the number of visitors and encourages sustainable practices, which reduces the effects of LULC. Bhutan's tourism policy objective is "High Value, Low Volume" and defines the Sustainable Development Fee (SDF) as a tourism levy that contributes to sustainable development initiatives. (Rinzin et al., 2007). Bhutan's approach shows how policy can effectively balance tourism with conservation in sensitive areas. Bhutan's "High Value, Low Volume" model could be modified in SNP and KNP to alleviate detrimental impacts on land cover and biodiversity (Mukherji et al., 2019). In addition, tourism is not the only thing that causes changes in land use and land cover. Other things that can have an effect are deforestation, unsustainable harvesting of forest products, forest fires, and grazing practices (Baral et al., 2012; Bhusal and Awasthi, 2024; Biswas and Kumar, 2024; Selawaty et al., 2024). Climate change makes these problems much worse by melting snow and glaciers at an alarming rate, which could hurt tourism and the beauty of the Himalayas (Selawaty et al., 2024). Moreover, indigenous cultures are evolving as individuals transition from traditional occupations like agriculture and livestock grazing to tourism-related employment (Bhusal and Awasthi, 2024; Pasa, 2021). The recent rise in tourism after the COVID-19 pandemic adds to these existing pressures, which means more resources and infrastructure are needed. This could lead to more habitat loss and damage to ecosystems (Baral et al., 2012).

To find a balance between conservation and socio-economic development in Nepal's national parks, this study used integrated management strategies. Many foreign tourists come to SNP, but not enough come to KNP. So, changing the flow of tourists and making plans can help the people who live in KNP make a better living. It also shows how important it is for national parks to have different policies based on what each park needs. These policies should focus on: (a) putting into place practices that make tourism more sustainable, (b) coming up with good ways to deal with climate change, (c) encouraging park management, local communities, researchers, and policymakers to work together closely, and (d) using advanced geospatial and modeling techniques to look at how climate change, tourism, and land use all affect each other.

3.4.6. Limitation and Future Outlook

There are some challenges with this chapter study; the accuracy of the classification may be affected by the fact that there is not much cloud-free Landsat data available and the resolution of the data. Changes in land use and land cover (LULC) were also affected by the seasons. Additionally, the lack of directly comparable LULC maps from prior studies, notwithstanding the existence of LULC class statistics from Garrard et al. (2016), constrained the direct comparison of the findings. LULC classification outcomes align closely with the findings reported by Bajracharya et al. (2009) and Uddin et al. (2015). The lack of meteorological station data and KNP's local tourist data impedes a comprehensive analysis of the interactions among the various factors affecting LULC change.

Future studies employing high-resolution imagery, ground-truthing, and comprehensive meteorological and tourism datasets would rectify these deficiencies. This research integrates tourism data to contextualize the observed LULC changes, offering an initial quantification of tourism's impact based on the correlation between visitor trends and alterations in built-up and agricultural land. More detailed quantitative analysis, like direct correlation or regression, to fully measure how tourism affects specific LULC categories. Future research utilizing these methodologies may more effectively elucidate the intricate relationships between tourism expansion and land cover changes, thereby facilitating the formulation of specific sustainability initiatives.

3.5 Summary of Chapter

This study examined land use and land cover dynamics in the core and buffer zones of SNP and KNP in Nepal from 1989 to 2021 and from 1991 to 2020, respectively. This study utilized open-access Landsat imagery, tourist statistics, climate data, and CA-ANN modeling for its execution. The findings indicate substantial land use and land cover (LULC) alterations influenced by a complex interaction of natural and anthropogenic factors, notably climate change, population expansion, and tourism development. From 1989 to 2021, the area covered by snow and glaciers in SNP shrank by a lot, by 140.25 km^2 (9.93%). In the same way, forest cover dropped by 15.36 km^2 (1.09%), mostly in the buffer zone, where it lost 13.45 km^2 (0.95%). Along with these losses, the core zone that was exposed by melting snow saw an increase in bare land of 68.84 km^2 (4.87%) and an increase in grasslands of 42.97 km^2 (3.04%). The park also saw a 0.80 km^2 increase in built-up areas, which is a sign of more tourism-related activities and infrastructure development. According to LULC projections for the business-as-usual scenario, snow and glacier cover will continue to decrease by 22.84 km^2 in the core zone by 2032. The forest loss will be 1.16 km^2 in SNP by 2032.

LULC changes in KNP are not as bad as those in SNP, but they are still worrying. From 1991 to 2020, the amount of forest in KNP went down by 19.33 km^2 (3.1%), while the amount of agricultural land went up by 8.09 km^2 (1.3%) and the amount of grassland went up by 14.33 km^2 (2.3%) in the buffer zone. The buffer zone also saw an increase of 1.09 km^2 in the built-up area. If current trends continue, the projected LULC dynamics show that forest cover in KNP could drop by 18.44 km^2 (2.91%) and 5.37 km^2 (0.85%) in the buffer and core zones by 2030. This is mostly because of more farms and people moving into the area.

These quantitative LULC changes show that there are serious environmental problems in both parks and need effective conservation strategies. One way to do this is to change national park policies based on how many tourists visit and what jobs are available. Some of the most important suggestions are to put zoning laws in place to stop the growth of tourism infrastructure, especially in sensitive buffer zones, and to start projects to plant trees and restore forests. To cut down on resource needs, it's important to strengthen community-based conservation efforts, such as getting people involved in managing forests and biodiversity. Also, satellite imaging and remote sensing should be used to keep track of trends in land use and land cover (LULC) and climate data.

Chapter 4. Community Perception, Attitude, and Belief Towards Protected Area System in SNP and KNP

4.1. Introduction

Protected Area's system of Nepal's is a great example of how to conserve the environment and promote development sustainably. It focuses on getting communities involved and having local people take care of the areas. The country is now a world leader in community-based forest management. This shows how conservation efforts can be combined with the need for sustainable resource use and development (Paudyal et al., 2017). These protected areas, which include national parks and conservation areas, are vital for preserving biodiversity, protecting natural resources, and promoting sustainable tourism. While tourism brings significant economic benefits to remote mountain regions, it also presents complex challenges for sustainability. Most local people perceive that PA tourism has addressed their livelihood needs. National parks balance these dynamics by safeguarding unique ecosystems and cultural heritage sites while supporting local and national economic growth through tourism.

Ecotourism and agritourism have emerged as integrated approaches that aim to address these conflicts by promoting sustainability alongside economic growth. Although ecotourism gained global prominence when the United Nations declared 2002 the 'Year of Ecotourism' (Anandaraj and Phil, 2015). However, challenges with the concept emerged in the early to mid-1990s, particularly in developing countries and LDCs, where ecotourism models have often struggled to deliver on conservation promises. Instead, many initiatives have focused disproportionately on tourism development, side-lining ecological sustainability. Wondirad and Ewnetu, 2019 highlighted the governance issues, weak political commitment, operational inefficiencies, and limited community engagement as obstacles to achieving sustainable ecotourism. Similar issues are observed in South Asian countries, including India, Nepal, and Bangladesh, where ecotourism's rapid growth has sometimes prioritized tourism development over ecological sustainability, particularly in areas with Indigenous communities that require tailored conservation strategies.

Mountain tourism, a prominent sector in Nepal, capitalizes on the country's scenic landscapes and unique cultural offerings. While this form of tourism contributes approximately 7% to Nepal's

GDP and significantly boosts foreign exchange (Regmi et al., 2023), but it is also associated with environmental costs. Nepal et al. (2019) noted a unidirectional causality between tourist arrivals and emissions, underscoring a need for robust management frameworks and data-driven thresholds to balance growth and sustainability (MacLellan et al., 2009). Furthermore, population growth, poverty, environmental degradation, and politics complicate Nepal's tourism landscape, often increasing marginalization as mountain communities integrate with lowland economies, leaving them vulnerable and economically disadvantaged.

The success of conservation initiatives in national parks ultimately depends on supporting and engaging local communities living within or near these protected areas. Community perceptions, attitudes, and beliefs are central to conservation outcomes, as local people are often most directly affected by tourism and environmental policies. Conservation initiatives may face resistance without their support, potentially undermining park objectives.

This chapter explores the intricate interplay among agriculture, tourism, and forests in SNP and KNP, focusing on their interdependence and impacts on forest cover, and compares two parks in Nepal's Protected Area (PA) system, each with unique tourism intensity, geographical characteristics, and community dynamics. By examining these drivers, the research seeks to clarify the pressures and opportunities associated with tourism-driven development within sensitive mountain ecosystems. This chapter analyses the relationships among tourism, agriculture, and perceived changes in forests in SNP and KNP, and it provides the evidence that makes the Integrated Land-Use and Community Adaptation Framework (ILCAF) decisions. As tourism grows, it frequently competes directly with agriculture for limited land and labor resources, resulting in conflicts over resource allocation (Ghadami et al., 2022; Sutawa, 2012; Torres & Momsen, 2004). Moreover, the close linkages between tourism, agriculture, and forests underscore an urgent need for sustainable planning. Without such measures, forest land is often pressured to be converted into agricultural land or used for tourism. To address these pressing issues, integrated concepts like ecotourism and agritourism were introduced to enhance sustainability and resource management.

This study seeks to fill this gap by investigating community perceptions, attitudes, and beliefs regarding the development of SNP and KNP. This research provides valuable insights into how local communities perceive the conservation, tourism, and development activities of these national parks, based on surveys and interviews. These findings will provide a foundation for developing a

framework that aligns with park management and local people's needs to protect mountain landscapes.

4.2 Rationale of the study

The rationale for choosing the study sites from the Protected Area of Nepal, the SNP from the north-eastern region, and the KNP from the far western region for this study stems from the distinct types of tourism they attract from the various other countries, which offer unique visions into the interactions between tourism, conservation, and community perspectives. While SNP attracts high levels of nature-based tourism due to its pristine landscapes and called a UNESCO World Heritage site, KNP primarily attracts religious tourists because of its spiritual environment. This contrast allows for a comparative analysis of community attitudes toward tourism and conservation under different environmental, seasonal, and cultural contexts.

The study includes the George and Bennett's (2005) comparative case study approach, compatible with complex analyses with "too many variables, too few cases." Using the Sustainable Tourism Attitude Scale (SUS-TAS) (Choi and Sirakaya, 2005; Jeelani et al., 2023b) as a theoretical framework, the study assesses local perceptions of sustainable tourism in these regions. This approach highlights the impact of tourism on local communities, considering factors like economic benefits, sectoral integration, and the role of coherent policies in promoting sustainable development.

4.3 Research Objectives

Local people of the national park solely depend on forests for subsistence, and this dependency is expected to increase in the future. This study aims to analyze the complex interactions between human activities, forest cover change, and various other influencing factors. By combining survey data with satellite imagery, the research examines the relationships among agriculture, tourism, and environmental factors like climate change, focusing on forest loss and its conversion to built-up areas and agricultural land. The analysis underscores the theoretical linkages among these sectors, emphasizing their interdependencies and mutual influences.

Using a comparative case study approach, the study examines the dynamics within SNP and KNP, assessing the key parameters that impact forest cover change, including tourism and other contributing factors. It identifies the critical challenges arise from these interactions and proposes

theoretical frameworks specifically, the nexus approach and community-based forest management to address them. These frameworks aim to achieve the comprehensive recommendations to mitigate the negative impacts and enhance the sustainability of these intertwined sectors.

4.4 Methods

4.4.1 Study Design

This chapter uses a comparative case-study design centered on Sagarmatha National Park (SNP) and Khaptad National Park (KNP) to examine how tourism intensity and socio-ecological context shape community perceptions of forest change. Figure 4.1 shows the overall methodology of the chapter. The household is the unit of analysis, with settlements sampled in both core and buffer zones, so responses are comparable within and across parks.

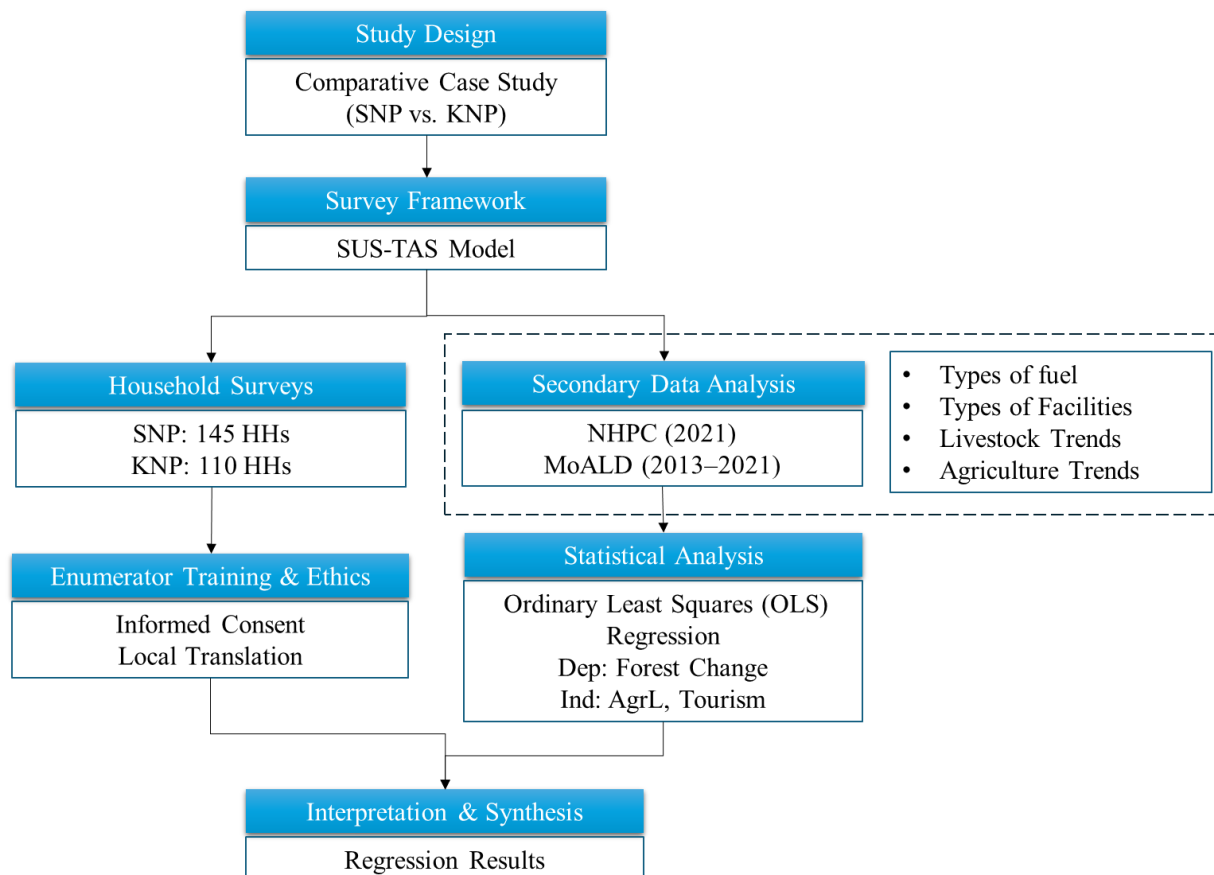


Figure 4.1: Flowchart of the methodology used for the analysis of the community survey.

4.4.2 Secondary Data Sources and Analysis

To situate household perceptions in measurable local pressures, secondary statistics were compiled prior to survey analysis. Population and energy-use figures came from the National Population and Housing Census (2021); agriculture and livestock series for 2013–2021 were drawn from the Ministry of Agriculture and Livestock Development; tourism-facility information for SNP followed the park-level audit reported by Sun and Watanabe (2021). District names and boundaries were reconciled to a common reference, units were standardized across sources, and category definitions were aligned across years. For communication and traceability, these data are presented as consolidated summary tables and time-series figures in this chapter, with explicit notes beneath any paired plots stating “Y-axis scales differ” when applicable.

4.4.3 Field Data Collection

4.4.3.1 Survey framework and instrument design (SUS-TAS)

This study employed the SUS-TAS model to explore local community perceptions through a primary survey conducted in SNP and KNP. The data collection and analysis framework was based on the SUS-TAS model developed by Choi and Sirakaya (2005). This model has been applied in several contexts, particularly in mountainous areas (Jeelani et al., 2023b; Obradović et al., 2021; Yu et al., 2011). The survey covered multiple dimensions of community life within the national parks. It aimed to assess perspectives on sustainable tourism development and its effects on forest cover, forest dependencies, and general tourist satisfaction.

4.4.3.2 Field implementation procedures

Localization procedures involved forward translation into Nepali and independent back-translation into English to ensure semantic equivalence; ensuring clear communication with respondents, and a small pilot test ($n=20-30$) validated clarity and timing prior to full deployment. The Cronbach's alpha was used for each subscale to check for reliability ($\alpha \geq 0.70$), and the KMO index (≥ 0.60) and Bartlett's test to check for construct adequacy before doing factor analysis. The results are provided with the survey diagnostics. Following standard SUS-TAS procedures, subscale scores were calculated as the average of their individual items, and an overall attitude

guide was determined as the average of the subscale means, with higher values indicating more favorable perspectives on sustainable tourism. The study examined the effects of tourism on forests and community satisfaction within parks. It asked questions about farming and ranching to find out how they affect forest cover and how tourism affects land use and forest resources. The research uses Ordinary Least Squares (OLS) and binary question formats to explain resident attitudes regarding tourism development and its environmental impacts. Statistical models utilized composite SUS-TAS indices and essential covariates (e.g., forest dependence, household tourism engagement) to forecast perceived forest change. Similar methodologies have been used to evaluate community perceptions of tourism in different locations. (Brouder and Lundmark, 2011; Parbat et al., 2020; Polyzos and Minetos, 2011).

The study used stratified random sampling by settlement and zone to ensure we talked with the people from different communities with exposure to tourism exposure. We talked to 145 households in SNP and 110 in KNP. The trained Enumerators conducted face-to-face interviews. In addition to SUS-TAS, modules recorded forest dependence (fuelwood/fodder collection and frequency), household tourism involvement (lodge/homestay/guide/porter), alterations in agricultural practices and productivity, livestock ownership, and a singular ordered item regarding perceived forest-cover change over approximately two decades.

4.4.3.3 Statistical analysis and coding for regression

The research used Ordinary Least Squares (OLS) regression to find out how statistically significant community perceptions were. Although OLS is commonly utilized, we recognize the limitations encountered when it is applied to survey items assessed on ordinal scales. The analysis was based on previous perception studies by measuring the effect of certain factors. The covariates were selected in advance because they were important to the research questions. Interpretation integrated the regression results with insights from subsequent field visits, which offered qualitative context and enhanced inference (Magadán-Díaz and Rivas-García, 2022).

4.4.3.4 Coding and construction of analytical variables

The dependent variable is the household-level, well-organized numerical assessment of perceived alterations in forest cover change. To ensure consistency, categorical survey responses were converted into numerical codes prior to analysis (Annexure A5). For each survey question,

the original text responses (e.g., Increased/Decreased, Yes/No, satisfaction levels) were transformed into coded numeric variables stored in the dataset as the corresponding `bi_ / bi_` columns. The coding scheme was designed to preserve direction and ordering, such that:

- **positive values** represent an increase or more favorable condition,
- **negative values** represent a decrease or less favorable condition, and
- **zero** represents a neutral/baseline response (where applicable).

Specifically, perceived forest-cover change was coded as Increase = +1, No change = 0, and Decrease = -1, where negative values therefore indicate perceived forest loss (Table 4.1). Agricultural productivity change was coded using the same three-level structure: Increased = +1, No change = 0, and Decreased = -1. Binary responses—including household tourism engagement, forest dependence, and livestock dependence—were coded as Yes = 1 and No = 0.

Associations between perceived forest change and hypothesized drivers were estimated using the following OLS model. (Kazungu et al., 2021). The mathematical equation for OLS regression is expressed as follows:

$$Y_i = \beta_0 + \beta_1 X_{agri,i} + \beta_2 X_{tour,i} + \beta_3 X_{dep,i} + \beta_4 X_{liv,i} + \varepsilon_i \quad (\text{eq 4.1})$$

where Y_i denotes household i 's perceived forest-cover change over approximately two decades such that negative values indicate a perceived decrease in forest-cover (forest loss). β_0 is the intercept, representing the expected value of Y_i when all predictors are 0 (baseline condition). $X_{agri,i}$ captures perceived change in agricultural productivity and was coded ordinally, with values indicating perceived improvement or decline. $X_{tour,i}$ captures household tourism engagement (Yes/No), indicating whether the respondent reported tourism impacts at the household level. $X_{dep,i}$ measures forest dependence (Yes/ No), indicating whether the household depends on forest resources. $X_{liv,i}$ reflects livestock dependence (Yes/ No), indicating whether livestock is part of the household system. ε_i is the error term capturing unobserved influences on perceived forest change.

Table 4.1 summarizes the dependent and independent variables and numerical coding used in the regression models (SNP and KNP). Models report coefficient estimates, 95% confidence intervals, two-sided p-values at $\alpha = 0.05$, and R^2 . Diagnostics checks included multicollinearity assessment ($VIF < 5$), residual inspection, and heteroskedasticity; robust standard errors were applied where indicated. Overall, this coding approach improves transparency and reproducibility

by explicitly documenting the mapping between original survey responses and the numerical variables used in quantitative analysis (Table 4.1; Annexure A5).

Table 4.1. Dependent and independent variables and numerical coding used in the regression models (SNP and KNP)

Symbol	Variable (type)	Definition (What it represents)	Response options (questionnaire)	Numerical coding used in analysis
Y_i	Perceived forest-cover change (Dependent variable)	Household (i)'s perceived change in forest cover over ~20 years	Increase / No change / Decrease	Increase = +1 ; No change = 0 ; Decrease = -1 (<i>negative = perceived forest loss</i>)
$X_{agri,i}$	Agricultural productivity change (Independent)	Household (i)'s perceived change in agricultural productivity	Increased / No change / Decreased	Increased = +1 ; No change = 0 ; Decreased = -1
$X_{tour,i}$	Household tourism engagement (Independent)	Whether the household participates in tourism-related livelihood activities (e.g., lodge/homestay/guide/porter)	Yes / No	Yes = 1 ; No = 0
$X_{dep,i}$	Forest dependence (Independent)	Household reliance on forest resources (fuelwood and/or fodder collection)	Yes / No	Yes = 1 ; No = 0
$X_{liv,i}$	Livestock dependence (Independent)	Whether livestock is an important livelihood component for the household	Yes / No	Yes = 1 ; No = 0

4.4.4 Ethics and Data Quality Control

Before starting the interview, the study aims to inform that the nature of participation were explained, and verbal informed consent was obtained. Respondents could skip any question or withdraw at any time. Identifiers were not engaged in the analytical file. Daily field checks ensured generality and internal consistency; supervisor callbacks verified a subset of records. During entry and cleaning, automated range and logic checks were applied; missingness was minimal and handled by listwise deletion in the regression models, with effective sample sizes reported.

4.5 Results

The survey results gave us useful information about how people in the area feel about tourism and other agricultural sectors, such as livestock and other ways to make a living, as well as how they affect forests. The study collected important information by working with communities in SNP and KNP. This information will help suggest a way to manage these areas in other protected areas. While talking to the female respondent a special care was taken in the study because they are very important to manage the tourism in Nepal, where they help to keep and run tourism facilities (B. P. Acharya and Halpenny, 2013).

4.5.1 Secondary Data Analysis

4.5.1.1 Types of Fuels Used by Households in SNP and KNP Regions

The SNPs are under a lot of stress for forest resources because of the large number of tourists, guides, and porters who visit there. Many lodges and hotels heavily rely on firewood for fuel, which has raised sustainability concerns. A study by Nepal (2003) indicated that fuelwood consumption tripled in the country from 1976 to 1988, and the current tourism dynamics exacerbate this trend. The number of visitors often exceeds the local population by 10 to 12 times, leading to an increased demand for energy that surpasses local needs. Despite the environmental implications, many lodges continue to use the firewood for cooking and heating due to its low cost and availability (Sun & Watanabe, 2021). Moreover, the rapid construction of lodges, hotels, and tea houses within the parks has further heightened the demand for timber, with over 450 lodges now operating in the SNP (S. Bhatta, Devkota, et al., 2023).

Table 4.2: Number of households by types of fuel used for cooking in the SNP and KNP regions. (Source: NHPC, 2021)

Area	Types of fuels							
	Total	Wood/Firewood	LPG	Electricity	Cow Dung	Biogas	Kerosene	Other
Solukhumbu	26,239	21,785	3,945	400	1	56	51	1
Bajura	28,041	25,751	2,000	18	0	241	18	13
Bajhang	38,025	35,321	2,553	20	0	102	23	6
Doti	45,140	40,584	4,313	30	2	126	44	41
Achham	49,567	46,350	2,928	34	1	140	76	38

Table 4.2 shows the kinds of household fuels used in the SNP Solukhumbu District and the four districts that are part of KNP (Bajura, Bajhang, Doti, and Achham). The data comes from the 2021 National Household and Population Census. The data show that firewood is still the main fuel source for people living in the Solukhumbu District in the SNP. Some homes (3,945) use LPG (Liquid Petroleum Gas) as cooking fuel to save time and effort and to serve a lot of tourists during the busy season. However, firewood is still the main energy source for local hotels and lodges because it is cheap. Many people who live nearby collect the firwood from the forest and sell firewood at local markets to make a living. This puts even more pressure on forests outside the park.

Because tourism doesn't bring in much money, most families in KNP depend on firewood. Achham has the most people who depend on this, followed by Doti, Bajhang, and Bajura (Table 4.2). This dependence is made worse by the fact that people can't easily get other fuels and the economy is bad. Some families in the terai region have switched to LPG, but firewood is still the most common fuel. Deforestation is still on the rise, even though efforts are being made to protect the environment. This is mostly because of tourism and the need for fuel. In places like KNP, the need for firewood and the lack of other economic options put a constant strain on the forest ecosystem. This shows how important it is to have better conservation policies that balance local energy needs with sustainable resource use.

4.5.1.2 Types of Tourism Facilities in SNP and KNP Regions

Tourism facilities in SNP and KNP vary significantly in their type and scale, which provide essential support for visitors and contributing to local economies. Sun and Watanabe (2021) in SNP categorized tourism facilities into four primary types: lodges, shops, teashops, and porterhouses (Table. 4.3).

Table 4.3. Distribution and Expansion Intentions of Tourism Facilities in SNP (by Category, Number, and Sufficiency Perception)

Category	District	Number	Sufficient*	Insufficient*	More sufficient*	Remarks
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Lodge	Solukhumbu	318	198 (62.3%)	63 (19.8%)	57 (17.9%)	Expansion intent concentrated in Lukla (buffer) and Namche (core); timber limits raise construction costs (Funk et al., 2014).
Shop	Solukhumbu	101	—	—	—	No expansion data reported; high share are rented premises (core: 92.3%) (Funk et al., 2014).
Teashop	Solukhumbu	64	—	—	—	No expansion data reported; many rented (core: 60.7%)(Sun and Watanabe, 2021).
Porterhouse	Solukhumbu	53	—	—	—	No expansion data reported; most rented (core: 85.7%)(Sun and Watanabe, 2021).
Total		536	—	—	—	Tally across all surveyed facilities(Sun and Watanabe, 2021).

Lodges offer accommodation and day-night meals for tourists, shops sell a range of goods, teashops provide drinks and food to both tourists and locals (such as cafés and restaurants), and porterhouses supply specifically to porters and trekking guides. Based on their data, this study reveals that out of 536 tourism-related facilities surveyed in SNP, 43.5% are located in the buffer zone, while 56.5% are in the core zone, with most facilities situated at elevations between 2,600 and 3,000 meters. Lodges are particularly prevalent, with 318 surveyed, of which 57.2% are located in the core zone. A notable 19.8% of the lodges surveyed expressed plans for expansion, which may increase timber demand. Figure 4.2 shows the types of facilities in SNP.

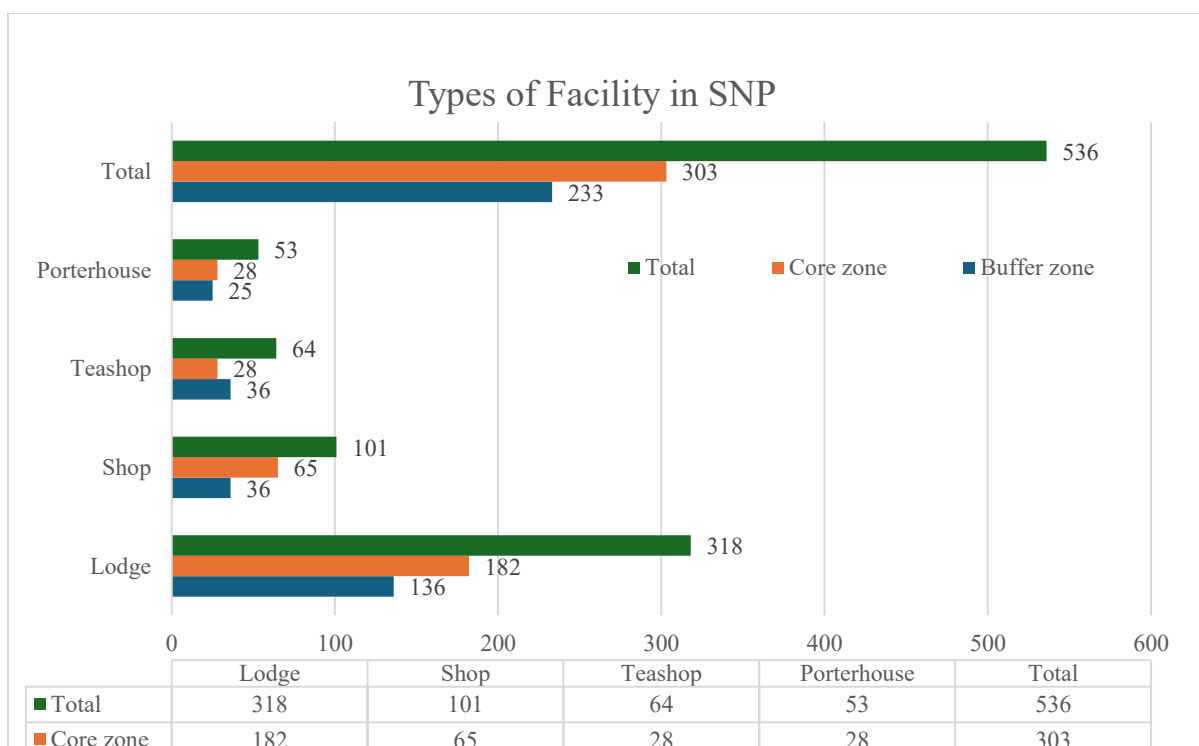


Figure 4.2: Types of Facility in SNP

In contrast, tourism infrastructure in KNP remains limited but essential, supporting the region's small but growing number of visitors. A field survey identified around 25 accommodations in KNP, with half located in the Doti district and the remainder spread across Bajhang, Bajura, and Achham (Table 4.4). These facilities, primarily family-run lodges and homestays, provide basic lodging and meals, and approximately 70% operate directly out of the owner's home. Some hoteliers, however, operate in rented spaces, especially during peak periods like the Ganga Dashahara festival, when visitor numbers surge.

Table 4.4: Surveyed facilities in KNP (n = 25). (Source: Field Survey)

District	Number	Sufficient	Insufficient	More sufficient	Remarks
Doti	10 (40%)	2 (10%)	8 (30%)	-	
Bajura	7 (25%)	-	7 (25%)	-	Increasing the facility and capacity
Achham	5 (20%)	-	5 (10%)	-	
Bajhang	3 (12%)	-	3 (15%)	-	

Total	25 (100%)	2 (10%)	23 (90%)	-
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These modest facilities, though less visible online and challenging for foreign tourists to locate without local assistance, play a critical role in supporting both tourism and local livelihoods. The majority of hotels in KNP were established after 1994, driven by increased interest in KNP's religious tourism opportunities. The hoteliers, while eager to expand their services, highlight the need for improved infrastructure, particularly road access, to support sustainable tourism growth. The average tourist expenditure in the KNP area is around NPR 500-700 per person per day, underscoring the affordability and simplicity of the available amenities.

4.5.1.3 Livestock Trends in SNP and KNP Regions

In the Khumbu area, livestock has been a vital component of local people who live there, with some families entirely reliant on it (Brower, 1988). The most common livestock which include yaks, naks, and hybrids like zopkio (male yak-cow cross) and dzomo (female yak-cow cross). Livestock aids three essential functions: transportation (for carrying loads), dairy products (milk, cheese, and butter), and manure (dung provides the primary compost for agriculture). Fourth, an increasingly important function is fuel. Sherpas dry cattle dung in the sun to use as “dung cakes” for fires.

In SNP, livestock ownership is more modest, with households typically keeping 1 to 5 animals, predominantly cows and goats. A few households' rear yaks, chauri, or sheep, adapting their practices to the high-altitude environment. Livelihoods in SNP are closely tied to agriculture and livestock, yet households with more diversified income sources, often linked to tourism, tend to have higher earnings. The number of pack animals in Solu Khumbu has been gradually increasing since 2013 (Figure 4.3). This is mainly because livestock raising, especially yaks and their hybrids, is important for moving goods and LPG (Sun and Watanabe, 2021). Yaks generate almost twice as much income as a human porter, making them a valuable part of tourism income (Y. D. Sherpa and Kayastha, 2009). Because of ongoing anthropogenic warming, the Himalayas' environmental baselines are changing rapidly. The rapid loss of glaciers and changes in snow cover are affecting the timing and amount of meltwater, which has effects on irrigation, rangeland phenology, biodiversity, and health (A. Tiwari and Dhakal, 2023). Impacts are often strengthened at elevated altitudes owing to ecosystem sensitivity (Khadka et al., 2014b). For herders, this means less food

and water available at certain times of the year, more pressure from heat and cold, changing disease patterns, and more life-threatening weather events. These things might lower milk production and reproduction and raise the death rates. To deal with this, households change the makeup of their herds, change the timing of their transhumance, invest in managing fodder and water, and find new ways to make money.

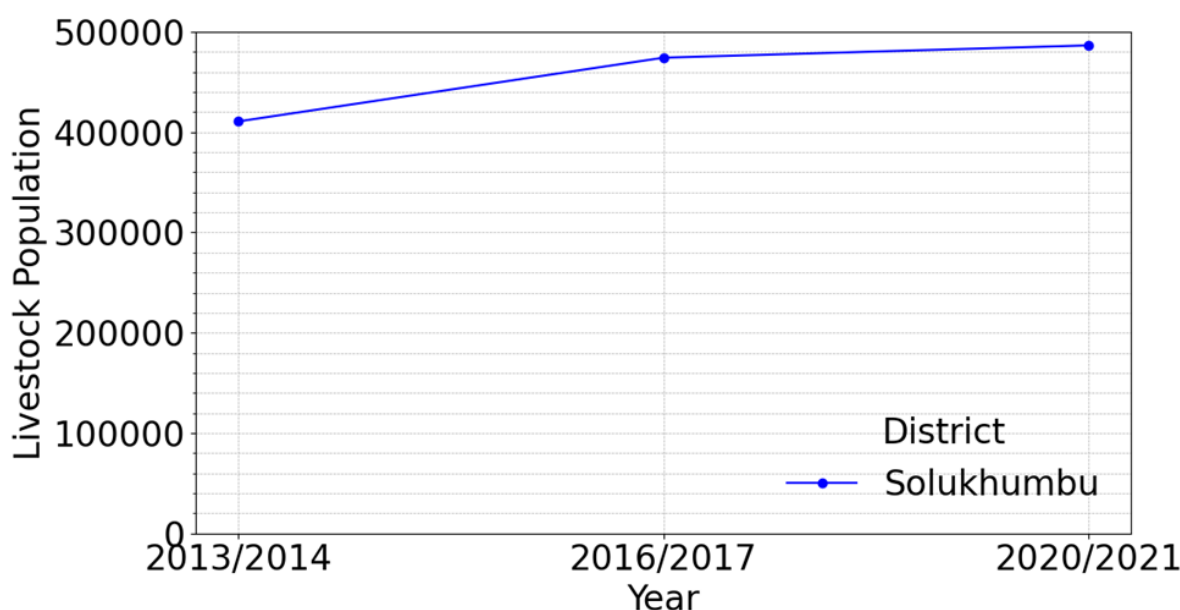


Figure 4.3: Livestock Population Trends in Areas Surrounding SNP from 2013-2021 (Data source: Ministry of Agriculture and Livestock Development: Department of Livestock Services).

Figure 4.4, on the other hand, provides data from the Ministry of Agriculture and Livestock Development, Department of Livestock Services, on the numbers of livestock in the KNP districts from 2013 to 2021. Figure 4.4 shows the trends in livestock. There is a clear difference in the trends across the district from FY 2013/14 to 2020/21. This is true for all four districts around Khaptad National Park. The total number of livestock in Bajhang went up from about 280,000 in 2013/14 to about 360,000 in 2016/17, then declined to about 320,000 in 2020/2, which is a net gain of about 40,000 head (14%). Bajura remained unchanged about 240,000 through 2016/17. By 2020/21, it had risen to about 260,000, which is an increase of about 20,000 head (8%). Achham has been steadily losing people, going from about 380,000 to about 320,000 to about 290,000, which is a net loss of about 90,000 people (24%). Doti has the highest livestock every year. The number of animals goes up from 420,000 to 450,000, then declines to 410,000 by 2020/21, which is a slight net decrease of about 10,000 head (2%) after a peak in the middle of the period. The number of animals in Bajura is going up, but it is decreasing in Achham and Doti. While the

livestock population is rising in Bajura, it is declining in Achham and Doti, possibly due to livestock depredation (Bashyal et al., 2022) and because of climate change (N. Paudyal et al., 2013).

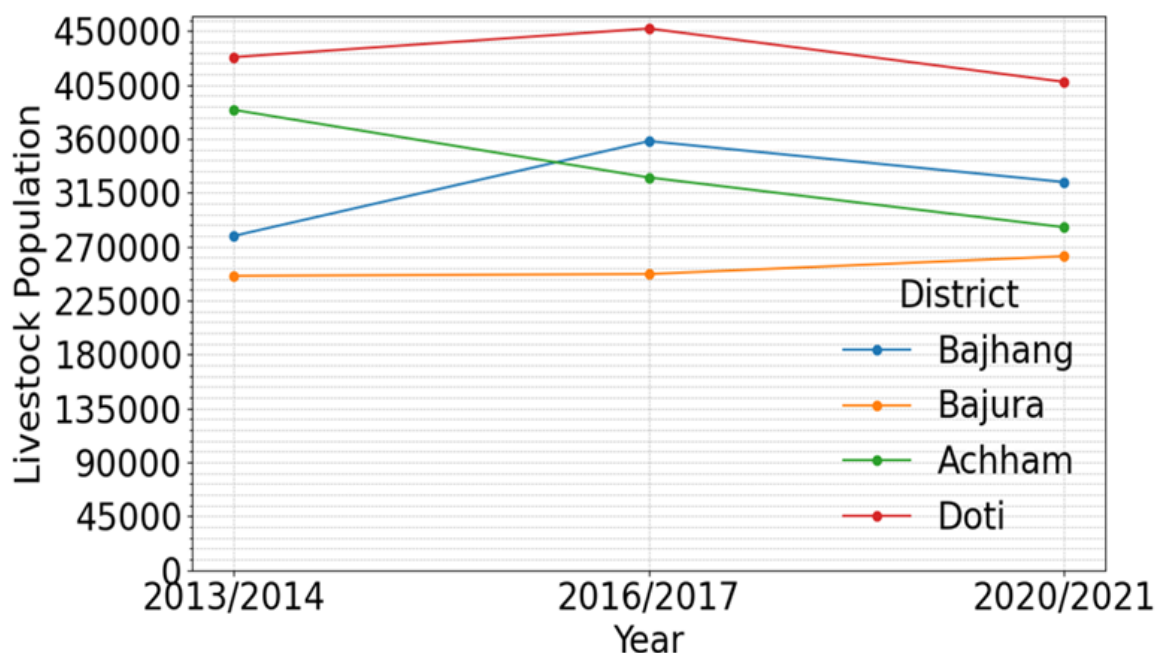


Figure 4.4 District-wise Livestock Population Trends in Areas Surrounding KNP from 2013-2021 (Data source: Ministry of Agriculture and Livestock Development: Department of Livestock Services).

In Bajhang, the rise has softened, and there is a net increase. The big jump to 2016/17, followed by a small correction, fits with a period of herd reconstruction and better market access (roads/market integration), followed by re-balancing as households make the most of their feed and labor constraints. Growing goat farming for meat markets (high festival demand) can increase head counts, even if the number of large ruminants remains the same or declines (Paudyal et al., 2013). Farmers have been reducing the number of larger ruminants, like cattle and buffalo, and are now more interested in smaller animals, like sheep and goats (Paudyal et al., 2013). Also, grazing for livestock can cause vegetation loss, soil compaction, and erosion, which can change LULC.

4.5.1.4 Agriculture Area and Yield Trends in SNP and KNP

Farming in the Khumbu is very different at different altitudes. In the lower valleys (about 2,600–3,200 m), families grow maize, paddy (in areas with irrigable terraces), wheat, and vegetables for their own use and for the lodges. At mid–high elevations (>3,200 m), the system

changes to rotations of potatoes with buckwheat, barley, and millet. That maize and millet take up the most space overall, while paddy and barley take up very little space. This is because there isn't much land that can be irrigated and the seasons are short. The middle bar is mostly made up of one very large millet area spike from 2016/17. Other than that, one outlier, the totals for 2013/14 and 2020/21 are similar, with maize being the main area holder and small shares of buckwheat and wheat. Paddy has gone up a lot (40–50% from 2013/14 to 2020/21), which means that water control, inputs, or varietal choice have improved in the few places where paddy can still be grown. Across crops, maize shows a mid-period dip in 2016/17 but rebounds by 2020/21 for a net gain of roughly 5–10%, a pattern typical of weather-sensitive rain-fed systems; millet increases gradually over the period (~5–10% net); buckwheat falls in 2016/17 but returns to about its initial level by 2020/21 (no net change); wheat posts the strongest improvement, rising from a low base by ~50–70%, likely reflecting small sown area but better seed/fertilizer access where it is grown; and barley declines in 2016/17 and only partially recovers by 2020/21, leaving a net negative trend consistent with its marginalization in some villages. Many families rely on subsistence farming, such as growing potatoes and buckwheat (Silwal et al., 2022). Changes in crop area and yield reflect larger LULC trends, such as more cropland near settlements and along trekking routes, small expansions of vegetable plots, and the conversion of some marginal terraces to build structures like lodges and trailside services. When households get into tourism, they often keep smaller but more valuable plots of land (for potatoes and vegetables) and cut back on labor-intensive cereals on marginal terraces. This is in line with small net area changes and better yields for key staples in 2020/21. Even though the amount of cropland stays the same or only grows a little, yields for some staples are expected to go up by 2020/21. Vegetables and potatoes will still be the main sources of food security and supply for households. These patterns fit with the idea that villages are getting more and more crowded, that tourism is bringing in more business, and that farming is getting better, all of which are happening in the context of short seasons, limited irrigable land, and a changing mountain climate.

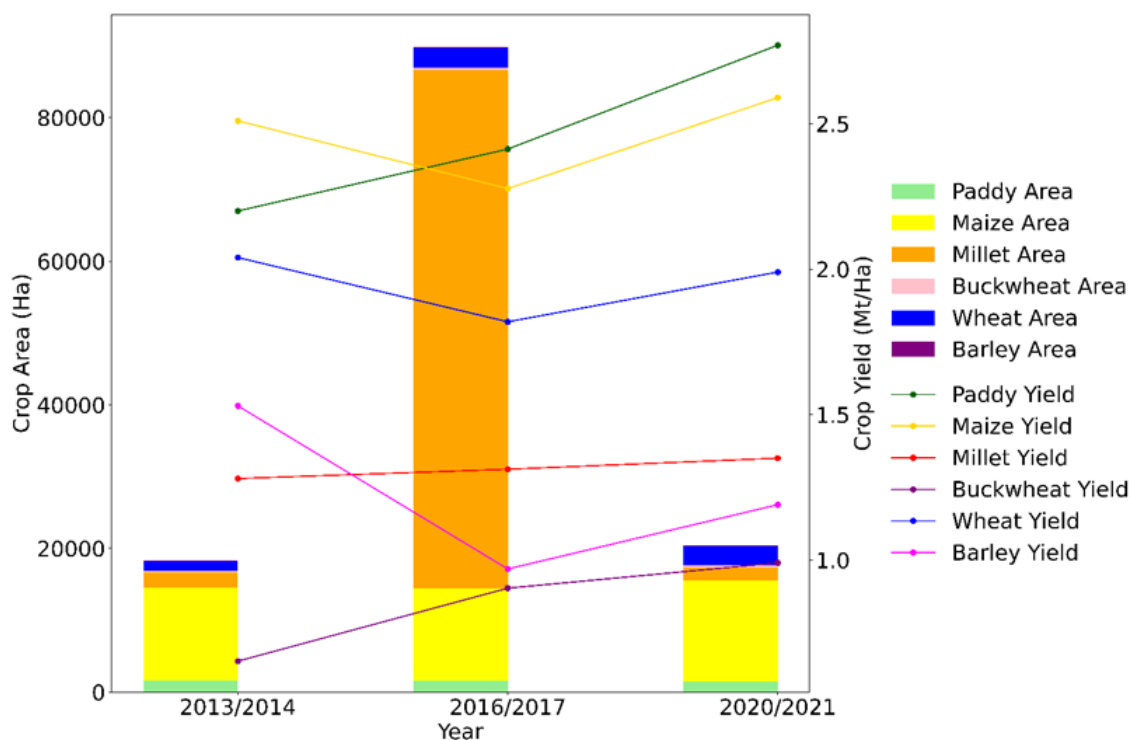


Figure 4.5: Trends of crop area and yield in districts surrounding SNP (2013-2021) (Data source: Ministry of Agriculture and Livestock Development: Planning and Development Cooperation Coordination Division).

Figure 4.6 shows the crop area and yield data from 2013 to 2021 for the districts around KNP. The Ministry of Agriculture and Livestock Development gathered this information. For most people in the area, subsistence farming is their main source of income. Terraced fields are often used to grow crops like maize, wheat, millet, and barley. The stacked bars on the left show the area of land used for each crop, and the lines on the right show the yield. There are three main patterns that stand out. First, the amount of paddy land grows quickly between 2013/14 and 2016/17, which means that rice is grown on a much larger share of the valley-floor and irrigable terraces in the four districts. The area for wheat also grows in 2020/21, but the areas for maize, millet, buckwheat, and barley stay about the same (with small increases for maize and millet). Third, yields vary by crop: paddy yield is highest in 2013/14, drops by 2016/17, and then levels off around 2020/21; maize and millet yield trend upward over the period; buckwheat dips in the middle of the period and then recovers; and wheat and barley rise from lower baselines. There is a perfect relationship between rice yield and rainfall, but maize and wheat had trends that changed or stayed the same as rainfall changed (Bhandari, 2013b). Changes in cultivated areas and yield trends were also shown.

Yield data shows that the region's rough terrain and lack of irrigation infrastructure make it hard to grow crops.

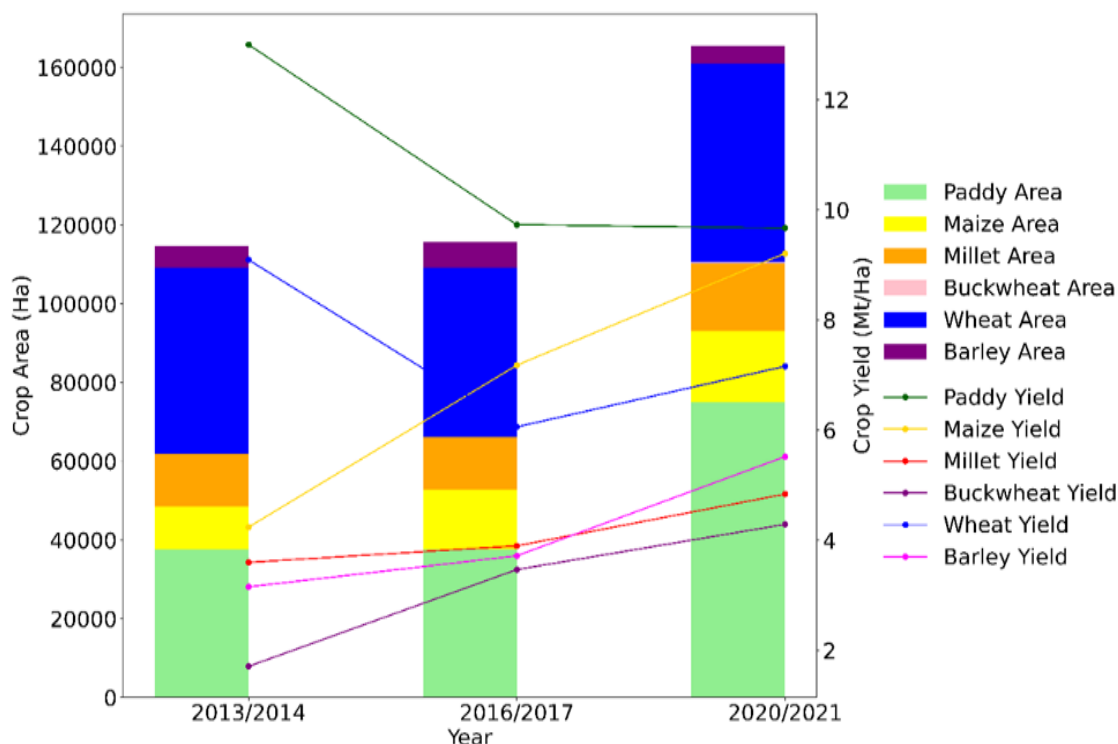


Figure 4.6: Trends of crop area and yield in districts surrounding KNP (2013-2021) (Data source: Ministry of Agriculture and Livestock Development: Planning and Development Cooperation Coordination Division).

The area for growing paddy has grown a lot from 2016/2017 to 2020/2021, but production has gone down from about 12 mt to 10 mt from 2013 to 2020. By 2020/21, the paddy area had grown a lot. This is probably due to a combination of things, such as the repair of small surface-irrigation schemes and canals ("kulo"), more reliable monsoon windows in some years, and the demand for rice in district towns. The rise in wheat area is in line with better access to seed and fertilizer, and the fact that a cool-season crop that follows paddy in irrigated blocks is appealing. The relatively stable areas for maize, millet, buckwheat, and barley, on the other hand, show that upland and rain-fed terraces were still limited by water and labor, even though productivity did improve slightly. Even though the area used for farming didn't change much, all districts saw an increase in the production of maize, millet, buckwheat, and barley.

Changes in temperature and precipitation are two of the most important things that affect how much crops yield. Bhandari (2013a) observed the influence of temperature and precipitation in the Doti. Also, as the population grows, more land is needed for farming, which can change LULC

and cause deforestation. Because there is not as much rain in the winter and the monsoon season is short, the way crops are grown has changed. Drought has hurt the people who live there by making it harder for animals to find water and for farmers to irrigate their crops. The slash-and-burn method is thought to make farming areas bigger, but it can also cause deforestation and soil erosion, which changes the landscape.

4.5.2 Household Survey Analysis (Primary Data)

4.5.2.1 Sociodemographic Characteristics of Respondents in SNP

A primary survey was conducted to capture local perceptions of tourism, examining community views, tourism’s impact on forest cover, and satisfaction with tourism development in national parks.

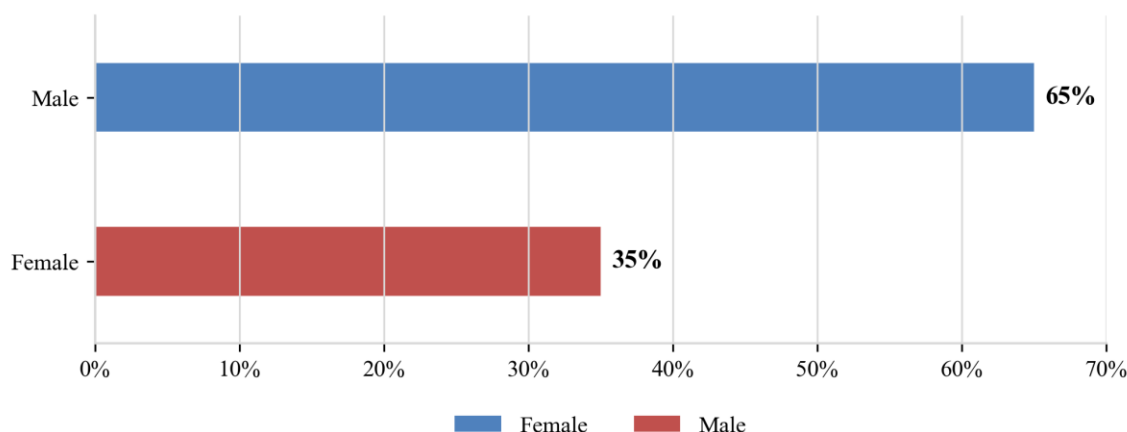


Figure 4.7: Gender of the respondent in SNP

We interviewed 145 households across the Sagarmatha/Khumbu buffer area. Based on the survey table, the settlement distribution is: Lukla (26%, n=38 HHs), Namche (18%, n=26), Ghat (13%, n=19), Khumjung (11%, n=16), and other villages (each <10 respondents), 31% (=45). Additional villages in the Sagarmatha area of the Solukhumbu district were also surveyed, though the number of respondents was fewer than 10 in each. As shown in Figure 4.7, the gender distribution among respondents was 65% men (n=95) and 35% women (n=51). The majority of respondents were aged 27–40, comprising 31.9% of the sample.

Most respondents were engaged in agriculture and livestock (48%), as shown in Table 4.5. Nearly two-thirds report livestock as part of their livelihood when accounting for “Agriculture and

Livestock” 48%, “Livestock” 9% and “Forest + Agriculture + Livestock” 6%—a combined 63%. Additional livelihood categories include agricultural products (19%) and forest products (4%), with some overlap in mixed categories. At the enterprise level, the hotel/lodge ownership is most common (37%), followed by homestay/tea shop/restaurant (18%), trekking guides (11%), and selling agricultural products + tea shop (11%). This combination reflects a tourism-anchored local economy with robust agro-pastoral linkages. A majority observe increases in agricultural output 60%, while 34% report decreases and 6% report no change. These responses are consistent with the crop-yield patterns described earlier (e.g., better potato/vegetable management near settlements, modest gains in cereals). They primarily cultivate vegetables and grains, such as potatoes, buckwheat, and millet. Additionally, around 75% of the surveyed population relied on livestock, with cows, goats, and buffalo being the most common animals. Diversified tourism activities, including trekking, meditation centers, and sightseeing, have contributed to the industry’s growth. When asked about tourism’s impact on forests, around 84% of respondents believed that household-led tourism had affected forest cover. Increased tourism activities, combined with agricultural demands and ongoing dependence on forest resources for livestock fodder and fuelwood, were reported to have contributed to a decline in forest cover. Many residents collect forest products regularly (daily, weekly, or monthly), making the forest a crucial resource in their lives. Regarding tourism satisfaction, 87% of respondents stated approval of the development led by the national park authorities. However, 80% reported that forest cover had decreased over the past 20 years, while only 20% indicated it had increased or remained unchanged. Together, these patterns show a tourism-dependent, agro-pastoral economy where households value tourism benefits but recognize intensifying pressure on forest resources.

Table 4.5: Detailed information on the socio-economic attributes of respondents (n = 145) across villages in the buffer zone of the SNP

	Variable categories	Percentage % (n=145)
Gender ratio	Male	65
	Female	35
Region	Ghat	13
	Lukla	26
	Khumjung	11
	Namche	18

	Other (less than 10 respondents)	31
Tourism satisfaction	Satisfied	72
	Highly satisfied	10
	Dissatisfaction	2
	Neutral	18
Type on trade	Forest product	4
	Agriculture product	19
	Livestock	9
	Forest and Agri and Livestock (product)	6
	Agriculture and livestock	48
	Agriculture and forest	3
Type of Fuel Energy	Wood/Firewood	83.4
	LPG	13.2
	Electricity Cow Dung	1.4
	Biogas	0
	Kerosene	2
	Other	0
Type of Enterprise	Hotel or lodges	37
	Trekking guide	11
	Homestay, tea shop, and restaurant	18
	Selling Agricultural products and a tea shop	11
Annual Income (NPR)	0 to 500,000	42
	500,001 to 17,00,000	55
	17,00,000 above	2
Agricultural production	Increased	60
	No change	6
	Decreased	34
Impact of tourism	Yes	84
	No	16
Forest change	Increase	19
	No change	2
	Decrease	80
Forest Dependence	Yes	97
	No	3

4.5.2.2 Sociodemographic Characteristics of Respondents in KNP

A total of 110 household survey data were collected from the buffer zone of KNP using random sampling techniques. Table 4.6 shows detailed information on the socio-economic attributes of the respondents. The most respondents were from Bajura district (30%, n=33), and the least were from Doti (21.8%, n=24). The survey collected information from 49 female respondents (44.5%) and 61 male respondents (55.5%), with an average age of 44.98 ± 15.35 years Figure 4.8. Most of the population is engaged in agriculture and livestock rearing (40.91%), followed by livestock rearing (36.3%) with smaller shares in Agriculture only 7.27% (n=8) and

Lodges/Homestays 5.45% (n=6). The primary livestock (93% of households keep animals) raised included cows 56.4% (62/110), goats 60.9% (67/110), buffaloes 57.3% (63/110). Respondents indicated they are highly dependent on agriculture, forests, and livestock as sources of income and daily necessities.

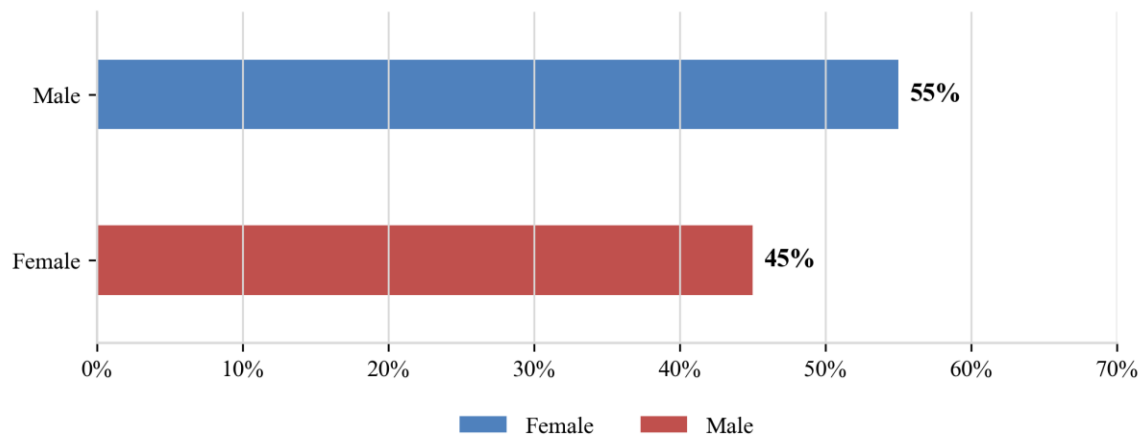


Figure 4.8: Gender of the respondents in KNP

Almost all of the people who answered the survey (93%) had livestock, which shows how important it is in the area (Bashyal et al., 2022). Even though they depended on it, 55% of those who answered said that agricultural productivity had gone down. Half of the people in the community think that household tourism has an effect on LULC, while the other half do not. Tourism is slowly developing in the area, with key activities like trekking, meditation, and sightseeing becoming important parts of mountain tourism-related activities. The vast majority of households (83.6%) relied on the nearby forest to get firewood and food for their animals. There were only 14.15% of the participants (n = 7) who were part of natural resources management groups, like the KNP buffer zone management committee and community forest user groups (CFUGs). The average time they had been involved was 0.87 ± 2.81 years (range = 0–28 years). Notably, 89% of those who answered said they rely on forest resources for their livelihoods. This shows how important forest products are for supporting local incomes. Fifty-four percent of people are happy with national park programs for household tourism. Lastly, the results showed that 37.27% of people thought the forest cover had gotten smaller in the last 20 years, 33.64% thought it had gotten bigger, and 29.09% thought it had stayed the same.

In KNP, raising livestock is still an important part of rural life. The survey data show that many people own livestock, and most families have cows, goats, and buffalo. The number of

animals each household has ranges from 2 to 10. This shows that KNP relies a lot on livestock farming. Many people who answered the survey depend on farming and livestock for their jobs. They often combine these with businesses that are related to tourism, like lodges and homestays. These businesses say they make more money each year, between 0 and 500,000 NPR, and better agricultural productivity is one reason for this.

In the KNP sample (n = 110), the majority of households continue to depend on biomass: 92 households (83.6%) indicate wood/firewood as their principal cooking fuel. LPG is the next most common type of fuel, with 10.9% of the total. Biogas comes next, with (2.7%). Only one household reported using electricity (0.9%), cow dung (0.9%), or kerosene (0.9%), and no other fuels were reported. This energy profile is very similar to the sociodemographic pattern in KNP. Almost all households (about 83.6%) use the forest regularly for fuelwood and fodder, and the local economy is agro-pastoral, with about 77% of people working in agriculture and/or livestock, and about 93% of people keeping animals. Since 40–41% of households are in the lowest income band ($\leq$ NPR 500,000) and tourism is still low and seasonal, many families do not have enough money to entirely switch to cleaner fuels, even if they know the benefits. The small but non-zero biogas share likely comes from households that live in areas that are warmer or have better water supply and have enough cattle and water; on the other hand, electric cooking is still not very common because it is expensive and not always reliable for cooking that needs a lot of heat.

These fuel choices help explain the survey's findings on how people think the forest is changing: While opinions are divided (about a third say they have less and a third say they have more), heavy fuelwood dependence in buffer settlements, along with collecting fodder for livestock, puts constant stress on nearby forests, especially where getting LPG is expensive or not always possible. The fact that half of the people think that household tourism affects land use and half don't show what KNP's tourism profile is like right now: Religious and seasonal visitors create localized peaks in fuel demand (for lodging and hosting guests) that are not seen in parks with year-round infrastructure for tourists.

Table 4.6: Detailed information on the socio-economic attributes of respondents (n = 110) across villages in the buffer zone of the KNP.

Variables	Variable categories	Percentage
Gender ratio	Male	55.45
	Female	44.55
Region	Achham	23.64

	Bajhang	24.55
	Bajura	30
	Doti	21.82
Tourism satisfaction	Satisfied	54.55
	Neutral	32.73
	Dissatisfaction	9.09
	Highly dissatisfaction	3.64
Type on trade	Agriculture	7.27
	Livestock	36.36
	Agri and Livestock	40.91
	Other (lodges or homestay)	5.45
Type of Fuel Energy	Wood/Firewood	83.6
	LPG	10.9
	Electricity Cow Dung	2.7
	Biogas	0.9
	Kerosene	0.9
	Other	0
Annual Income (NPR)	0 to 500,000	40.64
	500,001 to 1,700,000	36
	1,000,000 above	24.36
Agricultural production	Increased	54.54
	No change	1.82
	Decreased	43.64
Impact of tourism	Yes	50
	No	50
Forest Dependence	Yes	83.6
	No	16.4
Forest change	Increase	33.64
	No change	29.09
	Decrease	37.27

This connection between energy use and forest reliance has direct effects on policy. Increasing the affordability and availability of LPG for the last mile, scaling up the use of efficient biomass stoves in areas where the transition is slower, and focusing biogas on small areas that have enough warmth, water, and manure would all significantly lower the demand for fuelwood. In addition to better community forestry governance and regular monitoring (simple indicators of fuel stacking and fuelwood collection frequency), these steps fit into the larger plan laid out in this thesis to ease the pressure on buffer-zone forests while protecting household energy security.

People in the KNP buffer zone still mostly do farming and raise animals, with tourism as a growing but less important source of income. The fact that more than half of households reported a drop in production, that they depend heavily on forests, and that people have mixed feelings about changes in forest cover all point to resource stress, especially a lack of water, limited fodder, labor out-migration, and pressure on wildlife. Still, moderate satisfaction with park-led tourism

shows that there is room to grow inclusive tourism models while lowering the demand for fuelwood (for example, by using cleaner energy in lodges and more efficient stoves) and making goat and dairy value chains stronger. In terms of policy, the best way to balance conservation goals with job security would be to combine community forestry/Buffer-Zone governance with interventions in water, fodder, and energy.

4.5.3 OLS Regression Analysis

4.5.3.1 OLS regression for SNP

The results from the OLS regression model provide considerable insights into the factors driving forest cover changes in SNP as perceived by local communities (Table 4.7 and Fig. 4.8).

4.5.3.1.1 Overall Model Adequacy and Explained Variance

The analysis was conducted at a 5% significance level. The Multiple R-values of 0.414 show a moderate association between the independent and dependent variables (forest cover change). Moreover, the R^2 value of 0.171 suggests that the model's predictors can explain 17.1% of the variation in forest cover changes, which suggests a modest but meaningful explanatory capacity for perception-based household data.

4.5.3.1.2 Interpretation of Predictors: Significant and Non-Significant Effects

For SNP (n=145), the OLS model shows a moderate overall relationship between predictors and perceived forest cover change. At the 5% significance level, only agricultural productivity ($\beta=-0.220$, $p=0.002$) and household tourism ($\beta=-0.566$, $p=0.002$) are statistically significant, both with negative coefficients, indicating that higher productivity and greater tourism involvement are associated with a shift toward perceived forest decline (given the coding Decreased = -1, No change = 0, Increased = 1). In contrast, tourism satisfaction, forest dependency, sex, and livestock dependence are not significant ($p>0.05$), suggesting no clear independent association with perceived forest change in this model.

Key variables driving forest cover change include agricultural productivity ($p = 0.002$), with a significant negative coefficient of -0.220, indicating that higher agricultural productivity is associated with reduced forest cover due to land conversion. Similarly, household tourism ($p =$

0.002) has a negative coefficient of -0.566, suggesting that growth in tourism, particularly in areas like Sagarmatha National Park, also contributes to forest cover loss.

Forest dependency ($p = 0.449$) has a negative coefficient of -0.285, which is not statistically significant in this model, suggesting that the communities relying more on forest resources for fuelwood or fodder may experience more significant forest cover reduction. This pressure, particularly in the areas lacking sustainable forest management, is a well-documented driver of deforestation. Other variables did not show a statistically significant relationship with forest cover change in SNP, as indicated in Figure 4.8. Precisely, the tourism satisfaction ($p = 0.447$), sex ($p = 0.969$), and livestock dependence ($p = 0.432$) were not found to be substantial factors influencing forest cover in the park. These results indicate that community perceptions of park services, as reflected by tourism satisfaction, may not directly affect the land use. Additionally, the livestock dependence appears to have reduced, likely due to the adoption of modern agricultural practices and community forest management systems, which provide alternative feed sources and reduce reliance on forest resources.

Table 4.7: OLS regression model on socio-economic factors

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.099	0.407	0.242	0.809	-0.707	0.904
bi_agri-prod	-0.220	0.069	-3.205	0.002	-0.355	-0.084
bi_tourism	-0.566	0.176	-3.224	0.002	-0.913	-0.219
bi_satis	-0.082	0.107	-0.763	0.447	-0.293	0.130
bi_Forest dependence	-0.285	0.375	-0.760	0.449	-1.027	0.457
Bi Sex	-0.005	0.131	-0.039	0.969	-0.264	0.254
bi_livestock	0.114	0.145	0.788	0.432	-0.172	0.400

Regression Statistics	
Multiple R	0.414
R Square	0.171
Adjusted R Square	0.135
Standard Error	0.728
Observation	145

The OLS regression analysis of the SNP reveals key factors that affect the forest cover changes as locals perceive them. Two significant predictors are agricultural productivity and household tourism. An increase in agricultural productivity correlates with a reduction in forest cover, indicating that agricultural expansion may encroach on forests. Similarly, household tourism is

negatively associated with forest cover. In contrast, variables such as satisfaction with tourism development, forest dependence, sex, and livestock dependence showed no significant impact on forest changes, suggesting their influence on forest cover may be minimal or need further study.

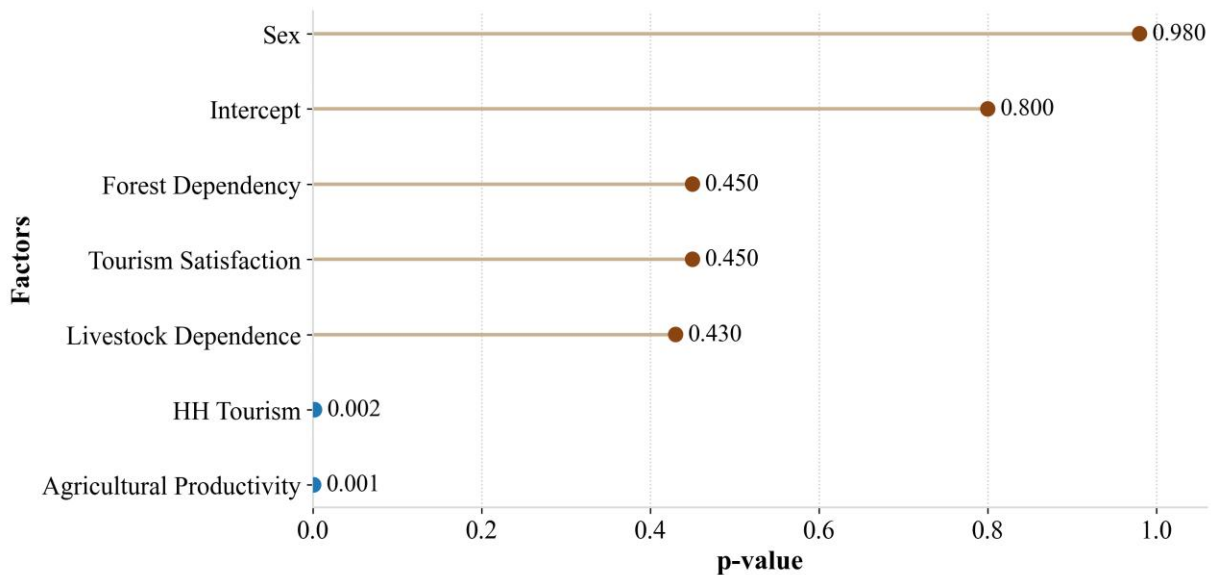


Figure 4.8: Distribution of P values in the OLS Model. The scatter plots depict the statistical significance of various factors, including agricultural productivity, household tourism, forest dependency, etc.

4.5.3.2 OLS regression for KNP

The OLS regression results provide valuable insights into the factors driving forest cover changes in KNP, as perceived by local communities (Table 4.8).

4.5.3.2.1 Overall Model Adequacy and Explained Variance

The analysis was conducted at a 0.05 significance level. The model's Multiple R-value of 0.783 indicates a strong association between the independent and dependent variables (forest cover change). Moreover, the R^2 value of 0.614 indicates that the model's predictors can explain 61.4% of the variation in forest cover changes, demonstrating a reasonably good fit.

4.5.3.2.2 Interpretation Of Predictors: Significant and Non-Significant Effects

The OLS results indicate that agricultural productivity, household tourism, and forest dependency are significant predictors of the dependent variable at the 5% level. Agricultural productivity shows a negative and highly significant association ($\beta=-0.35$, $p<0.001$), meaning that a one-unit increase in productivity is linked with a 0.35-unit decrease in the response, holding other factors constant. Household tourism has the largest negative effect ($\beta=-0.73$, $p<0.001$), suggesting stronger tourism involvement is associated with a 0.73-unit decrease in the outcome. Forest dependency is also negatively associated and statistically significant ($\beta=-0.29$, ($p=0.04$)), implying that greater reliance on forest resources corresponds to more negative changes in the response. In contrast, tourism satisfaction ($p=0.85$), sex ($p=0.62$), and livestock dependence ($p=0.99$) are not statistically significant, indicating no clear independent relationship with the outcome in this model. The intercept is marginal ($p=0.06$). The dependent variable is coded as Decreased = -1, No change = 0, Increased = 1, then these negative coefficients mean these factors push perceptions toward “decrease/decline” in the outcome.

Key variables were recognized as major factors influencing changes in forest cover. The coefficient of -0.35 for agricultural productivity ($p < 0.01$) is very negative. This means that as farming becomes more productive, forest cover decreases. This is probably because the population is growing, which leads to more farming, which means that forest land is turned into farmland. In the same way, household tourism ($p < 0.01$) has a significant negative coefficient of -0.73, which means that more people visiting their own homes is linked to less forest cover. However, the whole area of KNP's tourism needs to be better developed and stay focused on religious tourism, especially for people who live there.

Nepal has encountered difficulties associated with unsustainable tourism, adversely affecting forest cover in several regions (Baral et al., 2019). In addition, combining tourism with community welfare and managing natural resources requires a lot of time and special systems (Singh, 2021).

Table 4.8: OLS regression model on socio-economic factors for KNP

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.51	0.27	1.93	0.06	-0.01	1.04
Agricultural Productivity	-0.35	0.07	-5.12	0.00	-0.48	-0.21
Household Tourism	-0.73	0.14	-5.43	0.00	-1.00	-0.47
Forest Dependency of Communities	-0.29	0.14	-2.07	0.04	-0.56	-0.01

Tourism Satisfaction	0.01	0.08	0.19	0.85	-0.14	0.17
Sex	0.05	0.11	0.49	0.62	-0.16	0.27
livestock dependence	0.00	0.20	-0.02	0.99	-0.40	0.40

Regression Statistics	
Multiple R	0.783
R Square	0.613
Adjusted R Square	0.591
Standard Error	0.540
Observations	110

Figure 4.9 presents how local dependence on forest resources influences community perceptions, and with statistical analysis reveals significant and non-significant predictors of forest cover change in KNP. Forest dependency emerged as a significant predictor ($p = 0.04$) with a negative coefficient of -0.29. Communities that rely on resources such as fuelwood and fodder often see reductions in forest cover. This suggests that subsistence activities place notable pressure on forest ecosystems, particularly in areas lacking sustainable forest management strategies. In contrast, some variables showed no significant effect on forest cover change. For instance, tourism satisfaction ($p = 0.85$), sex ($p = 0.62$), and livestock dependence ($p = 0.99$) were not substantial influencers of forest cover in KNP.

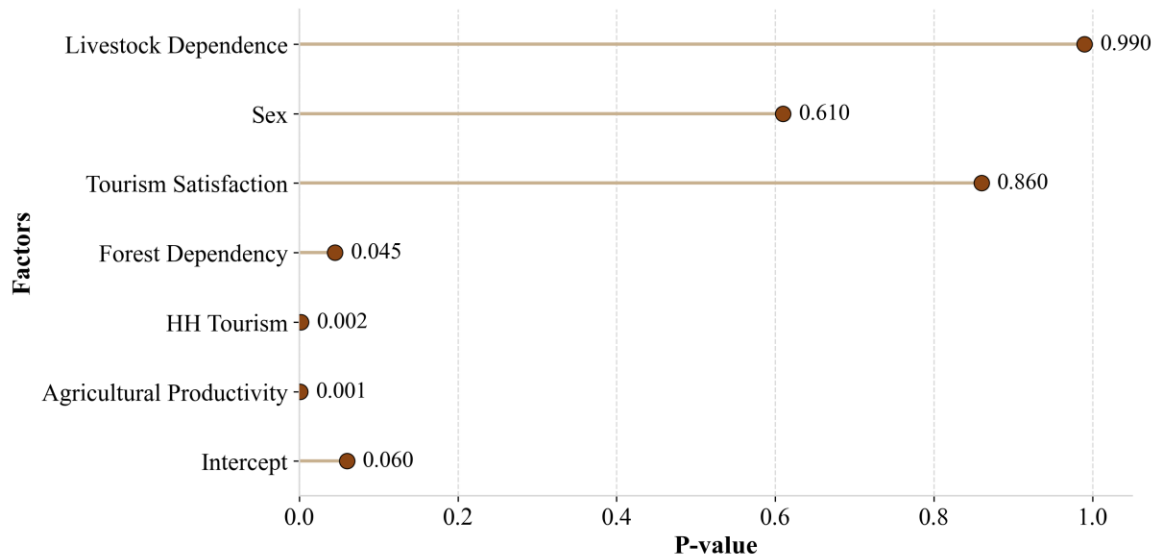


Figure 4.9: Distribution of P values in the OLS Model. The scatter plots show the statistical significance of various factors, including agricultural productivity, household tourism, and forest dependency.

This indicates that these factors do not significantly influence the variation in forest cover in KNP. Tourism satisfaction, which indicates the community's perception of the park's services to bolster tourism, may not have strong linkages. Similarly, livestock rearing may stem from modern agricultural practices and effective community forest management systems, which may reduce forest dependence by providing alternative feed sources.

4.6 Discussions

This chapter employs a comparative case study methodology, employing the SUS-TAS model to assess community perspectives on tourism and agriculture, their impacts on land use and land cover (LULC), and their implications for forest conservation in SNP and KNP. Employing a "Nexus Approach" that examines interconnections across sectors, this study elucidates both trade-offs and collaborations among agriculture, tourism, and forest resources within each park (Farsari, 2023; Hülsmann and Jampani, 2020).

4.6.1 Tourism–Agriculture–Forest Interactions, Livelihood Trade-offs, and Land Use Dynamics in SNP and KNP

In SNP and KNP, household-driven tourism exhibits a negative correlation with forest cover, as the development of tourism frequently leads to deforestation due to the demand for

infrastructure and resources (S. Bhatta, Devkota, et al., 2023). This problem with infrastructure, along with delays in important services like water supply, shows how hard it is for tourism to grow in a sustainable way. Bhatta et al. (2023) found similar results, showing that poor infrastructure makes it harder for tourism to grow in a way that is good for the environment. The research has provided convincing firsthand evidence by interacting with community members regarding the difficulties they encounter. Mr. Tez Bahadur from KNP (Buffer Zone) expressed his worry about how tourism is developing unevenly in the area:

"The people who live in the buffer zone are excited about the growth of tourism in the area, but we hope that the growth doesn't mean we have to give up our access to forest resources and that we can make a steady income."

For a long time, the country has recognised that developing the sector in national parks is not enough. SNP has had several problems because businesses that depend on tourism often don't agree with the park and the community, which threatens biodiversity mainly through bad, unsustainable infrastructure development (Sun and Watanabe, 2021). The park's limited management capacity, lack of funding, and unwillingness to work with important stakeholders make this problem even worse. It shows that people who live in the area and people who have a stake in it don't know that a World Heritage Site (WHS) management plan is needed. Park management wants to promote sustainable tourism to protect the environment and culture, but there are not many efforts to develop a tourism development policy like the one UNESCO suggests.

Tourism in SNP has drastically increased, which is good for the local economy but bad for the park's integrity because it has caused uncontrolled growth, more trash, and more air traffic. More than 85% of Sherpas work in tourism, and running lodges along the main trekking route is a very profitable business. However, the economic benefits diminish quickly when you leave this path. These problems can be fixed by promoting sustainable tourism that respects local cultural values and helps protect the environment. It is important to stop illegal activities in order to protect the park from the effects of tourism. To protect the SNP's unique cultural and environmental heritage while also promoting economic growth, it's important for people to get involved and for the forest to be better managed.

This chapter demonstrates that in SNP and KNP, farms with higher productivity are associated with reduced forest cover. This implies that people in these regions perceive agriculture as encroaching upon forests. People in KNP depend a lot on forest resources, which makes the loss

of forest cover even worse. This is especially true for people who live in buffer zones and depend on these resources because they don't have many other ways to make money, like tourism. This dynamic shows that there is a big trade-off between the two areas and that the rules for development are not being followed all the time in the national park.

This chapter found that farming is necessary for survival in both SNP and KNP, but the crops grown and the ways of farming are different in each. Different parks use different ways of growing crops. SNP grows a variety of grains and vegetables which well-suited in the high altitude. KNP, on the other hand, mostly grows rice and wheat, which are essential foods on a daily basis. Both SNP and KNP need to raise animals, but they do it in different ways. SNP raises yaks and sheep at high altitudes, while KNP raises a variety of animals. One major difference between households with higher incomes in both areas is that they earn income in different ways, particularly through tourism. This shows that having multiple ways to earn income can help keep the rural economy stable. Families in SNP grow crops, raise animals, and sell forest products, so it has a mixed economy. Tourism is also sometimes very crucial to handle. The facilities like hotels, lodges, and trekking services are examples of businesses that generate between 300,000 and 2,000,000 NPR a year. A lot of the people who took the survey in KNP rely on both farming and raising animals to make ends meet. They frequently run hotels and lodges, which are businesses related to tourism, along with these activities. These businesses say they generate more money, between 500,000 and 1,000,000 NPR each year. They are willing to enhance their business to make more money because their farms are more productive. Businesses that have expanded into more than one field, such as tourism and farming, always make more money. This presents how important it is to diversify to keep rural economies going and stabilize the income in both KNP and SNP.

Tourism affects local economies, and LULC changes vary across each park. Most of SNP's tourism is about hiking and cultural events. Most tourists (85%) are happy with it, but there are a lot of environmental problems in places with a lot of traffic. Outside events are more likely to affect communities that only rely on tourism during certain times of the year. Most of the time, domestic tourists go to KNP for religious or fun reasons. They don't always like the facilities or the damage to the environment. People still need forest resources a lot, even though they use them in different ways. Most people in SNP say that climate and soil problems are making things worse. In KNP, on the other hand, residents have mixed reports. Some say that community management is making the forest better.

Policies in both areas encourage using less fuelwood and protecting forests. SNP helps farmers get more done by using new technologies and resources from local governments. On the other hand, farming is hard in KNP because the soil is getting worse and there isn't enough water, even though the government is trying to help. This shows that the parks don't all get the same amount of help and resources. This chapter emphasizes the importance of cohesive, locally tailored plans to promote sustainable tourism and resource management in Nepal's protected areas.

4.6.2 Integrating the Nexus and Community-Driven Approaches to Manage Tourism and Forest Cover

Central and local authorities are currently collaborating to manage tourism in Nepal's mountain regions. Their focus has been on creating committees and plans to boost tourism. But these methods often account for the local context, which has led to uneven development that harms both the health of the forests and the health of the communities. A combined Nexus and community-driven approach could better meet the economic and environmental needs of these areas.

The Nexus approach shows how agriculture, tourism, and forestry all depend on each other. This means that policies and resource management plans should take into account the pressures and opportunities that are connected to the national parks. This method lets stakeholders deal with important trade-offs and get the most out of the benefits in all areas. (Farsari, 2023; Hülsmann and Jampani, 2020). This strategy can help local economies while also protecting natural resources by using Nexus principles in tourism and forest management. A community-driven framework based on Ostrom's ideas for managing common-pool resources (1990, 2009) is a good example of how to make tourism more sustainable. Communities can actively manage the effects of tourism when they have key tools like setting limits, making rules together, and keeping an eye on things. For instance, community-based committees that include a wide range of local stakeholders, such as women, people with disabilities, and other vulnerable groups, can make resource-use policies fairer and more accepted (Silwal et al., 2022).

Getting people in the community involved in building tourism infrastructure and implementing environmentally friendly farming methods that work with the area's unique ecology and culture makes people more likely to follow the rules and stick to environmentally friendly practices. Communities can keep an eye on how tourism and farming affect the health of the forest

with the help of participatory planning platforms and open monitoring systems. Regular checks by local experts help keep the balance between economic growth and protecting the environment. This helps solve big problems like losing forest cover and running out of resources. By using these different methods together, we can create a more resilient, community-focused model for sustainable tourism and forest conservation in national parks. This will help protect these ecologically sensitive areas in the long run.

4.7 Summary of Chapter

In summary, this chapter offered a comprehensive analysis of local communities' perceptions concerning the effects of various sectors, primarily tourism, on land use, land cover (LULC), and forest cover. The chapter explained the theoretical frameworks that informed the selection of sites for the primary surveys, thereby ensuring that the chosen locations were both representative and pertinent to the study. The methodology was also based on a review of the literature and a theoretical framework to back up the study.

The main surveys were conducted at two different locations. SNP and KNP are the national parks of Nepal. These places were chosen because they are unique and have active local communities that engage in a range of enterprises, including agriculture and tourism. The survey results showed that people who live in these areas believe that sectors like agriculture and household tourism development have a relatable impact on LULC and forest cover. This perception was not merely unreliable but substantiated by statistical analysis, which validated the community's views and affirmed that these sectors significantly impact the environment. The research integrated the Nexus approach and Common Resource Pool management strategies to examine the complex and interrelated nature of these issues. Doing so gave a full picture of the complicated interactions that were happening. The Nexus approach showed how different sectors depend on each other. The shared resource pool management approach, on the other hand, focused on working together to manage shared resources in a way that is good for the environment and encourages sustainable mountain tourism.

This chapter offers suggestions for more effective resource management and for encouraging environmentally sustainable tourism. It stresses how important it is to protect the environment, improve the economy, and keep cultural heritage alive. The ideas are based on ideas from cultural anthropology, tourism management, and sustainable development.

Chapter 5. General Discussion: Developing a Framework for Sustainable Tourism in Protected Areas

5.1 Introduction

This chapter combine the geospatial and socio-cultural findings from SNP and KNP to fulfil the study's fourth objective. The Fourth objective is to develop a new framework, the Integrated Land-Use and Community Adaptation Framework (ILCAF), that standardizes conservation objectives with the socio-economic needs of local communities. This study employed comparative analysis to examine two protected areas, KNP and SNP. These national parks are known for their religious tourism and substantial dependence on woods. This chapter presents the ILCAF, employing quantitative data derived from tourism statistics (Chapter 2), LULC analysis and Climate trends (Chapter 3), community survey results (Chapter 4). This framework is based on data from both SNP and KNP, which means it may be used in all of Nepal's others protected areas.

5.2 Unsustainable practices and their impact on resource stress in SNP

This study shows the decrease in forest cover in Sagarmatha, with future projections indicating that this decline may continue (Chapter 3, Figure 3.13a). As the home of Mount Everest, this park attracts many international tourists, requiring extensive infrastructure improvements (Chapter 3, Figure 3.9). Due to the increasing numbers of guest lodges, trekking paths, and support facilities, deforestation and the clearing of forested areas (Chapter 4, Table 4.2 and Table 4.3) (Sun and Watanabe, 2021). This kind of human intervention can affect the habitats. Now it has also become a challenge to find a balance between the economic benefits of tourism and protecting the environment. The forest cover in the buffer zone decreased by 13.45 km² from 1989 to 2021. The total area of snow and glaciers has decreased to 106.23 km² in the core zone and 11.11 km² in the buffer zone. The melting of snow and glaciers resulted in an increase of 68.84 km² of bare land in the core zone and 11.11 km² in the buffer zone (Chapter 3, Figure 3.7). The grassland region expanded by 42.97 km² in the core zone and 16.51 km² in the buffer zone (Figure 5.1) (Gupta, 2024).

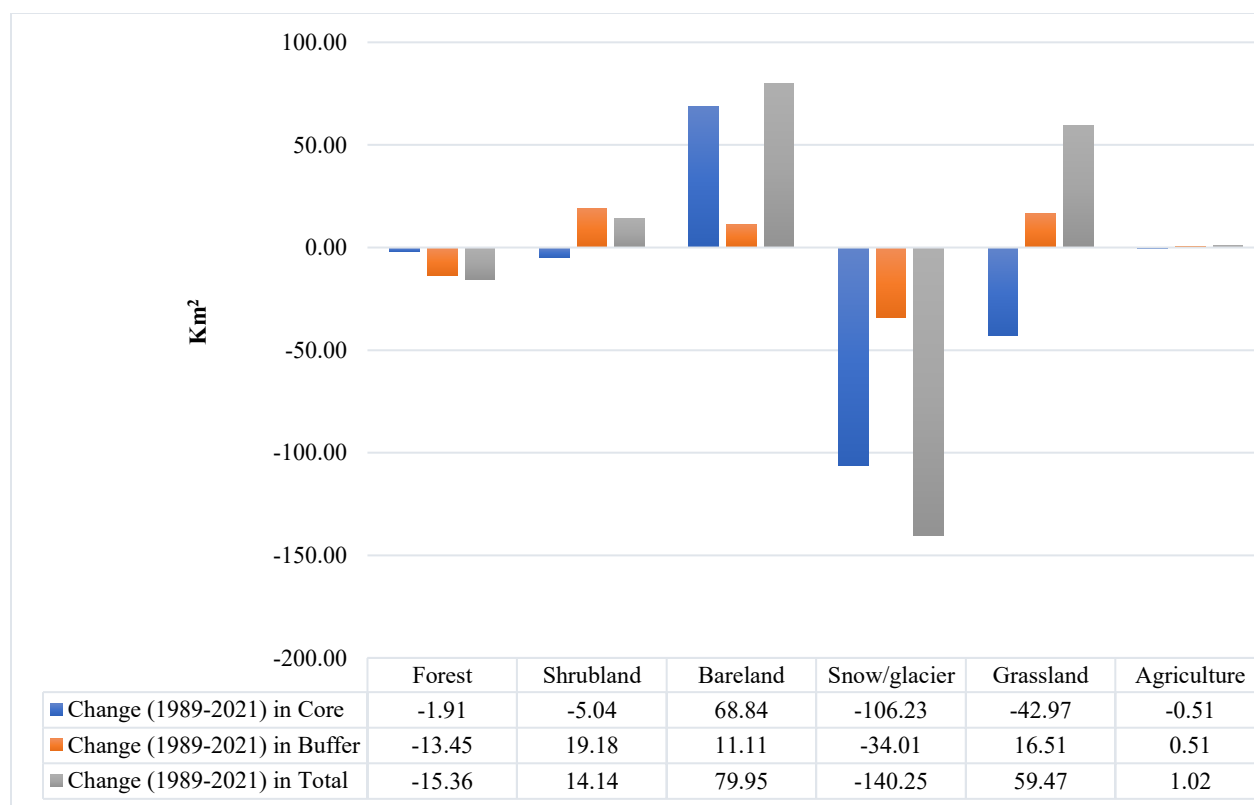


Figure 5.1: LULC Changes in SNP (1989–2021)

Due to the climate change glaciers might be melt down and I will be resulting as the more bare land (Garrard et al., 2016; Gupta, 2024). In this type of sensitive area, the growing population, more farming, and tourism can put more stress on land resources. Chapter 3, Figure 3.10 shows that climate change effecting on temperatures rising and rain falling less often globally. In SNP, over the last 200 years, *A. spectabilis* (East Himalayan Fir) has moved up about 0.93 meters per year, and *B. utilis* (Himalayan Birch) has moved up about 0.42 meters per year. This upward movement has caused species to move to new places and habitats to break up (Gaire et al., 2017).

This study also examined community perceptions regarding climate change and its impacts, alongside the agriculture, livestock, and tourism sectors, which were succinctly outlined in Chapter 4. People who lived in the SNP park's buffer zone, they said that climate change, unsustainable tourism, farming are responsible for the loss of forest cover. This is happening because of unsustainable development, and this effect can be seen easily in the National Park (Chapter 4, Table 4.4).

5.3 Development in KNP: Infrastructure and Sectoral Limitations

KNP primarily receives domestic tourists, usually for religious or seasonal visits (Bhatta et al., 2023). This type of tourism does not put constant pressure on KNP, but peak periods strain local services and increase demand for forest resources. The local communities around KNP are depends on forest resources, such as fuelwood, timber for construction, and non-timber forest products (NTFPs) (Chapter 4, Table 4.2). Extractions are still going on because of this dependence, which could put a lot of stress on the ecosystems of the KNP. if these issues are not handled in a proper way, then the effects of these can be seen in future. In the KNP the LULC patterns are stable if compared it to SNP although many challenges remain same as the SNP. Forest cover in KNP decreased by 18.63 km² from 1991 to 2020. Most of this change was in the buffer zone of the KNP, where 18.43 km² shifted to agriculture and shrubland (Gupta, 2024). Population growth, higher farming demand, and more livestock grazing may be the main drivers (Figure 5.2). KNP shows rising annual precipitation and temperature from 1994 to 2023 (Chapter 3, Figure 3.11), which may lead to more land conversion and deforestation, upsetting the park’s ecological balance.

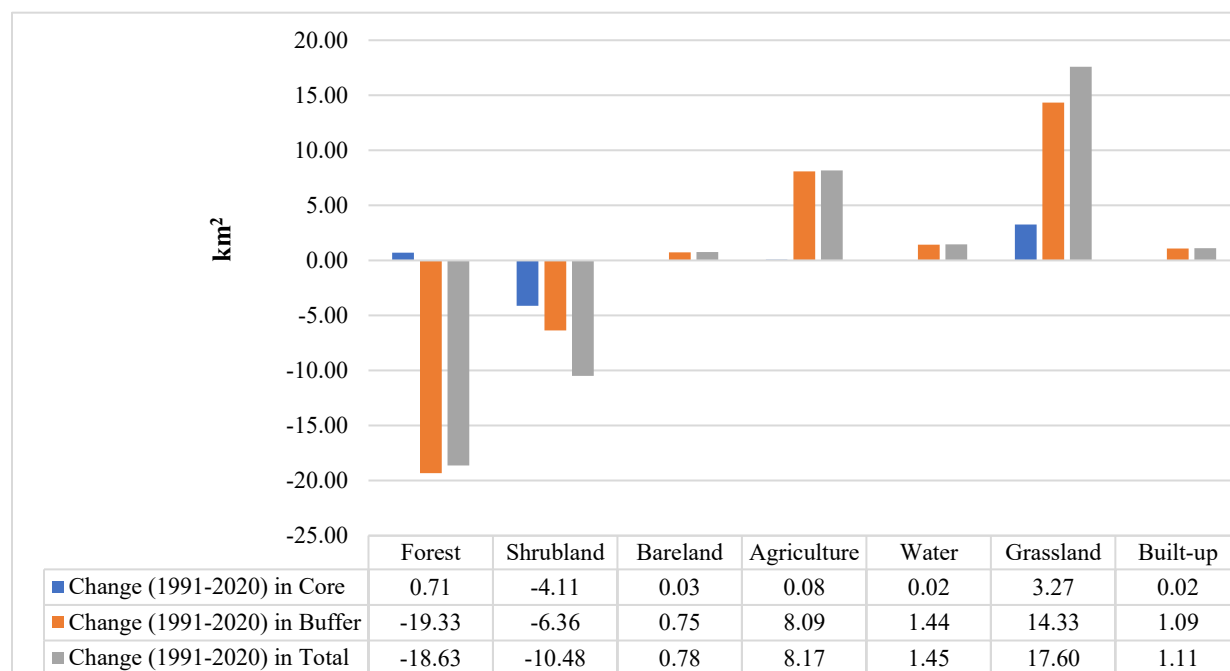


Figure 5.2: LULC Changes in KNP (1991–2020)

The findings shown in Table 4.5 of Chapter 4 demonstrate that the community insights provided by KNP indicate that individuals are concerned about issues such as climate change, agriculture, and tourism, all of which are affecting land use and forest cover. Many people who

live in the buffer zone believe that the expansion of agriculture and the raising of animals are contributing to the degradation of the forest because of the demand for more farmland and pasture. Participation from members of the community is required in order to find solutions to these significant issues. Programs that are designed to manage community forests can be of assistance in striking a balance between the objectives of conservation and the requirements of the people who live in the region. By supporting a co-management approach, local communities have the ability to assist in the monitoring of the forest, the prevention of illegal logging, and the protection of the park's resources. Having an understanding of the interests of agriculture, tourism, and conservation is essential in order to develop management plans that will be effective over time. The implementation of integrated regulations that take into account the requirements of these interconnected industries has the potential to put an end to land-use practices that are in conflict with one another. Climate impact evaluations ought to be carried out on newly proposed tourism and agricultural initiatives in order to guarantee that these endeavours will not have a negative influence on the forest cover. Evaluations of this nature make it possible to plan and execute actions to lessen the amount of damage that has been done. There is a great potential for improvement in conservation efforts in the region through the implementation of programs that educate people and create awareness. International Non-Governmental Organizations (INGOs), Non-Governmental Organizations (NGOs), and other groups can collaborate with local government and park authorities to organize awareness programs and workshops that will assist individuals in comprehending the interrelationships that exist between forest cover, agriculture, and tourism. Not only that, but the tourism plans for KNP need to be in accordance with sustainable tourism standards, particularly considering the fact that Khaptad is extremely environmentally conscious. It is possible, for instance, to establish a connection between the expansion of sustainable mountain tourism and the expansion of medicinal tourism. At the moment, Khaptad does not possess the necessary infrastructure to sustain tourism for an extended period of time. The national parks, environment, and forests ministries, as well as the tourist ministry, do not appear to collaborate particularly effectively with one another. The conservation of natural resources is the most essential component of sustainable development. In order to preserve the natural world, it is essential (Badal, 2024a). It is therefore imperative that all actions related to development be carried out in a manner that safeguards the environment, as this is the concept that underpins sustainable development.

If there is a need to make improvements to the infrastructure, it is imperative that these improvements be made in a manner that is environmentally friendly. The park does not currently possess the appropriate tourist infrastructure to support consistent and long-term tourism. This includes eco-friendly places to stay, trails that are well-maintained, and visitor centers among other things. It is essential to properly develop these buildings in order to ensure that they do not disrupt the delicate ecosystems that are found in Khaptad. Any structure, for instance, need to have as minimal of an impact on the environment as is humanly feasible, make use of materials that are both locally sourced and long-lasting, and adhere to stringent regulations that maintain the natural equilibrium of the park. By acting in this manner, KNP is able to demonstrate how to expand tourism without causing harm to a protected region.

5.4 Change Trends and Future Projections

The analysis of temporal trends from 1990 to 2020, with predictions using the CA-ANN model (Chapter 3). The result forecasted that there will be decline in both SNP and KNP. In SNP, built-up areas showed an upward trajectory due to tourism-driven infrastructure (Chapter 3, Figure 3.9), while in KNP, pasture and agriculture continued to encroach on forest areas. Climate data (Chapter 3, Figure 3.10) shown the increasing temperatures and decreasing snowfall, which might be stressing ecosystems. These findings show there is the need for adaptive land-use strategies that account for future pressures and landscape vulnerabilities.

5.5 Community Perception and Local Resource Dependency

We were able to acquire a better understanding of how individuals who live in close proximity to parks perceive changes in their environment and how they are dependent on natural resources by conducting community surveys. In the SNP, 80% of respondents said that the amount of forest cover has declined over the course of the last twenty years. According to them, the primary reasons can be the agriculture, tourism and the effects of climate change. In SNP 83.4% of people still depends on woods for a variety of requirements, including fuel, fodder, and other necessities. In addition, 84% of respondents stated that tourism has had an impact on the forest, primarily as a result of the construction of lodges and the utilization of firewood (Chapter 4, Table 4.2).

People in KNP held a variety of opinions 37.27% of respondents believed that the forest cover had decreased, while 33.64 percent believed that it had increased. In spite of this, the dependence on forests is quite strong; 83.6% of families frequently collect fuel and feed (Chapter 4, Table 4.5). Despite the fact that fewer tourists visit KNP, the strain that is placed on trees continues to be severe, particularly during festivals time. In Chapter 4, Table 4.5, it was found that 50% of the respondents were in agreement that tourism is altering the landscape.

5.6 Remote Sensing-Based Road Detection in KNP

The extension of roads in KNP was evaluated using high-resolution satellite data, which served as a proxy for anthropogenic, tourism-driven land transformation. This was done in addition to the broader changes that occurred at LULC. road networks were mapped and compared between the dates of 13 November 2016 and 8 November 2021 using PlanetScope data at a resolution of 3 meters. These periods is chosen because of minimal cloud cover and corresponding with peak post-monsoon visibility, which are optimal conditions for detecting terrain features. As can be seen in Figure 5.3, the geographical comparison sheds light on significant shifts that have occurred in the road density and alignment throughout the park over the course of these five years. It was confirmed by the analysis that there has been an increase in human activity in places that were previously undisturbed. The investigation found that new roads have been developed, and old roads have been expanded in different zones of KNP. This growth of the route is more noticeable in the districts of Bajhang and Bajura than it is in the districts of Doti and Achham. The majority of these recently constructed roads are situated within the buffer zone; however, there are a few that are situated in close proximity to the boundary of the core zone, which may result in the possibility of encroachment into core areas in the not-too-distant future. Photographs of these roads are presented in Figure 5.4, which provides a visual picture of the vegetation and road conditions that are present in the surrounding area. The park officials or the communities in the surrounding area are the ones who have launched this extension. These spatial changes highlight the critical need to incorporate road monitoring into conservation planning to prevent habitat fragmentation and to manage tourism-related pressures more effectively.

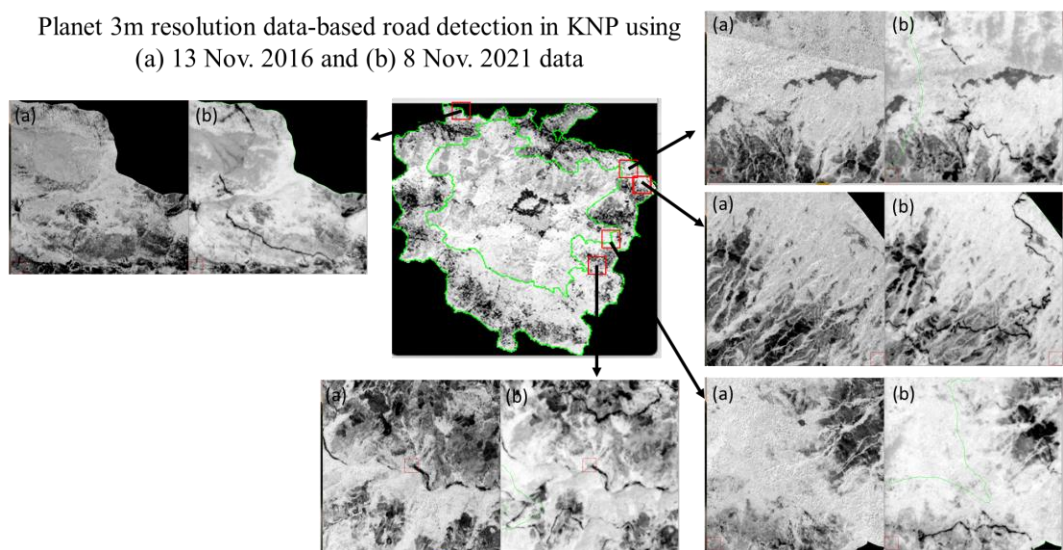


Figure 5.3: Planet 3m resolution data-based road detection in KNP using (a) 13 Nov. 2016 and (b) 8 Nov. 2021 data



Figure 5.4: Photographs of roads in KNP near Bajhang and Doti side in the buffer zone

These findings underscore the need for proactive monitoring and infrastructure planning in buffer zones, particularly in sacred or ecologically fragile areas. The application of satellite-based road monitoring directly contributes to ILCAF's component on participatory and remote-sensing-based monitoring.

5.7 Why a New Framework Is Needed for the Protected Area

5.7.1 Interacting pressures at the core–buffer interface

Himalayan protected areas are now facing many kinds of stress at the same time, with the strongest effects being felt in buffer zones. International trekking and the expansion of lodges in SNP have caused ongoing stress on solid waste and infrastructure, as well as other negative effects of tourism that have been reported by UNESCO's State of Conservation reports. These pressures are in addition to the ongoing use of grazing and fuelwood in nearby settlements. In contrast, KNP is known for soft-adventure and spiritual visits to the Khaptad Baba hermitage, as well as subsistence resource use that is common in remote buffer communities. At the same time, the Hindu Kush–Himalaya is warming quickly, glaciers are melting faster than the average for the whole world, and the risk of glacial lake outburst floods (GLOFs) is growing. These are all reasons why management should be proactive instead of reactive. Tourism growth, livelihood needs, and increasing cryosphere hazards all come together in ways that old methods have trouble dealing with (Centre, 2023).

5.7.2 Overview of Existing Frameworks

The tools that managers use the most only show part of the problem. The Management Effectiveness Tracking Tool (METT) gives a site-level scorecard of governance inputs, processes, and outputs. However, it does not show how land use changes, set limits on tourism, or define climate-hazard triggers. RAPPAM is made for quick, system-level scans of a network of protected areas, where threats and capacity needs are ranked at a low level of detail. The Sustainable Tourism Attitude Scale (SUS-TAS) measures how residents feel about sustainable tourism, while TESSA uses real-world examples to compare different states and show the benefits. Even though these tools are useful, they are not a spatial, forward-looking operating system for making core–buffer decisions when tourism, livelihoods, and climate are all at the same time.

5.7.3 Fragmented governance and static zoning limit adaptation

Nepal's buffer-zone policy was made to bring conservation and development together, and it says that 30–50% of park revenues should be shared with buffer communities. However, many studies show that implementation is often still sectoral, with tourism, forestry, land-use, and disaster-risk workstreams all going on at the same time. Community forestry and buffer institutions can also have problems with fairness and capacity. When the number of visitors, access networks, and climate risks change quickly, it is hard to change rules, funding, and enforcement quickly enough because zoning is fixed and accountability is spread out.

5.7.4 The missing integration: evidence, thresholds, and accountability

An integrated, spatially explicit method that views the core and buffer as a single, coupled system is missing from the standard toolkit. At minimum, managers require explicit carrying-capacity and access rules linked to those maps, regular remote-sensing LULC monitoring and access-network mapping, early-warning thresholds for weather extremes and the cryosphere, and a formal channel where community perceptions inform decisions rather than existing in stand-alone reports. Such spatial evidence is available and can be updated, according to recent work done specifically in Nepal that links LULC dynamics in SNP and KNP. The difficulty lies in integrating it with social metrics and climate risk to create an adaptive cycle with distinct roles, deadlines, and public indicators.

5.8 Designing a Framework for Sustainable Land Use and Community Adaptation in National Parks (ILCAF)

5.8.1 Framework Grounded from SNP and KNP Findings

The creation of the ILCAF was a direct response to the complicated environmental and socio-economic issues found in SNP and KNP. Figure 5.5 shows that the ILCAF was made step by step, starting with the LULC analysis from Chapter 3 that used satellites. This helped show clear differences in how the land has changed between areas with a lot of tourists and areas that are mostly used for farming and living (K. D. Bhatta and Chan, 2023; Sun and Watanabe, 2021).

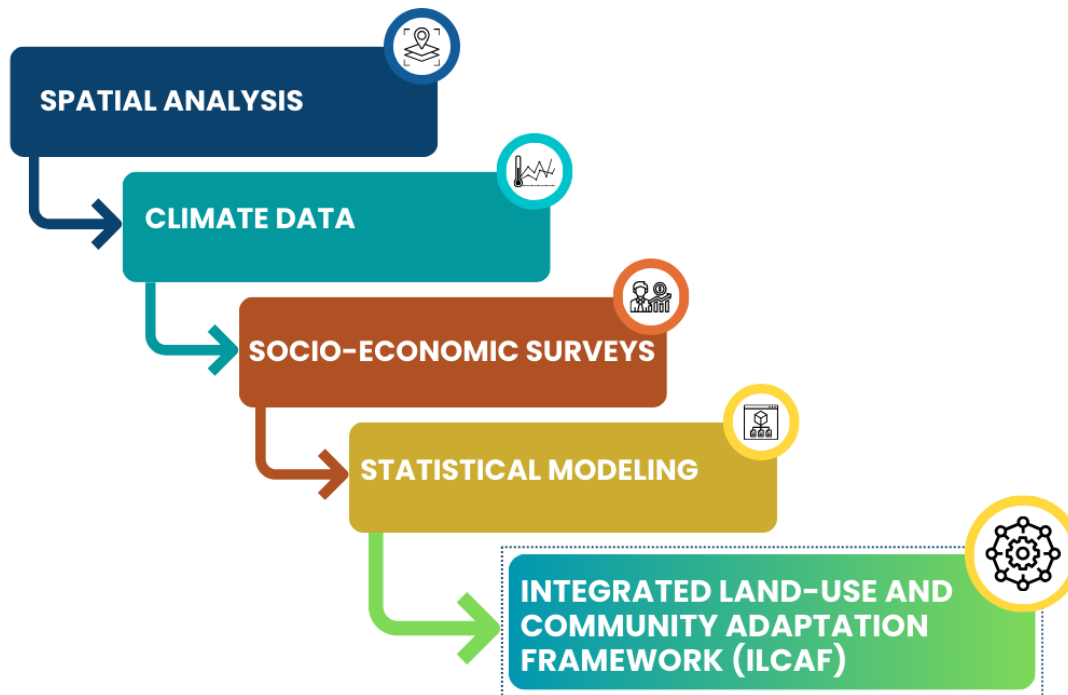


Figure 5.5: Flowchart showing the design process of the ILCAF Framework grounded in findings from SNP and KNP

After looking at the data in terms of space, climate data trends were added to see how warming temperatures and changing precipitation patterns affect land cover in SNP, especially noting how glaciers are melting and what that means for land cover (Chapter 3, Figure 3.10). Subsequently, socio-economic surveys were conducted to capture community perspectives, revealing deep forest dependency in both regions and variable perceptions on forest change (Chapter 4, Tables 4.1 and 4.5). OLS regression analysis confirmed these qualitative findings that agricultural production and family tourism participation in SNP and KNP were negatively correlated with forest cover (Chapter 4, Tables 4.3 and 4.4).

Collectively, these interconnected lines of inquiry provide clarity on the complicated connections between forest health, tourism, and farming, providing the scientific and practical foundation for ILCAF. The framework is not based on vague theories, but on real changes in the environment, the needs of communities, and measurable interactions between humans and nature (Hülsmann and Jampani, 2020).

5.8.2 Components of ILCAF

The ILCAF is structured around five interdependent components, each strategically designed to address the unique socio-ecological challenges identified in SNP and KNP. These components are derived directly from spatial analyses, socio-economic data, and stakeholder perceptions collected throughout the study.

5.8.2.1 Zonal Planning

Zonal planning is a spatial management approach that divides a protected area into functionally distinct zones—such as core and buffer zones—based on ecological sensitivity and permitted levels of human activity. The goal is to balance environmental conservation and sustainable resource use. The Core Zone at the center is reserved for strict biodiversity protection with minimal human disturbance. The surrounding Buffer Zone permits controlled, conservation-supportive uses, while the outer Transition Zone accommodates settlements and services—education, research, tourism, and monitoring—to reduce pressure on the core (Figure 5.6).

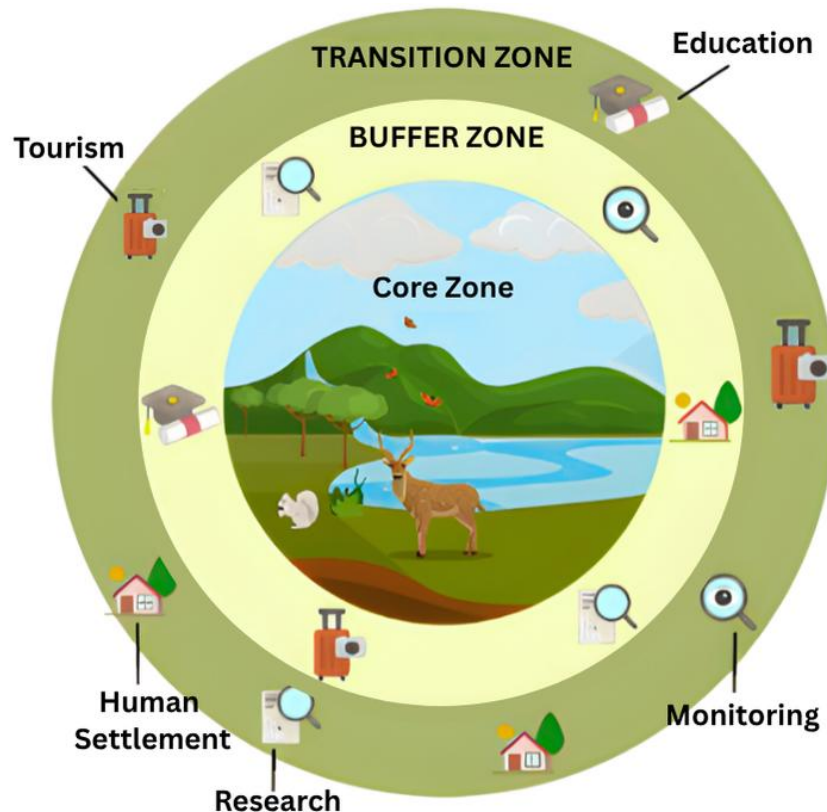


Figure 5.6: Zonal planning for a protected area showing three concentric zones.

5.8.2.2 Core Zone Strategies

The core zone is the most ecologically important and fragile part of protected landscapes. It is set aside for strict conservation with little or no human activity. These areas are very important for protecting biodiversity, native species, spiritual heritage, and ecosystems that help regulate the climate. The core zone of SNP is made up of glacial systems, alpine meadows, and high-altitude forests. These areas are very vulnerable to damage from climate change, species migration, and tourism-related encroachment. As glaciers melt and tree lines move up, core habitats that were once safe are now open to new types of biotic pressure, such as opportunistic grazing, trail expansion, and unregulated trekking (Gaire et al., 2017). To stop this from happening, seasonal zoning, limited access permits, and real-time remote monitoring can be used to protect these alpine systems from losing trees and splitting up habitats.

The core zone of KNP has sacred forest groves, grasslands with a lot of medicinal plants and conifer stands at high elevations. Illegal logging, religious pilgrimages, and firewood gathering are putting more and more pressure on these areas, especially during seasonal festivals. To stop degradation, it is important to strictly ban tree cutting, set up rules for managing religious tourism, and encourage the use of alternative energy sources in nearby buffer zones.

Taking cues from India's Kanha National Park, where completely banning human activities in core areas has helped restore tiger habitats and sal forests (Qureshi et al., 2006). Nepal could look into similar models of exclusionary conservation that also include community compensation plans. These could include community-managed buffer incentives, payments for ecosystem services (PES), and rotational pilgrimage planning that takes pressure of sensitive areas.

5.8.2.3 Buffer Zone Strategies

Buffer zones are areas of ecological transition that protect core zones from human activity. Their main purpose is to soak up the effects of tourism, farming, and resource extraction, but they can only be used in small amounts. These areas in SNP and KNP are getting worse because people depend on fuelwood, graze their animals, expand their farms, and build unregulated tourist infrastructure. Tourism infrastructure like fuelwood use in lodges, trail expansion, and unregulated construction are the main causes of forest degradation in SNP. The ILCAF framework suggests

enforcing eco-certification for places to stay, encouraging clean energy options like solar power, and putting zoning rules in place to limit new development to lessen these effects. Putting limits on the number of trekking permits during certain times of the year can help protect the environment. It's also a good idea to plant native trees in areas that have been damaged. These methods are based on successful practices from the Annapurna Conservation Area, where tourism is controlled in buffer zones to protect the area's core ecological integrity (N. Baral et al., 2007). In KNP, the main cause of forest loss is that people depend on timber, fuelwood, and NTFPs for their basic needs, which gets worse during seasonal pilgrimages. ILCAF encourages people to map out areas of degradation and harvest in a controlled way to keep from overusing them. More people can use biogas, LPG, and better cookstoves, which can help protect forests. Overgrazing can be fixed by rotating grazing and making new pastures. Policy says that 50% of park revenue can be used for conservation and livelihoods again, but bad governance and weak implementation make this less effective (DNPWC, 2024a). ILCAF wants better monitoring, stricter rules for how land can be used, and more community involvement to make buffer zones more resilient. Forest degradation in buffer zones endangers both biodiversity and the protective function of these areas. Good management can turn them into active socio-ecological systems that help both conservation and the health of the community. This strategy is in line with the LULC trends seen in both parks: SNP's buffer zone deforestation because of more tourists (Chapter 3, Figure 3.13a) and KNP's change to agriculture and grassland (Chapter 3, Figure 3.14b). ILCAF backs the idea of using specific land-use rules to mark off core and buffer zones so that development is in line with ecological sensitivity. Within the ILCAF framework, CFUGs are necessary to stop deforestation in SNP and KNP.

In SNP, the demand for firewood and land from tourists has sped up the destruction of forests in buffer zones. CFUGs, such as LPG and solar systems, can control the collection of firewood, keep an eye on the health of the forest, and direct tourism money toward the use of clean energy (WWF-Nepal, 2023). Also, by working with eco-tourism projects, CFUGs can encourage long-term use of forests and improve the benefits for the community.

In KNP, the problem of forest degradation is mostly caused by families' need for wood for fuel and building. In this area, CFUGs can set up user agreements, enforce rotational harvesting systems, and get families involved in programs to restore the forest. KNP has fewer tourists and more reliance on natural resources, which makes it a great place to strengthen CFUGs as

community-level guardians of forest sustainability. This part focuses on making Community Forest User Groups (CFUGs) stronger because both parks depend heavily on forest resources. For example, 97% of SNP households and 99.3% of KNP households depend on firewood (Chapter 4, Table 4.2 and 4.5). It includes promoting alternative energy sources like LPG and biogas, starting reforestation programs to bring back areas that have been damaged, and giving people job training that is linked to conservation.

5.8.2.4 Sustainable Tourism Infrastructure

Well-planned tourism infrastructure can help nature and people in protected areas. ILCAF links building plans with eco-friendly tourism to meet two goals first one is the protect forests and second one is to support stable incomes. In SNP and KNP tourism should be low-impact and run by communities so the environment is protected, and benefits are shared fairly. Homestays and cultural tours create local jobs and reduce the need for new lodges and fuelwood. In SNP, fast tourism growth has raised fuelwood use and led to unplanned building in buffer zones. The regulated homestays that use existing houses can lower impacts, keep culture authentic, and offer visitor education on local ecology and stewardship. KNP has strong cultural and spiritual value and gets few visitors overall but sharp seasonal peaks; homestays can add guided heritage walks, visits to sacred sites, and stories of Khaptad Baba. These approaches match successful models in the Annapurna Conservation Area and in Bhutan, where community-based tourism supports both the economy and forest conservation (Baral et al., 2007; Rinzin et al., 2007). Current gaps—weak rules in SNP and poor, unsustainable facilities in KNP—undermine outcomes (Badal, 2024b). ILCAF addresses these gaps through eco-certification of lodging, support for community-based tourism, and measures such as rotational grazing to reduce pressure on alpine grasslands.

5.8.2.5 Participatory Monitoring

It is necessary to conduct timely and accurate monitoring of environmental changes in order to achieve effective conservation in protected areas such as the SNP and the KNP. These two parks are experiencing an increase in the amount of pressure they are under as a result of tourism, the extraction of forest resources, and the effects of climate change, which include glacier melt (SNP) and shifting vegetation zones (KNP). Within the scope of the International Land Cover Assessment

scope (ILCAF), satellite and community-based monitoring are crucial instruments for tracking real-time forest health, changes in land use, and human activities.

In the SNP, the high number of trekking tourists has led to the expansion of trails without proper regulation, the deterioration of forests in close proximity to communities, and an increase in the demand for fuelwood. This monitoring, for instance, helps detect early indicators of erosion and forest thinning along major routes, like as the Everest Base Camp track, during peak trekking seasons. For instance, this monitoring helps detect these early signs. It is possible that vulnerable alpine ecosystems will decline dramatically and irrevocably if this oversight is not provided. On the other hand, KNP is experiencing difficulties with forest degradation as a result of the high community dependence on timber, fuelwood, and grazing habitats. The distant location of the park makes it difficult to conduct monitoring on the ground. In this context, the incorporation of participatory monitoring with satellite-based Land Use and Land Cover (LULC) evaluations becomes particularly relevant.

Through the utilization of remote sensing in conjunction with community involvement, both parks are guaranteed to achieve both technical precision and local significance. Through the implementation of this strategy, early warning systems are strengthened, data-driven planning is supported, and greater community ownership of conservation activities is developed. Monitoring becomes an essential component of integrated and adaptive park management as a result of this action, which fulfills the dual objectives of preserving biodiversity and ensuring the continuation of livelihoods.

Data from the top down and participation from the bottom up are both necessary for effective conservation. In order to monitor changes in forest quality, trail density, and land conversion in real time, the International Land Conservation and Forestry Agency (ILCAF) merges satellite-based monitoring with community-led observation networks. With this dual approach, transparency is increased, community ownership is strengthened, and decision-making ability is improved (Chapter 4.4.3).

5.8.2.6 Cross-Sectoral Governance

Collaboration between the tourist, conservation, and governance sectors is required in order to effectively manage both SNP and KNP. This can be done by utilizing case studies from all throughout the country, which is a need of the ILCAF framework, which highlights that core and

buffer zones should have several strategies. Glacial and alpine ecosystems, both of which are fragile, can be found in the core zone of SNP. DNPWC, MoFE, and other agencies like ICIMOD collaborate to secure the preservation of biodiversity and to keep an eye on glaciers. Similar to how they do in Makalu-Barun National Park, seasonal zoning and limited access, both of which are implemented with SPCC, contribute to the reduction of the strain that tourism exerts on the park (MoFE, 2022). NTB, MoCTCA, TAAN, SPCC, and local committees need to collaborate in order to control eco-certification, trail use, and the use of clean energy in the buffer zone of SNP, which has many hiking routes and towns. NTNC handles tourism in Annapurna in a manner that is comparable to this, which has contributed to the preservation of the forest and reduced the amount of firewood that is required (Baral and colleagues, 2007). Better waste management has also been achieved by SNP because of public-private collaborations.

It is common for religious places in the core zone of KNP to sustain damage during festivities. By working together, the Department of National Parks and Wildlife, Ministry of the Environment, and religious bodies may make conservation a component of spiritual activities. According to Nepal and Spiteri (2011), the KNP may implement the monastery-led stewardship model that Langtang has developed in order to initiate rotational pilgrimages and educate people about conservation. Due to the fact that it relies on forests for grazing and fuelwood, the buffer zone that surrounds KNP requires collaboration between rural municipalities, basal zone management councils, and forest user organizations. These organizations are able to control harvesting, promote cookstoves, and increase the availability of biogas with the assistance of the Ministry of Food and Environment and the Department of National Parks and Wildlife. According to Budhathoki (2004), Chitwan's buffer zone earnings and local monitoring assistance were essential in halting deforestation. These lessons are applicable in this context. There is potential for governance to become even more robust with the participation of religious leaders and women's groups.

When it comes to planning, ILCAF encourages tourism, forestry, religious, and administrative groups to collaborate with one another in order to address the issue of institutional fragmentation. Through the utilization of contribution from the community, it ensures that conservation and development are in harmony with one another, that everyone is included, and that they are founded on culture.

Table 5.1 Integrated Land-Use and Community Adaptation Framework (ILCAF) for SNP and KNP

Component	Description	SNP Application (High Tourism, Ecological Stress)	Responsible Authorities/Agencies (SNP)	KNP Application (Low Tourism, High Forest Dependency)	Responsible Authorities/Agencies (KNP)
Zonal Planning	Core Zone Strategy	• Glacier and alpine zone protection	Department of National Parks and Wildlife Conservation (DNPWC), Sagarmatha National Park Office, Himalayan Climate Initiative (HCI)	• Define sacred and ecological core zones	Department of National Parks and Wildlife Conservation (DNPWC), Khaptad National Park Office, Local Community Leaders
		• Restrict new infrastructure development		• Manage trails to prevent buffer zone encroachment	
	Buffer Zone Strategy	• Limit new constructions	Buffer Zone Management Committees (BZMC), Nepal Tourism Board (NTB), Local Trekking Associations, Sagarmatha Pollution Control Committee (SPCC)	• Map high-risk buffer areas	Buffer Zone Management Committees (BZMC), Rural Municipality Offices, Khaptad Area Development Committee
		• Enforce eco-certification of lodges		• Increase patrolling	
		• Cap trekkers seasonally		• Certify informal trails	
		• Promote alternative energy sources		• Install signage and erosion control	
				• Promote alternative energy use	
Forest Stewardship Capacity Building	Forest monitoring and tourism-enhancing training	• Use tourism revenue for reforestation	Sagarmatha Pollution Control Committee (SPCC), Nepal Tourism Board (NTB), Sagarmatha National Park Office, World Wildlife Fund Nepal (WWF-Nepal)	• Support Community Forestry User Groups (CFUGs)	Community Forestry User Groups (CFUGs), Local Governments, Forest Research and Training Centre (FRTC), Federation of Community Forestry Users Nepal (FECOFUN)
		• Train youth in eco-tourism skills		• Capacity development using advanced geospatial tools for forest monitoring	
Tourism Infrastructure for Conservation and Livelihoods	Eco-sensitive development strategies	• Enforce eco-certification of accommodations	Nepal Tourism Board (NTB), Sagarmatha Pollution Control Committee (SPCC), Trekking Agencies Association of Nepal (TAAN), Local Eco-Lodge Operators	• Develop homestays and cultural tours	Khaptad Tourism Development Committee, Nepal Tourism Board (NTB) – Regional Office, Local Municipalities
		• Introduce tourist caps during peak season		• Promote alternatives to fuelwood	
		• Promote off-season travel		• Introduce rotational grazing	
				• Design spiritual tourism routes	
Satellite and Community Monitoring	Remote and participatory monitoring	• Develop monthly dashboards on trail and forest health using satellite and field data	Department of National Parks and Wildlife Conservation (DNPWC), Sagarmatha Pollution Control Committee (SPCC), International Centre for Integrated Mountain Development (ICIMOD), Everest Link GIS Unit	• Conduct regular Land Use and Land Cover (LULC) assessments	Forest Resource Assessment Nepal (FRA Nepal), Khaptad National Park Office, National Academy of Science and Technology (NAST) – GIS Labs
				• Detect encroachment and trail expansion	
Cross-Sector Coordination	Integrated governance across sectors	• Coordinate NTB, park authority, and trekking agencies	Nepal Tourism Board (NTB), Ministry of Culture, Tourism and Civil Aviation (MoCTCA), Department of National Parks and Wildlife Conservation (DNPWC), Trekking Agencies Association of Nepal (TAAN)	• Coordinate with provincial government, DNPWC, and local religious bodies	Government of Province 7, Department of National Parks and Wildlife Conservation (DNPWC), Ministry of Forests and Environment (MoFE), Religious Councils
		• Integrate tourism development with conservation goals		• Align tourism, forest, and cultural values	

5.9 Comparative overview of protected-area management approaches

SNP and KNP face overlapping pressures tourism build-out, subsistence forest use, and accelerating mountain hazards (glacier retreat, GLOF-related risks)—yet the standard tools each cover a single slice of this problem (management scorecards, system scans, ES valuation, or perceptions). None of them, on their own, link core–buffer LULC dynamics, tourism capacity, community preferences, and climate/hazard triggers into one adaptive loop. In High Mountain Asia, IPCC AR6 and related work underscore rising exposure to cryosphere-driven floods and instability, reinforcing the need to embed anticipatory triggers (e.g., lake-level or heat-stress thresholds) into park decision-making.

The assessment tools in Table 5.2 align with their documented scopes. METT-4 is a site-level management scorecard for a single protected area; it tracks inputs, processes, and some outputs, but it does not map land-use change, tourism carrying capacity, or climate triggers (METT_4_Handbook 2021). RAPPAM is designed for system-level (country/region) rapid assessment to identify threats, vulnerabilities, and management priorities across a network—broad and comparative, but coarse and non-spatial (Jungius),(RAPPAM: Rapid Assessment and Prioritisation of Protected Area Management Tool).

TESSA is a site-based ecosystem-services toolkit that estimates benefits (e.g., water, carbon) under alternative states; it is not a governance or LULC-forecasting tool (‘TESSA (Toolkit for Ecosystem Service Site-Based Assessment)’. SUS-TAS is a validated scale to measure residents’ attitudes toward sustainable tourism—strong for perceptions, not for spatial monitoring or zoning design (Choi and Sirakaya, 2005).

For this thesis, LULC mapping with Random Forest and scenario testing with CA-based models/ANN are methodologically well-supported: RF is widely evidenced as robust for remote-sensing classification, and CA/ANN families are used to test spatial development trajectories (Belgiu and Drăguț, 2016).

Table 5.2 Comparative overview of protected-area management approaches

Criterion	ILCAF (this Study)	METT-4	RAPPAM	TESSA	SUS-TAS	IPA (HWC)
Primary purpose/output	Integrated, spatial core–buffer management with maps, thresholds, roles, and scenarios	Site-level management scorecard of effectiveness	System-level rapid assessment and prioritization across a PA network	Site-based ES (ecosystem service) assessment and valuation	Residents’ attitudes to sustainable tourism	Priority matrix for HWC actions from importance vs performance
Spatial focus/scale	Core and buffer zones; RS-based LULC now + CA-ANN futures	Single PA (site)	Country/region portfolio of PAs	Single site/habitat	Community/resident survey area	HWC interface zones/settlements
What it measures	LULC change (RF), trail/settlement pressure, tourism capacity, climate/hazard triggers, perceptions, governance	Inputs/processes/outputs of management; threats and responses	Threats, vulnerabilities, pressures, and management gaps across the system	ES indicators (e.g., water, carbon, tourism) and comparative states	Multi-dimensional attitude scale toward sustainable tourism	Perceived importance vs performance of HWC strategies
Strengths	Bridges ecology–tourism–social–governance; adaptive with triggers; decision-ready dashboards	Widely used, quick, comparable scores	Gives a network-wide overview for targeting resources	Makes ES benefits tangible; suitable for cases/budgets	Validated, interpretable social metric	Simple triage; clear priorities for conflict mitigation
Limitations	Requires multi-source data and coordination (but yields operational plan)	Not spatial/LULC-forecasting; no climate triggers	Coarse; not site-spatial; snapshot-type	Valuation-oriented, not a governance or zoning tool	Perceptions only; not spatial or management-design	Narrow to HWC; not full park management
How to use inside ILCAF	(Framework hub)	Annual scorecards feed the ILCAF action register	3–5-yr system scan to set ILCAF priorities	ES cases inform ILCAF investment/benefit-sharing	Track social license; adjust zoning/capacity and co-management	Rank HWC actions; implement via ILCAF roles and budgets
Why ILCAF is better	Only option that integrates spatial LULC + tourism capacity + climate triggers + community inputs into one adaptive, accountable plan	—	—	—	—	—

5.10 Applicability of ILCAF Across Nepal's Protected Areas

Nepal's protected-area network spans 12 national parks, 6 conservation areas, 1 wildlife reserve, 1 hunting reserve, and 13 buffer zones. These are spreads from the lowland Terai to the high Himalaya. This geographic and socio-ecological diversity requires a management approach that is both adaptable and coherent. This ILCAF, developed as part of this thesis, is intended to serve that purpose. It combines spatial LULC monitoring with rules for tourism and access management, community co-management, and climate-risk triggers. It is structured so that the same core elements can be adapted to different park contexts (DNPWC, 2024a).

The Annapurna Conservation Area, Langtang National Park, and Chitwan National Park are examples of areas that are ecologically sensitive and undergo high levels of tourism. These areas require the implementation of visitor management tools such as clear zoning, limits on the number of people who can stay in a particular area, and eco-standards for accommodations. In this area have the need of satellite-based oversight and regular audits. In the Annapurna model of zoning and community-based tourism governance, it is demonstrated how laws that are based on capacity can conserve the environment while still delivering advantages to the community. According to N. Baral et al. (2008), the ILCAF puts this into action by utilizing standardized monitoring techniques and decision thresholds.

In lower-tourism, forest-dependent parks (e.g., Makalu-Barun, Rara, Bardia), the framework's emphasis shifts toward community forestry and buffer-zone co-management, rotational grazing plans, and clean-energy transitions that reduce pressure on fuelwood and fodder while protecting livelihoods.

When it comes to pilgrimage and cultural landscapes, such as Shivapuri-Nagarjun and Shey-Phoksundo, the International Land Conservation and Forestry Fund (ILCAF) incorporate cultural coordination mechanisms. These mechanisms include the recognition of sacred sites, visitor education, and engagement with religious councils. The goal of these mechanisms is to strengthen conservation outcomes by incorporating traditional ecological knowledge and cultural values, rather than operating together with park management. According to Bhagwat and Rutte (2006), the conservation importance of sacred natural locations has been well documented, and formal recognition enhances the longevity and validity of preservation.

The connection of the ILCAF with national policy and global targets makes it possible to scale the ILCAF across the entire system. At the national level, Nepal's National Basic Standards and Action Plan (2014–2020) calls for site-specific, adaptive management that is

integrated into local planning. Additionally, the Protected Area Management Strategy 2022–2030 places an emphasis on decentralized, data-informed, multi-stakeholder governance. These are precisely the operating conditions that ILCAF is designed to put into practice. A transparent escalation from park dashboards to national and international accounts can be supported by the framework's indicators and reporting cadence.

In conclusion, the internal evidence base associated with this thesis provides justification for the deployment of ILCAF across Nepal's PA network. On the other hand, in Khaptad, subsistence agriculture and forest extraction dominate stress despite low visitor volumes. In Sagarmatha, the concentration of tourism infrastructure expansion and the corresponding rise in forest degradation that was identified in the LULC analyses are repeated in the community feelings of pressure. These contrasts demonstrate that drivers interact differently depending on the environment, and that a single-sector instrument is insufficient to capture the full picture. In order for managers to be able to change decisions at the core–buffer interface rather than reacting after degradation has occurred, the modular design of ILCAF translates those findings into a practical operational model. This model (ILCAF) is one that routinely updates spatial evidence, relates it to locally legitimate rules, and names accountable actors. (See the cited figures and tables inside the first five chapters of the thesis.)

5.11 Exportability of the ILCAF Framework in Nepal's Protected Area System

The ILCAF is developed through a comprehensive analysis of SNP and KNP. This is structured to serve as a replicable, scalable model for sustainable management across Nepal's entire protected area system. Its modular design allows it to be customized for different ecological, social, economic, and cultural contexts, making it a useful tool for planning conservation at the landscape level (Figure 5.7). In the Nepal's there are lot of different types of national parks, from glacier areas in the north to subtropical forests in the south. There are problems in every national parks. ILCAF uses zoning, eco-friendly lodgings, and visitor limits to protect nature and reduce the burden on services in busy parks with lots of visitors. ILCAF promotes community-managed forests, clean energy, and other ways to generate money in quieter parks where people depend on forest resources. This minimizes the risk of deforestation.

ILCAF is useful for the protected areas which has deep cultural and spiritual significance. It supports integrating traditional ecological knowledge, sacred site protection and religious tourism management. This framework enhances both ecological

conservation and also safeguarding of Nepal’s intangible cultural heritage. ILCAF have the operational flexibility, rooted in participatory governance, evidence-based monitoring and multi-stakeholder collaboration this distinguishes the ILCAF from the others framework. The framework empowers local groups BZMCs, rural municipalities, and forest user groups to make decisions, while staying aligned with national strategies and global conservation goals. By ILCAF the single system can be developed for planning land use, protecting ecosystems, and making communities more resilient across all of Nepal's national parks. The plan is adaptable in ILCAF and enough to work for any park, no matter what its ecology, tourism pressure, or ability to administer. It can be used in a way that meets local needs while still following national standards.

Exportability of the ILCAF Framework in Nepal’s Protected Area System

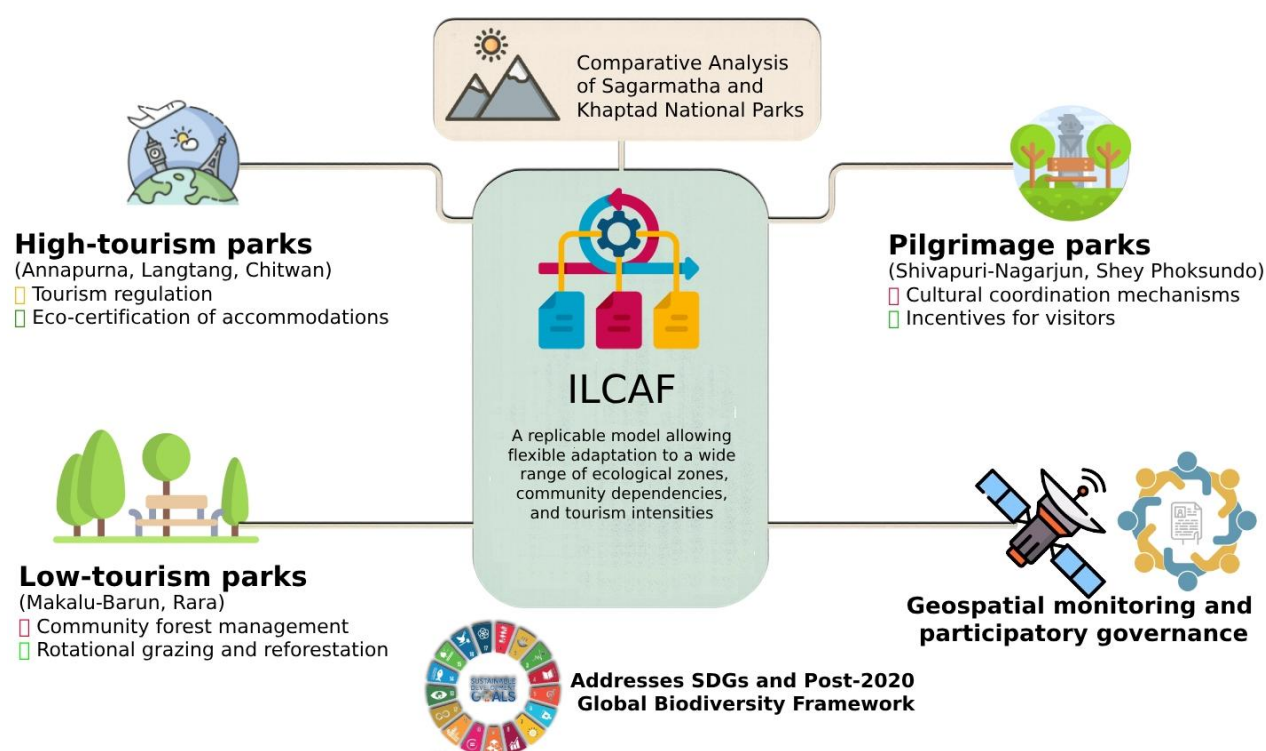


Figure 5.7: Exportability of the ILCAF Framework in Nepal’s Protected Area System

ILCAF framework is aligned with Nepal’s core policy including the National Biodiversity Strategy and Action Plan (NBSAP), the Protected Area Management Strategy 2022–2030, and international frameworks such as the Post-2020 Global Biodiversity Framework. This framework also supports the multiple Sustainable Development Goals (SDGs), mainly related to climate resilience (SDG 13), sustainable communities (SDG 11), biodiversity (SDG 15), and inclusive governance (SDG 16).

This Chapter consolidate the findings from geospatial analyses, climate assessments, and community perception studies into the ILCAF. This framework also offers a comprehensive, strategic, and scalable solution to the intertwined challenges of deforestation, unsustainable tourism, and climate vulnerability. LCAF is a reliable, evidence-based framework that helps with adaptive, participatory, and inclusive management in all of Nepal's national parks.

5.12 Summary of Chapter

This chapter analyzes the geospatial, climate and social evidence from SNP and KNP to show how tourism growth, forest use, and rapid glacier change interact most strongly at the core–buffer boundary. Our study showed why routine assessment tools are not enough today. METT-4 tracks site management at the park level but gives no spatial, forward-looking guidance. RAPPAM offers a coarse, non-spatial system scan. TESSA estimates site-based ecosystem service benefits, and SUS-TAS measures residents' attitudes. Each is useful, yet none links LULC change, tourism capacity, community voices, and climate triggers in one cycle. By contrast, ILCAF uses methods that are well supported by Random Forest for classification and CA/ANN for scenarios. Remote-sensing and land-change studies back them, giving the framework credibility and decision value. This study showed the framework can work widely across common Nepal park contexts: capacity-based access and zoning in high-tourism areas; community forestry, rotational grazing, and clean energy where forest dependence is high; and culturally informed stewardship in pilgrimage landscapes. ILCAF's routines—spatial monitoring, thresholds, roles, and feedback—match Nepal's policies for adaptive, participatory management, and it can be adopted without new mandates while also strengthening accountability to national plans at multiple government levels.

Chapter 5 shows that an integrated, spatial, and community-based approach is both necessary and feasible to protect biodiversity and livelihoods under rapidly changing mountain climate conditions today.

Chapter 6. Conclusions and Recommendations

This study investigated the dynamics of LULC and the effects of climate change on the core and buffer zones of SNP and KNP by alignment with the research objectives. This study not only enhances the technical methodologies for examining LULC but also provide the practical applications for sustainable tourism, addressing significant knowledge deficiencies in mountain LULC research. This study combines historical LULC changes, CA-ANN-based LULC forecasts, and climate change to create a baseline for future conservation efforts. It also looks into how natural and human-made factors work together to change LULC in high-mountain ecosystems. This study used a questionnaire to learn community views and what factors drive land-use/land-cover change and mountain tourism. This research examines the interrelations between various sectors (tourism and agriculture) and their environmental impact. The results of this study hold significant implications for the formulation of a new framework for sustainable tourism practices, especially concerning land use management and biodiversity conservation in mountainous tourism areas.

6.1 Spatiotemporal Trends in Land Transformation in SNP and KNP

This chapter integrates findings from Landsat-derived LULC mapping (business-as-usual forecasts, and community surveys (SUS-TAS) to fulfil the study objectives. This research uses them to measure past changes, predict near-term trends, and turn the results into practical management actions. The Landsat datasets with open-access satellite observations, random forest classification methods, and high-resolution images for validation to look at the LULC changes in the core and buffer zones of two national parks were used. The findings indicate substantial LULC alterations influenced by a multifaceted interaction of natural and anthropogenic factors, notably climate change, population expansion, and tourism development. From 1989 to 2021, the area covered by snow and glaciers in SNP shrank by a huge 140.25 km². The forest cover also went down by 15.36 km² in the whole area, mostly in the buffer zone, which lost 13.45 km². In the core zone, there was an increase of 68.84 km² of bare land and 42.97 km² of grasslands. The park also saw an increase in built-up areas of 0.80 km², which is a sign of more tourism-related activities and infrastructure development.

LULC changes in KNP are not as clear as they are in SNP, but they are still worrying. From 1991 to 2020, the amount of forest cover in KNP went down by 19.33 km², while the

amount of agricultural land went up by 8.09 km² and the amount of grassland went up by 14.33 km². In the buffer zone, the area that was built up also grew by 1.09 km².

These quantitative LULC changes show that parks are facing serious environmental problems and that effective conservation strategies are needed. For example, national park policies should be different based on the number of tourists and the options for making a living.

6.2 LULC future projections of SNP and KNP

Estimating future LULC in a BAU scenario helps us predict future environmental problems and the overall damage caused by different natural and human factors. These LULC studies reveal critical trajectories of land-use change essential for comprehending the effects of mountain tourism and for enabling policymakers to preserve ecological integrity and enhance ecosystem services for future generations. This study utilized CA-ANN modelling to forecast future LULC under a BAU scenario.

The projections make it clear what will happen in the near future. They show that forest cover will keep going down in both buffer and core zones in SNP from 1989 to 2032 and in KNP from 1991 to 2030. In SNP, it is expected that bare land will decrease in both zones, and that snow and glacier cover will decrease in the core zone by 2032. From 1991 to 2030, built-up and agricultural areas are expected to grow in both parts of the KNP region.

The LULC projections show that by 2032, the core zone of SNP will have lost another 22.84 km² of snow and glacier cover under BAU. If things keep going the way they are, the forest cover in KNP is expected to decrease by 18.44 km² in the buffer zone and 5.37 km² in the core zone by 2030. This is mostly because of farming and more people moving into the area. These forecasts give us information about how landscapes change over time that traditional, retrospective LULC analyses often miss. This helps us get a full picture of how landscapes change in sensitive mountain areas. The CA-ANN-based projections give us a look ahead at how land cover will change because of tourism and climate change. This study is different because it takes a comprehensive look at both current and future changes in ecologically sensitive mountain areas, giving policymakers useful information.

6.3 Community perspective to develop sustainable mountain tourism in the Protected Areas.

This section uses SUS-TAS household surveys, focused discussions, and field observations to show how local opinions can help SNP and KNP have sustainable mountain

tourism. The two goals are to find out how tourism affects people's lives and land use, and to turn community priorities into useful tools for managing mountain protected areas. The results show that what people in the community corresponds to the patterns of change over time and space that remote sensing found.

Respondents consistently link tourism activities at the household level to more stress on nearby forests, mostly because of energy needs, building materials. People in communities also connect the growth and intensification of farming to the decline of forests at the edges. This is because of a combination of population growth, seasonal visitors, and market incentives. At the same time, households that rely on forest resources (fuelwood, fodder, timber) say that these resources are becoming harder to find and that it takes longer to collect them. This shows how energy poverty affects decisions about how to use land. These perceptions corroborate the ecological diagnostics delineated previously in the thesis: the expansion of built footprints, the alteration of cryosphere/grassland transitions in SNP, and the persistent pressure on forest mosaics in KNP. It's important to remember that perceptions are based on the situation. In SNP, tourism is closely linked to high altitude trekking paths, groups of lodges, and seasonal peaks that cross over fragile alpine ecotones and pasture systems.

People in communities talk about the conflicts between visitor services, biomass use, and keeping vegetation buffers along trails and near the treeline.

The main things that happen in KNP are religious tourism, mixed farming, and the links between villages and forests. People in households say that there should be clear rules about homestays, how to deal with waste and water in temple areas, and other ways to make money that don't involve cutting down trees or burning wood. These points of view should be read differently because the underlying mechanisms (tourism, agriculture, energy) are the same, but the leverage points and acceptable trade-offs are different for each park. To make these community priorities into policy, you need to use a set of tools that work together. First, tourism growth should be planned by ecological zone, with clear limits on how many people can stay in sensitive areas and how much infrastructure can be built there. When appropriate, permits can be tied to meeting standards for energy, waste, and water. Regular audits can also provide consistent rewards and punishments.

Second, community forestry and agroforestry need to be better so that they can provide fuel, fodder, and small amounts of timber without cutting down core forest patches.

Agroforestry buffers at the edges of settlements and forests can help ease pressure and create new ways for people to make money that fit with their skills and the local market.

Third, communities always stress that a planned switch from biomass to cleaner energy sources for homes and homestays is necessary to ease the daily extraction pressure. We need a system of government that puts the community first in order for these tools to work. Community-based co-management committees that make sure women and other groups that aren't well represented can take part are where boundaries, rules, monitoring arrangements, conflict resolution, and graduated sanctions can all be co-designed and improved over time. Putting these committees into the structures that already exist in the buffer zone can make them more real and cut down on duplication. People in communities say that rules should be easy to understand, available to everyone, and the same all year round. People are less likely to follow rules if they aren't clear or if they are enforced on a case-by-case basis. This is especially true during busy tourist seasons. To be effective, monitoring and adaptive management must utilize both remote-sensing indicators and community-sourced information. Everyone would have a common starting point for making changes if there was a yearly public "State of the Park" report that talked about the condition of the forest, changes in the built footprint, trail-adjacent buffers, tourism volumes, and the mix of energy used by households. When certain limits are crossed, like when vegetative buffers along certain corridors are lost or when built-up areas grow beyond agreed-upon limits, actions that have already been agreed upon can be taken. Some of these actions could be temporary bans on new buildings, targeted energy subsidies, or stricter enforcement in some areas. By using clear measurements and predictable responses, authorities and communities can go from reactive policing to preventive stewardship. This way of thinking has certain effects on parks. The main goal of SNP is to keep the number of trekking corridors low, protect high-altitude vegetation buffers, and plan seasonal grazing so that tourism services don't harm fragile alpine systems over time. It's very important to change the energy sources used in homes and lodges if you want to cut down on the amount of fuelwood taken from areas near the treeline and busy roads.

In KNP, formalizing visitor management for homestays and temple areas (solid waste, sanitation, and water) should happen at the same time as implementing community forestry and mixed-farming agroforestry packages that help families make more money while putting less stress on core forest patches. In both parks, diversifying livelihoods in line with local

comparative advantages (such as non-timber forest products, value-added agriculture, guiding, and cultural services) can help separate income from forest extraction.

6.4 ILCAF for Mountain Protected Areas: Concluding Framework for Action

The ILCAF created in this study addresses significant governance issues in Nepal's protected area system, particularly the disunity of sectoral policies and the insufficient involvement of local communities in resource management. ILCAF promotes integrated planning that includes tourism, agriculture, and forest conservation. This means that conservation efforts are in line with development goals instead of being separate from them. This integration lessens conflicts between sectors and creates a clear path toward sustainable land-use governance in mountain areas that are sensitive to the environment. One of ILCAF's best features is that it includes real-time environmental monitoring and vulnerability assessment. The addition of real-time data streams makes it possible to make decisions quickly by finding new ecological stresses, like too many tourists or land conversion that isn't sustainable. For example, using advanced AI tools to keep an eye on how tourists move around can help control how many people visit ecologically sensitive areas. Also, vulnerability assessments that are specific to each park's situation, like glacial retreat in alpine zones or deforestation in mid-hill buffer areas, make the framework better at helping with site-specific adaptive interventions. ILCAF is based on the idea of collaborative resource governance, which means that everyone in the community should be involved. The framework incorporates indigenous knowledge and enhances local stewardship by involving local communities in data collection, monitoring, and decision-making. This participatory approach enhances implementation effectiveness and guarantees that conservation strategies are culturally relevant and socially acceptable.

The framework's applicability is evidenced by the comparative analysis of SNP and KNP. SNP has a lot of international tourists, but KNP has a lot of religious tourists during certain times of the year and is more dependent on the forest. This difference makes it easy to see how ILCAF uses adaptive management strategies based on the amount of tourism, the way people make a living, and the socio-ecological vulnerabilities. The framework's adaptability allows for context-specific modifications to management strategies, facilitating its scalability throughout Nepal's diverse national park system.

ILCAF brings together key parts like real-time monitoring, indicators for specific sectors, and ways for people to get involved to improve resilience planning and help adaptive governance. These elements make it possible to do long-term evaluations of socio-ecological vulnerability and help people make decisions based on facts. In places with a lot of stress, like SNP, ILCAF could put regulating the number of tourists and reducing the damage that tourism does to the environment at the top of its list of priorities. On the other hand, the framework in KNP may focus on building infrastructure for eco-tourism, taking care of forests, and finding new ways to make a living. Using forest transition theory in this way makes it possible to balance the need for agricultural growth with the need to protect the environment.

ILCAF offers a scientifically sound and operationally practical model for achieving a balance between environmental sustainability and community resilience by integrating cross-sectoral connections and aligning local governance frameworks with national conservation policies. The framework's multidimensional structure allows for more flexible, data-driven, and inclusive management practices. This makes it a model that can be used in other protected areas in Nepal and similar mountain ecosystems around the world.

6.5 Limitations and Future Scope

This study has some limitations that provide directions for future research:

- The limited availability of Landsat data without clouds and their spatial resolution may affect the accuracy of LULC classification. Better ways to choose and prepare data could lead to better classification results
- Changes in LULC are affected by seasonal changes. This study utilizes single-season data, highlighting the necessity for multi-seasonal datasets that accurately represent the dynamic characteristics of LULC.
- The absence of meteorological station data prevents a comprehensive examination of the relationship between climate change and land use/land cover change.
- The collection of questionnaire survey data in the core zone could clarify the effects of diverse factors influencing LULC changes within that area.
- The absence of local tourist data for KNP makes it hard to do a full comparative analysis of past tourist trends, the problems they caused, and the growth of tourism-related infrastructure. Filling in these data gaps would make it easier to look more closely at how tourism affects LULC.

Future research efforts will address these limitations and explain the complex nature of LULC changes and the diverse factors that influence these dynamics. Improve classification accuracy through better data selection and pre-processing, and conduct multi-seasonal LULC analysis for enhanced understanding. Integrate meteorological and tourism datasets for more comprehensive analysis. Expand core zone survey data for richer insights. Focus on multi-sectoral, long-term monitoring for better park management. Future research in these areas can advance mountain LULC research by providing additional information and informing better management plans for national park.

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Annexures

Table A1. LULC change and prediction of SNP

Classes	Area (Km ²)															
	1989		2000		2010		2021		2032		Change 1989-2021			Change 2021-2032		
	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Total	Core	Buffer	Total
Forest	36.75	85.1	37.48	82.81	35.71	78.2	34.84	71.65	33.45	71.43	-1.91	-13.45	-15.36	-1.39	-0.22	-1.61
Shrubland	119.98	38.69	113.75	45.15	130.16	53.26	114.94	57.87	96.38	54.15	-5.04	19.18	14.14	-18.56	-3.72	-22.28
Bareland	456.55	63.59	531.57	76.8	503.13	68.31	525.38	74.71	555.05	72.5	68.84	11.11	79.95	29.67	-2.21	27.46
Agriculture	2.22	2.5	2.27	2.61	2.63	2.33	2.73	3.01	3.77	3.43	0.51	0.51	1.02	1.04	0.42	1.46
Water	2.77	1.29	2.37	1.06	4.42	1.17	3.83	0.99	3.86	0.96	1.06	-0.29	0.77	0.03	-0.03	-0.01
Snow/glacier	384.92	70.45	321.25	50.37	300.82	44.91	278.69	36.44	255.85	30.49	-106.23	-34.01	-140.25	-22.84	-5.95	-28.79
Grassland	114.59	16.94	110.66	20.05	141.65	29.9	157.56	33.45	165.48	44.85	42.97	16.51	59.47	7.92	11.4	19.32
Glacier lake	6.65	1.35	4.31	1.28	5.47	1.84	8.88	2.14	12.32	2.34	2.23	0.8	3.02	3.44	0.2	3.64
Built-up	0.21	0.04	0.3	0.12	0.38	0.17	0.65	0.4	0.74	0.41	0.44	0.36	0.8	0.09	0.01	0.1
Kharka	6.71	0.99	7.39	0.69	6.98	0.86	3.86	0.28	4.45	0.39	-2.85	-0.71	-3.56	0.59	0.11	0.7

Table A2. LULC change and prediction of KNP

Classes	Area (Km ²)															
	1991		1999		2010		2020		2030		Change 1991-2020			Change 2020-2030		
	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Core	Buffer	Total	Core	Buffer	Total
Forest	252.01	205.83	241.64	200.59	252.19	191.34	252.72	186.5	247.35	168.06	0.71	-19.33	-18.63	-5.37	-18.44	-23.8
Shrubland	15.74	62.76	26.03	61.32	16.09	64.13	11.63	56.4	8.16	53.29	-4.11	-6.36	-10.48	-3.47	-3.11	-6.58
Bareland	0.05	0.05	0.06	0.1	0.04	0.2	0.08	0.8	0.09	1.3	0.03	0.75	0.78	0.01	0.5	0.51
Agriculture	3.76	79	3.78	84.71	2.84	86.31	3.83	87.09	7.5	101.66	0.08	8.09	8.17	3.67	14.56	18.23
Water	0.03	0.8	0.04	1.17	0.17	2.1	0.05	2.23	0.09	2.4	0.02	1.44	1.45	0.04	0.17	0.21
Grassland	7.37	4.59	7.41	4.68	7.62	8.15	10.64	18.93	15.74	24.95	3.27	14.33	17.6	5.1	6.03	11.13
Built-up	0	1.29	0.01	1.74	0.02	2.1	0.02	2.38	0.04	2.66	0.02	1.09	1.11	0.02	0.28	0.3

Table A3. Accuracy assessment error matrix of SNP of years (a) 1989, (b) 2000, (c) 2010, (d) 2021

(a) 1989													
Class		Reference											UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Snow/glacier	Grassland	Glacier Lake	Built-up	Karkha	Total	
Classified	Forest	55	2		4							61	90.16
	Shrubland	3	38	3				3				47	80.85
	Bareland		1	43			1	2		2		49	87.76
	Agriculture	9			51						5	65	78.46
	Water					25			12			37	67.57
	Snow/glacier		2	12			121					135	89.63
	Grassland		1	4			2	30				37	81.08
	Glacier Lake					11			20			31	64.52
	Built-up			7						24		31	77.42
	Karkha				7						20	27	74.07
	Total	67	44	69	62	36	124	32	35	26	25	520	
PA (%)		82.09	86.36	62.32	82.26	69.44	97.58	93.75	57.14	92.31	80	82.12	
Kappa = 0.794													
(b) 2000													
Class		Reference											UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Snow/glacier	Grassland	Glacier Lake	Built-up	Karkha	Total	
Classified	Forest	45	1		2							48	93.75
	Shrubland	4	38	2					3			47	80.85
	Bareland		3	62			2					67	92.54
	Agriculture	7			41						6	54	75.92
	Water					30			16			46	65.22
	Snow/glacier		2	14			140					156	89.74
	Grassland		4	1			2	30				37	81.08
	Glacier Lake					13			21			34	61.77
	Built-up			3						19		22	86.36
	Karkha				2			1			16	19	84.21
	Total	56	48	82	45	43	144	31	40	19	22	530	
PA (%)		80.36	79.17	75.61	91.11	69.77	97.22	96.74	52.5	100.00	72.72	83.4	

Kappa = 0.806													
(c) 2010													
Class		Reference											UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Snow/glacier	Grassland	Glacier Lake	Built-up	Karkha	Total	
Classified	Forest	53	2		3		1				3	62	85.48
	Shrubland	5	42	3					2			52	80.77
	Bareland		4	52			2					58	89.66
	Agriculture	6			49						7	62	79.03
	Water					32			14			46	69.57
	Snow/glacier		2	12			171		1			186	91.94
	Grassland	1	4	1			2	33				41	80.49
	Glacier Lake					11			31			42	73.81
	Built-up			2						23		25	92
	Karkha	3	3		5			1			19	31	61.29
Total	68	57	70	57	43	176	34	48	23	29	605		
PA (%)		77.94	73.68	7.29	85.97	74.42	97.16	97.06	64.58	100.00	65.52	83.47	
Kappa = 0.806													
(d) 2021													
Class		Reference											UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Snow/glacier	Grassland	Glacier Lake	Built-up	Karkha	Total	
Classified	Forest	48	3	0	5		1				3	60	80
	Shrubland	6	40	3					1			50	80
	Bareland		5	69			2					76	90.79
	Agriculture	3			44						3	50	88
	Water					31			11			42	73.81
	Snow/glacier		2	9			131		1			143	91.61
	Grassland	1	3	1			2	36				43	83.72
	Glacier Lake					11			23			34	67.65
	Built-up			2						18		20	90
	Karkha		2		1			1			20	24	83.33
Total	58	55	84	50	42	136	37	36	18	26	542		
PA (%)		82.76	72.73	82.14	88	73.81	96.32	97.3	63.89	100.00	76.92	84.87	
Kappa = 0.825													

Table A4. Accuracy assessment error matrix of KNP of years (a) 1991, (b) 1999, (c) 2010, (d) 2020

(a) 1991										
Class		Reference								UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Grassland	Built-up	Total	
Classified	Forest	277	7	2	5	7	3		301	92.03
	Shrubland	8	36	1	1		1		47	76.6
	Bareland		1	9	1	1	1		13	69.23
	Agriculture	6	3	2	48				59	81.36
	Water			1		19	2		22	70.37
	Grassland	2	1	3	4	2	21		33	63.64
	Built-up			8				21	29	72.41
	Total	293	48	26	59	29	28	21	504	
PA (%)		94.54	75	34.62	81.36	65.52	75	100.00	OA = 85.516%	
Kappa = 0.767										
(b) 1999										
Class		Reference								UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Grassland	Built-up	Total	
Classified	Forest	269	7		24		7		307	87.62
	Shrubland	11	56	1	3				71	78.87
	Bareland			32					32	100.00
	Agriculture	19	5	1	41	1			67	61.19
	Water			1		23	2		26	88.46
	Grassland	1					31		32	96.88
	Built-up							19	19	100.00
	Total	300	68	35	68	24	40	19	554	
PA (%)		89.67	82.35	91.43	60.29	95.83	77.5	100.00	OA = 85.02%	
Kappa = 0.772										
(c) 2010										
Class		Reference								UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Grassland	Built-up	Total	

Classified	Forest	255	17		2		2		276	92.39
	Shrubland	14	42	1	1		6		64	65.63
	Bareland			33				7	40	82.5
	Agriculture	1	6	4	42		2	1	56	75.00
	Water			1		21			22	95.46
	Grassland		3				19		22	86.36
	Built-up			8				16	24	66.67
	Total	270	68	47	45	21	29	24	504	
PA (%)		94.44	61.77	70.21	93.33	100	65.52	66.67	OA = 84.92%	
Kappa = 0.773										
(d) 2020										
Class		Reference								UA (%)
		Forest	Shrubland	Bareland	Agriculture	Water	Grassland	Built-up	Total	
Classified	Forest	255	12		6		5		278	91.73
	Shrubland	11	33		3		2		49	67.35
	Bareland			27				3	30	90
	Agriculture	2	4	1	51		1		59	86.44
	Water					25			25	100.00
	Grassland	3	3		1		11		18	61.11
	Built-up			6				15	21	71.43
	Total	271	52	34	61	25	19	18	480	
PA (%)		94.1	63.46	79.41	83.61	100.00	57.9	83.33	OA = 86.86%	
Kappa = 0.794										

Table A5: 1. Questionnaire response coding scheme (correspondence table)

Questionnaire variable	Response option	Numeric code	Coded column in the dataset	Notes/interpretation
Sex	Female (F)	1	Bi_Sex	Reference coding: 1=Female, 0=Male
	Male (M)	0	Bi_Sex	Reference coding: 1=Female, 0=Male
Forest_change (perceived forest change/loss)	Increased	1	bi_Fore	Higher value indicates perceived increase
	No change	0	bi_Fore	Neutral / no perceived change

	Decreased	-1	bi_Fore	Lower value indicates perceived decrease (forest loss)
Agri_prod (agricultural productivity)	Increased	1	bi_agri_prod	higher value indicates increased productivity
	No change	0	bi_agri_prod	No perceived change
	Decreased	-1	bi_agri_prod	Lower value indicates reduced productivity
HH_tourism_impact_LULC (tourism impact on LULC at the household)	Yes	1	bi_tourism	Tourism impact reported
	No	0	bi_tourism	No tourism impact reported
Tour_satisfied (tourism satisfaction)	Highly satisfied	1	bi_satis	Most positive response
	Satisfied	0	bi_satis	Baseline / moderately positive
	Neutral	-1	bi_satis	Less positive response
	Dissatisfied	-2	bi_satis	Least positive response
Forest_depend (forest dependency)	Yes	1	bi_Forest_dependence	Household dependent on forest resources
	No	0	bi_Forest_dependence	Not dependent
Livestocks (livestock dependency/ownership)	Yes	1	bi_livestock	Livestock present/dependent
	No	0	bi_livestock	No livestock / not dependent

Appendix 2. Questionnaire response coding scheme KNP (correspondence table)

Annexure A6: Questionnaire Survey

Questionnaire survey on tourism, agriculture, and LULC

Informed Consent

Please read the following, which explains this research study, including the associated risks and benefits, if any. You are being asked to participate in the research conducted by Ms. Ankita Gupta, Hokkaido University, Sapporo (Japan), for her PhD degree. This should help you decide whether or not you want to participate in the study. Agreeing to this will confirm that you have been informed about the research and want to participate. Taking part in this study is completely voluntary and anonymous.

Research Description

Mountainous regions have emerged among the most sensitive ecosystems under the global climate change scenario. Inhabitants living in these areas play a significant role in maintaining the ecosystem, which serves as a storehouse of essential environmental goods and services to the local community and the global community. Mountain tourism in Nepal plays a significant role in providing livelihood to these rural communities, and it interconnects local people with the mountain environment. Due to the growing demand for resources, the mountain ecosystem suffers deforestation, forest degradation, landslides, overgrazing, biodiversity loss, and a decline in productivity. Therefore, Land-use and land-cover (LULC) change has become an essential subject for global environmental change occurring in many national parks in mountainous regions that urgently need to be addressed. The proposed research focuses on the tourism-LULC nexus that can influence mountain societies in SNP and KNP in Nepal. These two national parks are quite diverse regarding flora, fauna, eco-tourism activities, elevation, accessibility, etc.

Risks and Benefits

There are no foreseeable risks or discomforts for participating in this study. You may not receive any direct benefit from taking part in this study. However, by participating in this study, you support the researcher and the country in the sustainable development of tourism and agriculture in your area.

Ending your Participation

You have the right to withdraw your consent or stop participating at any time. You have the right to refuse to answer any question(s) or participate in any procedure for any reason. Refusing

to participate in this study will not result in any penalty or loss of benefits to which you are otherwise entitled.

Description of Procedures

If you agree to participate in this study, you will be asked to complete a survey lasting approximately 45 minutes.

Confidentiality

I will make every effort to maintain the confidentiality of your responses. Only the research study team will have access to the data and information about participation, which will not be shared with others except for scientific publication and community necessities.

The researcher can be reached through email Ankita Gupta at email: ankita.gupta.x8@elms.hokudai.ac.jp

Information of resource person:

1. Full Name:
2. Address:
3. Contact number:

Information of respondent:

1. National Park:
2. District:
1. Municipality:
2. Location:
3. Full Name:
4. Caste or ethnicity:
5. Age:
6. Sex:
7. Level of education:
8. Occupation:
9. Marriage status:

10. Family size:

General questions:

1. How many households are in the village?
2. What are the ethnic groups in the village? (Enlist: The most dominant (in terms of household number) at the top and least dominant at the bottom)
3. Are you a resident or a migrant?
4. How is the general climate in the study site? (Open perception-based response) Hint: General climate: Average, minimum, and maximum temperature in summer and winter and annual liquid and solid precipitation.
5. What are the primary livelihood sources? (Enlist: The most important at the top and the least important at the bottom)
6. Do you think Climate change has directly or indirectly impacted the park and the surrounding region?

Agriculture and livelihood:

1. What is the average agricultural landholding size in the village? (Use local units and note the equation to convert into standard units)
2. What are the primary crops in the village? Enlist: The most important at the top and least influential at the bottom)
3. What is the primary livestock? Enlist: The most important at the top and least necessary at the bottom
4. How many months is the food production from your land enough for your family's requirements?
5. Specify when your food production meets your household demand.
6. Do you sell crop(s)?
7. What are the animals you raise, and how many?
8. Do you usually face food shortages during any specific period in the year?
Example for period reporting: From 2nd week of Jan (Chairtra) to 1st week of Feb (Asar)
 - a. No (skip to next question)
 - b. If Yes (Specify the periods):
9. What are the reasons for food shortages?

[Hint: insufficient food production, hoarding, limited access to forest/wild food products, lack or loss of income to buy food, food supply constraints from other areas, etc.]

10. How do you manage food shortages?

Hint: reduce the number of meals per day, depending on food supply from the government or other organizations, for free or at a subsidized rate.

11. Do you hire any labor for agricultural activities?
 - a. If yes, for what purposes?
 - b. How is labor hired for agricultural activities? Please explain.
Hint: Adequate or Inadequate
 - c. Are these male and female laborers within the village or outside the town? Please explain.
12. Do you get adequate and required agricultural inputs (seed, pesticides, fertilizers, etc.)?
13. How do you access the market for food purchases (Hint: name and distance of nearest market; means of transportation)?
14. Do you have adequate income to purchase food items of your choice?
15. What food items are supplied to the village from other areas or markets?
16. Did the government supply you with any food items? Specify in form and quantity.
17. Did you receive government support (either kind or cash)? Yes or No.
 - (a) If yes, how? Hint: subsidized rate, free food
18. Has any other organization supported you (either kind of cash)? If yes, what organization and form of support (kind or money)?
19. What kind of trade do you engage in? Please describe (e.g., forest products, agricultural products, other goods)
20. What kind of Fuelwood do you use? And where do you acquire these from forest or government?
21. Who is your major customer? (Local, tourists, cross-border tourists, etc.)
22. What is your average annual financial turnover?
23. Where do you source your materials for your enterprise? For example, local farms and forests are within, out-of-state, or out of the country.
24. How did you acquire these goods?

Were they delivered? If yes, who delivered it? How (mode of transport)? How frequently?
25. What changes have occurred in the agriculture pattern or agricultural land in the last ten years?

Tourism

1. What is the primary activity here for the tourist? (Rank from 1-7)
 - a. Landscape
 - b. Trekking/Hiking
 - c. Cultural monuments
 - d. Documentary
 - e. Photography
 - f. Recreation
 - g. Camping

- h. Others (please specify)
2. How many tourists visit your area in one season?
3. How many rooms (besides the kitchen, toilet, and store) do you have in this house?
4. Do you or someone living in this household own this dwelling?
5. Do you own this house?
6. Do you or someone in this household own any other house elsewhere?
7. What are your house's primary construction materials (interior and exterior)?
8. What do you mainly use for cooking purposes?
 - a. Fuelwood
 - b. Electricity
 - c. Solar
 - d. Petroleum (Kerosine or Gas)
 - e. Dung cake
 - f. Improved cookstove operated by electricity
 - g. Improved cookstove operated by dung cake, pellet
 - h. All of the above
9. What do you mainly use for heating purposes?
 - i. Fuelwood
 - j. Electricity
 - k. Solar
 - l. Petroleum (Kerosine or Gas)
 - m. Dung cake
 - n. Improved cookstove operated by electricity
 - o. Improved cookstove used by dung cake, pellet
 - p. All of the above
10. Did your household provide tourism services like hotels, guides, and trekking to tourists during the last 12 months?
11. If yes, for Q10, how many family members were engaged in this service?
12. If you are operating a hotel, how many rooms do you have?
13. How many tourists stayed in your house in the last 12 months?
14. What is the total amount of money you earned from tourism activity during the last 12 months?
15. Are you trained to operate the hotel/trekking guide?
16. Are there any complaints or compliments by the tourists regarding your hospitality?
17. Do you think this business is sustainable for you?
 - If yes?
 - If no?
18. What are the best activities implemented for tourism? E.g., Meditation, only hiking
19. What is your opinion of tourism development in your community?
 - a. Highly satisfied
 - b. Satisfied

- c. Neutral
- d. Dissatisfied
- e. Highly dissatisfied

Land use land cover (forest resources)

1. Did you depend on forest resources for your household requirements?
If yes, what products did you collect from forests? Please explain what each product is used for, e.g., for timber, fuel, fruit, medicinal and aromatic plants, other non-timber forest products (e.g., slate, mushroom, vegetables, etc.), fodder, bedding, others: please specify
2. From where did you collect these forest products- community forest, government forest, sacred forest, private forest?
3. Who goes to the forest to collect forest products?
-Men or Women/Adult or Child
4. How often did you collect these products? E.g., daily (specify products), weekly basis, etc. Please rate the availability of these forest products on a scale of 1-5 (1 most easily available; 5 most scarce).
5. Did you earn any income from the sale of forest products?
 - Selling fuelwood/timber/NTFPs and others
 - Average earnings last year
 - Contribution to household income
6. Where did you sell these products?
7. Who sold these products? (Male/Female/Adult/Child)
8. Forest cover in this area in the last 20 years
 - a. Forest cover increased
 - b. Forest cover decreased
9. If increased or decreased, what are the primary reasons? (Enlist 1-5)
10. Are you accessing forest resources from the Buffer Zone or core area of this park?
11. Do you think climate change has impacted forest cover in the region?

Annexure A7: Field photographs collected during the survey

