

## RESEARCH ARTICLE

## LAND USE AND LAND COVER DYNAMICS AND FACTORS AFFECTING IT IN THE CENTRAL HIMALAYA

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## ARTICLE DETAILS

## Article History:

Received 01 June 2024  
Revised 03 July 2024  
Accepted 05 August 2024  
Available online 15 August 2024

## ABSTRACT

This paper examines land use and land cover dynamics in the Central Himalaya using twelve Landsat satellite images from 1991 and 2021. It also delves with the factors affecting land use and land cover change in the Central Himalaya. Processed with specialised remote sensing/GIS software (ArcGIS 10.8), false colour composites were generated, and a supervised classification with a maximum likelihood process was employed to create a land use and land cover map. Eight land use classes were identified, including snow cover, alpine pasturelands, temperate forest, tropical broadleaf forest, agricultural land, barren land, built up areas, and water bodies. Forests dominate the region (56.7%), followed by glaciers (20%) and alpine pasturelands (9.67%). Notably, snow cover and alpine pasturelands decreased by 21.59% and 7.28 %, respectively. Two land use categories - water bodies and barren land increased by above 100% whereas agricultural land increased by 60.59%. There was a nominal increase in subtropical forests while temperate forests cover remained the same with an accuracy of 86.89 % (Kappa Coefficient). In some patches, temperate forests decreased due to the expansion of pine forests towards high altitudes. Warming of middle altitudes and higher reaches noticed as the major factor of decreasing snow cover. Population growth, out-migration, climate change, and natural hazards were other primary reasons for land use and land cover change.

## KEYWORDS

Land Use Land Cover Changes, Maximum likelihood process, Landscape metrics, climate change, fragmentation, Central Himalaya.

## 1. INTRODUCTION

Land Use and Land Cover Change (LULCC) has become a prime concern for researchers worldwide because it has a significant impact on climate change (Rogan and Chen, 2004; Pielke, 2011; Climate Change, 2014). LULCC takes place because of how people use and change the land, which depends on things like where the land is, who lives there, and what they need (Lambin, 2001; FAO, 2004; Karwariya and Goyal, 2011; Tsai et al., 2019). Most of the time, it's human activities that change the land, and there's a connection between how the land looks (land cover) and how it's used (land use) (Whitby, 1992; Abate, 2011). Factors like population growth and what people need from the land are the main reasons for these changes, and they happen differently depending on where people are (Desta and Fetene, 2020; Berihun et al., 2019; Qasim et al., 2013). While these changes can often help people make money, they can also hurt the environment (Betrua et al., 2019). This can damage ecosystems over time (Schürmann et al., 2020).

Land use is the term used to describe the human use of land. It represents the economic and cultural activities that are practiced at a given place. On the other hand, land cover is defined as the observed physical cover on the earth's surface, including vegetation (natural or planted) and human constructions (USEPA, 2024). The land's inherent potential, coupled with the intricate interplay of cultural backgrounds, physical requirements, and societal conditions, shapes the land use patterns of specific regions (FAO, 2004; Karwariya and Goyal, 2011; Tsai et al., 2019). These changes, occurring within and across different land systems, lead to foreseeable and sometimes predictable shifts in land use patterns (Fresco, 1993). Scientists now use tools like satellite images and computer technology to

understand and map these changes, which makes it easier to see what's happening to the land over time (Lillesand et al., 2008; Campbell, 2007; Teffera et al., 2018).

Mountain environments, renowned for their fragility, face substantial challenges, particularly in regions like the Himalaya, which is among the most unstable and delicate mountain areas globally. Influenced by factors such as land use alterations and climate change, these ecosystems undergo significant impacts (Lambin et al., 2001; Miede et al., 2009; Macchi, 2010; Shrestha et al., 2012; Joshi et al., 2012). The Himalayan region, including the Central Himalayas, has witnessed significant LULCC over the past few decades, rendering the land less productive or unproductive and raising concerns for sustainable development in the region. LULCC is highly complex in the Himalaya, driven by accelerated anthropogenic impacts on resources. These changes have long-term negative ramifications (Rasool et al., 2016). Human-induced drivers of land use change are notably intricate, impacting various policies governing land use management (Adgar and Brown, 1994; Krummer and Turner, 1994).

The Central Himalaya, a region characterized by its awe-inspiring landscapes, ecological diversity, and rich cultural heritage, has witnessed significant transformations in land use and land cover over the past few decades. Nestled between the plains of the Indian subcontinent and the towering peaks of the Greater Himalaya, this region serves as a critical ecological and hydrological buffer, impacting the lives of millions of people downstream. However, the delicate balance of this unique ecosystem is increasingly being challenged by anthropogenic activities and global environmental changes. LULCC in the Central Himalaya are complex phenomena driven by a combination of natural and human-induced

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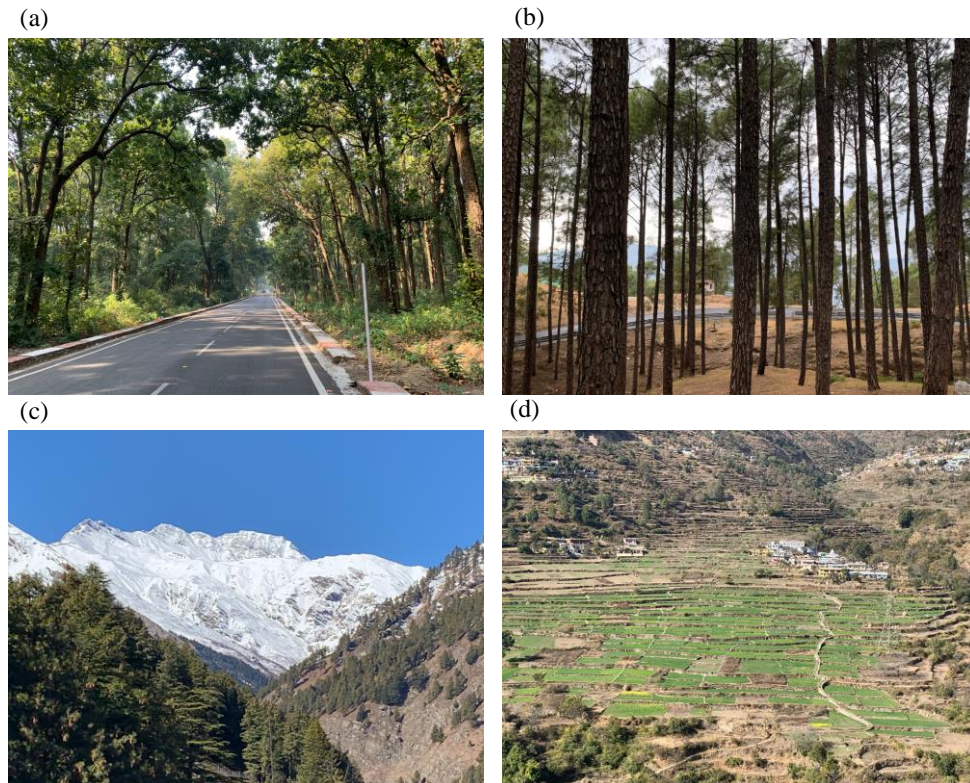
factors. Population growth, agricultural expansion, urbanization, infrastructure development, and climate change have emerged as key drivers influencing the patterns and dynamics of land use in this region. Understanding these changes is essential for effective environmental management, sustainable development, and the preservation of the ecosystem services that the Central Himalaya provides.

The Central Himalaya stands as a biodiversity hotspot (Chandra et al., 2010; Sati, 2023). However, extensive deforestation and the resulting fragmentation of forests in this region have led to severe environmental degradation, representing a critical issue in the Central Himalaya and a fundamental cause of biodiversity loss (Roy, 2000; Sharma 2007; Sati, 2019). Ministry of Environment and Forests (MoEF) data reveals that, since 1980, 44,868 hectares of forest land in Central Himalaya have been converted for non-forest purposes, with 9,500 hectares earmarked for road construction, followed by 5,500 hectares for hydro-projects, and 3,100 hectares for transmission lines. Anthropogenic drivers have been extensively studied for their impact on natural resources, biodiversity, habitat loss, and forest fragmentation (Kala, 2015). However, the Central Himalayan region confronts various hazards, including landslides,

extreme rainfall events, floods, and forest fires, further exacerbating the challenges faced by the mountain landscape and its forest ecosystems (Huebner, 1995).

Agriculture serves as the primary occupation for the people of the Central Himalaya, with approximately 70% of the population directly or indirectly involved in this sector (Tiwari and Joshi, 2014). This heavy reliance on agriculture may contribute to the overexploitation of natural resources in the region (Sati, 2023). Given the fragile nature of the Central Himalaya and the escalating human activity, there is a significant threat to the natural landscape, particularly in the forest ecosystem. Consequently, forest cover has faced mounting pressure over the past few decades in the region.

The Central Himalaya spans both vertically and horizontally. It encompasses plain regions, river valleys, middle altitudes, highlands, alpine pasturelands, and the Greater Himalaya. In terms of land use categories, there are snow cover, alpine pasturelands, forestland, agricultural land, built-up areas, and water bodies (Figure 1).



**Figure 1:** Land use patterns (a) Monsoon deciduous forests, (b) pine forests, (c) temperate forests and snow cover areas, and (d) agricultural land and rural settlements

This study aims to provide an overview of LULCC and the key drivers and consequences of LULCC in the Central Himalaya, drawing upon the latest scientific research and observations. The intricate interplay between human activities and environmental processes in this region underscores the need for interdisciplinary research and holistic approaches to address the challenges posed by changing land use and land cover. Many scholars have conducted studies on LULCC in the Himalayan region, applied secondary sources data from the government records. Furthermore, the studies were conducted at the small drainage basin levels. Meanwhile, this study adds new and valid land use data using satellite imageries for the past 30 years and covering the entire Central Himalaya. In addition, this paper also elucidates the precise factors affecting land use land cover changes in the Central Himalayan region.

## 2. STUDY AREA

The Central Himalaya encompasses an area of 54,384 km<sup>2</sup>, featuring three-dimensional landscapes including river valleys, the middle Himalaya, and the Greater Himalaya. The physiography ranges from plain regions to river valleys, small hills, steep and precipitous mountains, and snow-clad high Himalaya. The land-use pattern includes snow cover, forestland, arable land, barren land, settlements, and water bodies. The highest proportion of land is under forest cover, followed by snow and arable land. The areas under water bodies and settlements are relatively small. However, in the recent past, there has been a decrease in snow cover and temperate forest

area, while water bodies, settlements, and barren land have increased. The climate varies according to altitude and determines the pattern of forest distribution, ranging from tropical to subtropical and temperate, and from broadleaf to pine, mixed-oak, coniferous, and alpine pasturelands. Recently, the distribution pattern of forest species has varied due to high climate variability and change. The Central Himalaya comprises two geographical and cultural entities – Garhwal and Kumaon. The Garhwal Himalaya consists of seven districts, whereas the Kumaon Himalaya has six districts. Population density varies from the plain region (high) to mountainous mainland (low). Economic development is nominal, and a large portion of the population depends on practicing agriculture. Additionally, the population has increased, leading to out-migration. The region is highly vulnerable to climate change and natural hazards.

## 3. METHODOLOGY

### 3.1 Data Source

The United States Geological Survey Earth Explorer portal served as the source for satellite images in the present work. Orthorectified images, with UTM projection and WGS 84 datum, comprised Landsat 8 OLI (Operational Land Imager) data for the year 2021 and Landsat 4-5 TM (Thematic Mapper) data for the year 1991 were utilized for the research (Table 1). For the years 1991 and 2021, a total of 12 images covering the entire Uttarakhand region were downloaded (Path 144 with rows 38-39; Path 145 with rows 38-39; Path 146 with rows 38-39).

Table 1: Description of spatial data used for the research					
Year	Satellite/Sensor	Spatial resolution (m)	Path/row	Used band combination	Date
1991	Landsat 5 TM	30	144/38, 144/39, 145/38, 145/39, 146/38, 146/39	Blue, Green, Red, Near Infrared, Short Wave Infrared 1 & 2	7 <sup>th</sup> March
2021	Landsat 8 OLI	30	144/38, 144/39, 145/38, 145/39, 146/38, 146/39	Blue, Green, Red, Near Infrared, Short Wave Infrared 1 & 2	9 <sup>th</sup> April

**3.2 Image Processing and Classification**

The entire image processing and analysis was performed using ArcGIS software version 10.8. Multiple bands of satellite images were stacked (visible bands, infrared, and shortwave infrared) together to produce a standard false-color composite (SFCC), followed by the mosaicking process for all images of the same duration. All mosaics underwent atmospheric and radiometric corrections. Subsequently, the study area was extracted from each mosaic, and a supervised classification with maximum likelihood was applied to classify the land use and land covers. A total of eight classes were produced: snow cover, alpine pasturelands, temperate forest, subtropical forest, agricultural land, barren land, built up areas, and water bodies. After the classification process, confusion matrix was calculated based on randomly chosen 160 pixels to estimate the error. Google Earth imagery was used to compare with these points with same co-ordinates to estimate overall accuracy (88.75%) and kappa coefficient (86.89%).

After the classification process, changes in different classes were detected over a period of 30 years. Classified images were further processed in Fragstat software version 3.0 to derive landscape metrics (Table 2). Generally, for the class level analysis of fragmentation and temporal change in disintegration, five widely accepted and most suitable class metrics were chosen after reviewing relevant literature (Tolessa et al., 2016; Fu et al., 2022). Class area (CA), percentage of landscape (PLAND), number of patches (NP), patch density (PD), and perimeter area ratio (PARA) were computed as per the following equations in Fragstat (McGarigal, 2015).

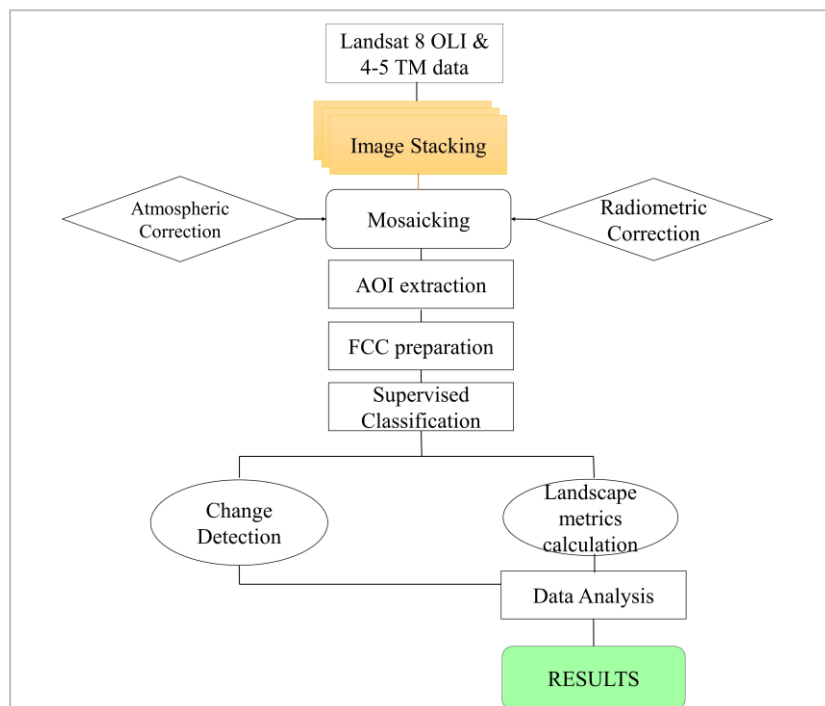
$$PLAND = \frac{\text{Area of the specific class}}{\text{Area of the entire landscape}} \times 100 \tag{1}$$

$$PD = \frac{\text{Number of Patches}}{\text{Unit area}} \left( \frac{10000}{100} \right) \tag{2}$$

$$PARA\_MN = \frac{\text{Exposed perimeter}}{\text{Area of specific class type}} \tag{3}$$

Table 2: Details of the landscape metrics used for class level analysis in this study.					
Metric	Abbreviation	Unit	Range	Description	References
Total Class Area	CA	ha	> 0	Class area is the metric of spatial extent of any class	(Li et al., 2004; Zheng et al., 2022)
Percentage of Landscape	PLAND	%	0-100	This metric indicates percentage of area of a specific class within the landscape	Weng, 2007; Xiang et al (2022)
Number of Patches	NP	None	> 0	NP = 1 means the LULC type contains only one patch	Li et al (2004); Fu et al (2022)
Patch Density	PD	Number per 100 ha	> 0	Number of patches in a specific LULC class per hectare area	(Su et al., 2011; Fu et al., 2022)
Mean Perimeter Area Ratio	PARA_MN	None	> 0	The ratio between total class perimeter and class area measuring complexity of shape.	(Cabacinha and Castro, 2009; Zheng et al., 2022)

CA and PLAND are directly proportional to growth of a particular class. Conversely, NP, PD, and PARA\_MN are positively correlated to fragmentation, where, higher values indicate more amount of disintegration at class level within a landscape (Su et al., 2011). A detailed methodology flowchart is presented in Figure 2.



**Figure 2:** Flow chart of methodology

4. RESULTS

4.1 Land Use Pattern in 1991

There are a total of eight broad land-use categories, including snow cover, alpine pasturelands, temperate forests, subtropical forests, agricultural land, built-up areas, barren land, and water bodies (Table 3). In 1991, the highest area was covered by forest, including alpine pasturelands, constituting more than 60%, with temperate forest accounting for the largest portion (28.08%). It was followed by subtropical forests (27.8%), snow cover (25.51%), alpine pasturelands (10.42%), and agricultural land (4.51%). The lowest areas were occupied by water bodies (0.4%) and barren land (1.2%), with built-up areas at 2.1%.

The NP under each category of land use was the highest in temperate forests, followed by agricultural land and subtropical forests (257270, 229597, and 149542 number of patches, respectively). However, PD showed a different trend with the highest value in temperate forest, followed by agricultural land and subtropical forest and other categories had a density of less than one patch per 100 ha (Table 3), which indicates highest fragmentation in agricultural land in 1991. Perimeter area ratio was maximum in agricultural land, followed by water bodies and subtropical forest. This represents lowest distance from edge to core in agricultural land making it most vulnerable to fragmentation. While, water body shown this kind of result due to abundance of linear feature like streams and rivers. The lowest number of patches was observed in water bodies, followed by snow cover and alpine pasturelands.

Class Name	Class Area (ha <sup>1</sup> )	Percentage of Landscape (%)	Number of Patches	Patch Density (NP/100 ha <sup>-1</sup> )	Mean Perimeter Area Ratio
Snow Cover	1364952	25.51	18346	0.34	970
Alpine pasturelands	557676	10.42	43337	0.43	1012
Temperate Forests	1502428	28.08	257270	2.58	1099
Subtropical Forest	1486642	27.79	149542	1.50	1104
Agricultural Land	241319	4.51	229597	2.30	1168
Built-up areas	111928	2.09	59397	0.59	968
Barren Land	63593	1.19	49333	0.49	1035
Water Bodies	21458	0.4	16177	0.16	1121

Source: Data were generated in Fragstat 3.0 Software based on supervised classified maps.

Figure 3 shows different land-use categories and their distribution. The snow cover area is located in the extreme north, primarily bordered with Tibet (China). This region comprises a large area with perpetual snow throughout the year. Below it are alpine pasturelands, and accordingly, different forest types—coniferous, mixed-oak, pine, and monsoon

deciduous—are distributed. The extreme southern part features fertile plains, with dense settlements found in the plain regions, middle altitudes, river valleys, and the highlands, in descending order. The area is characterized by numerous perennial rivers, highland and lowland lakes, and dam reservoirs.

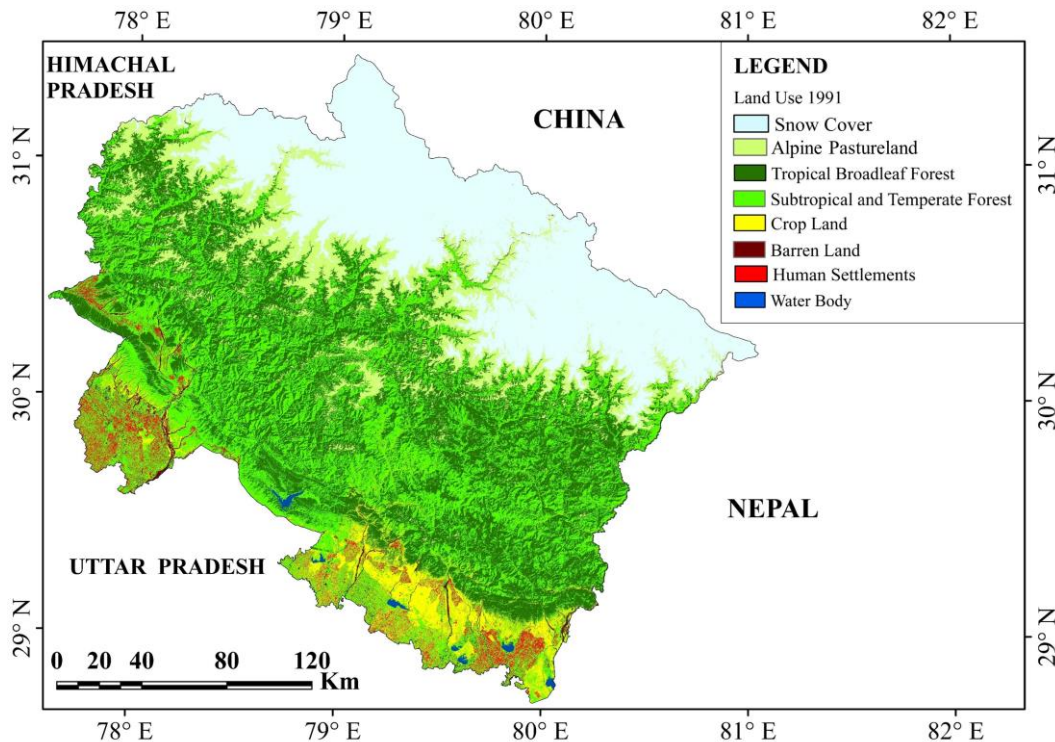


Figure 3: Land use pattern in 1991

4.2 Land Use Pattern in 2021

The land-use categories in 2021 were similar to those in 1991, but there were changes in the area coverage (Table 4). Out of the total 5354069 ha geographical area, snow cover accounted for 20%, while alpine pasturelands covered 9.69%. Forest cover, including alpine pasturelands, remained above 60%. Agricultural land constituted 7.25%, barren land 3.34%, built-up areas 2.2%, and water bodies (0.83). Significant changes were observed in all land-use categories, with some increasing and others

decreasing. The number of patches and their density varied accordingly. The density of alpine pastureland was the highest, followed by temperate forests and agricultural land (Table 4). PD in alpine pastureland increased rapidly within 30 years despite of decrease in CA, which demarcates the highest amount of fragmentation. On the other hand, other land use and land covers experienced rise in PD along with CA illustrating patches expansion due to addition of new areas under each classes. Interestingly, along with reduction in CA, PD also decreases due to disappearance of multiple patches caused by global warming (Table 4, Table 5).

Table 4: Land Use Pattern 2021					
Class name	Class Area (ha <sup>-1</sup> )	Percentage of Landscape (%)	Number of Patches	Patch Density (NP/100 ha <sup>-1</sup> )	Mean Perimeter Area ratio
Snow cover	1070232	20	17072	0.32	1077
Alpine pasturelands	517083	9.67	388518	6.33	1091
Temperate forest	1511433	28.25	477352	4.15	1102
Subtropical forest	1525918	28.52	288102	2.81	1067
Agricultural land	387545	7.25	368638	3.59	1166
Built-up area	118985	2.22	252433	2.46	1178
Barren land	178468	3.34	314684	3.06	1120
Water bodies	44405	0.83	85413	0.83	1109

Source: Data were generated in Fragstat 3.0 Software based on supervised classified maps.

In 2021, there was a remarkable change in the land-use pattern. The snow cover area and alpine pastureland experienced considerable shrinkage. The alpine grasslands shifted towards the north, encroaching into the snow areas. Similarly, temperate forests also migrated to higher altitudes and towards the north. However, the forest area under both temperate and subtropical regions increased. At the state level, the built-up area increased nominally, whereas a significant increase was noticed mainly in the river valleys and plain regions—Doon, Dwar, and Tarai (Figure. 4). Water bodies increased due to the construction of large dam reservoirs.

### 4.3 Land Cover Change 1919-2021

Land cover change was analyzed (Table 5). It was observed that the snow area decreased by 21.59%. Similarly, alpine pastureland also decreased by 7.28%. In terms of an increase in area, the highest increase was observed under barren land, followed by water bodies. Arable land also increased by 60.59%, and the built-up area increased by 6.30%. There was a nominal increase under temperate and subtropical forests (0.6% and 2.64% respectively).

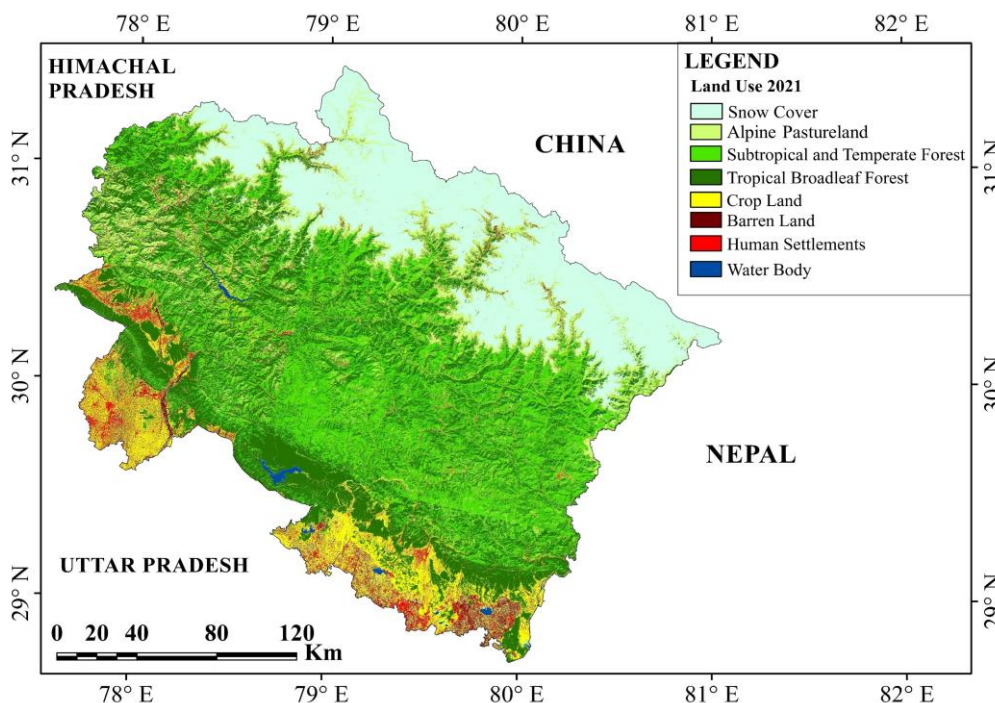


Figure 4: Land use pattern in 2021

Table 5: Land cover change (%) 1991-2021		
Class Name	Change (ha)	Change (%)
Snow cover	-294720	-21.59
Alpine pastureland	-40593	-7.28
Temperate forest	9005	0.6
Subtropical forest	39276	2.64
Agricultural land	146226	60.59
Built-up area	7057	6.30
Barren land	114875	180.64
Water bodies	22947	106.1

Source: Data were generated in Fragstat 3.0 Software based on supervised classified maps.

In this section, we have explained changes in some land-use categories in detail. The selection of these categories was based on the magnitude of changes and their significance.

#### 4.3.1 Snow Cover Change

One of the significant changes that the Central Himalaya has observed in the past

three decades is the decreasing snow cover. The northern part of the Central Himalaya, which constitutes one-third of the total geographical area, is snow-covered and hosts world-famous glaciers. These glaciers gained attention, especially after the Inter-governmental Panel for Climate Change (IPCC) 4<sup>th</sup> report, which highlighted that Himalayan glaciers are melting at an alarming rate. This study revealed that in 1991, the total snow cover was approximately 25.51%, decreasing to 20% in 2021, indicating a 21.59% decrease over the past 30 years (Figure 5).

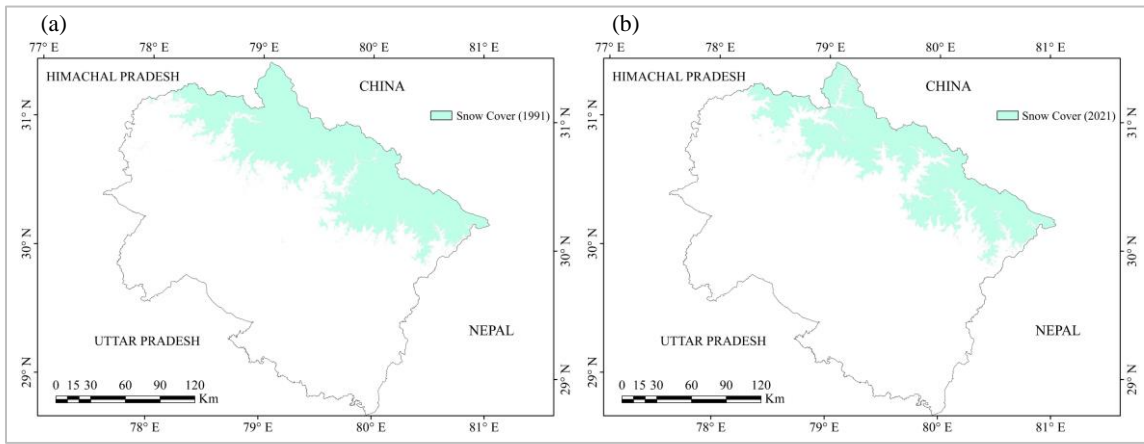


Figure 5: Snow cover (a) 1991 and (b) 2021

4.3.2 Change in Alpine Pasturelands

Alpine pasturelands are ecologically fragile zones that remain snow-covered for six months during winter. In the summer, various medicinal plants and flowers flourish.

We observed that the area under alpine pasturelands decreased by approximately 7.28% over the past three decades (Figure 6). These pasturelands are shifting towards higher altitudes, encroaching upon the snow-covered areas. Meanwhile, they are being replaced by temperate forests in the lower altitudes.

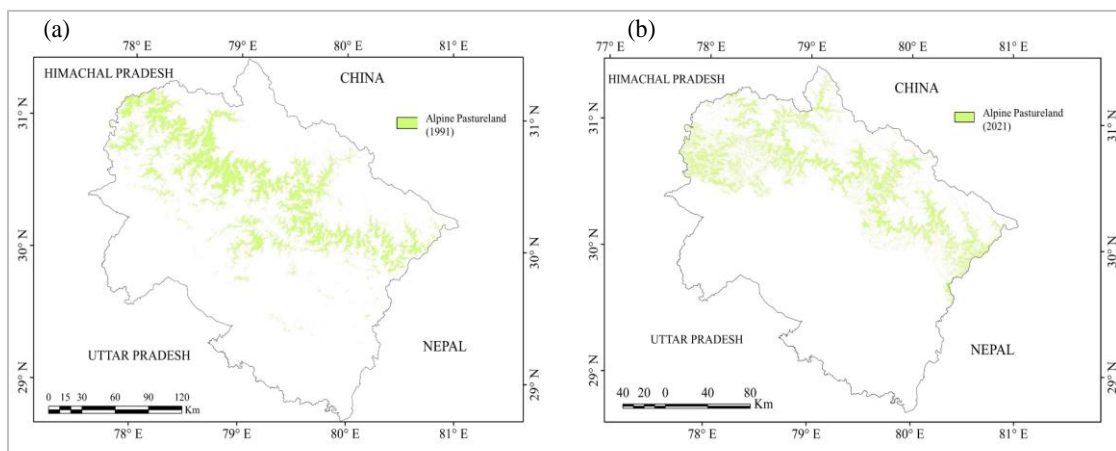


Figure 6: Change in alpine pasturelands (a) 1991 (b) 2021

4.3.3 Change in Built-up Area

A tremendous change was noticed in the built-up area across almost the entire Central Himalayan region, varying from mountainous areas to the Doon Valley, Haridwar, Nainital, and Udhm Singh Nagar (USN) districts (Sati, 2013). In the mountainous areas, the built-up areas did not increase significantly, whereas in the plain regions, including the Doon Valley, there was a substantial increase in built-up areas (Figure 7).

The Doon Valley, stretching approximately 76 km long and 28 km wide,

lies between the Ganga River in the east and the Yamuna River in the west. This change was primarily due to the natural increase in population and rural-urban migration. This is evident from the fact that the population of Dehradun city in 1991 was less than 0.4 million, whereas it is now above 1.4 million. The entire Doon Valley, except for some patches of dense forests in Raja Ji National Parks, has transformed into a concrete jungle, connecting Haridwar, Rishikesh, and Ponta Sahib. Due to the increase in built-up areas, agricultural land has shrunk, leading to large-scale changes in land use and land cover.

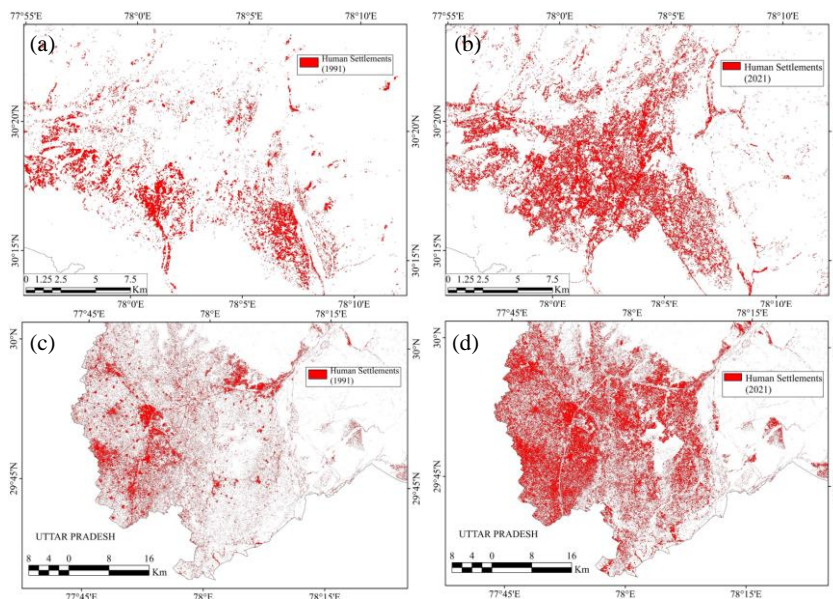


Figure 7: Increasing built area (a & b) Doon Valley (1991 and 2021, respectively) and (c & d) Haridwar district (1991 and 2021, respectively)

4.3.4 Change in Area Under Water Bodies

Water bodies have increased in the past three decades. This study reveals that water bodies in the Central Himalaya are increasing due to two main reasons. The first reason is the construction of dam reservoirs. All the rivers in the region have one or more dam reservoirs, contributing to the

increase in water bodies. The second reason is the melting of snow/glaciers, leading to the creation of glacial-fed artificial lakes. These changes have influenced land use changes in the study region. Figure 8 illustrates that due to the construction of the Tehri high dam, an area approximately 76 km long and 5 km wide is now covered by water.

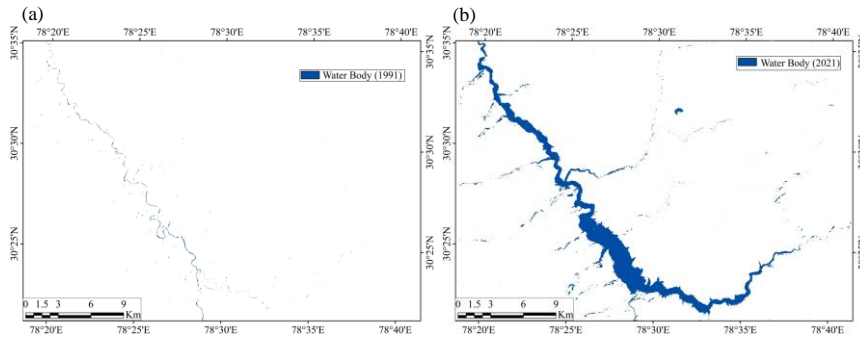


Figure 8: Change in area under water bodies 1991-2021

4.4 Major Factors Affecting Land Use Change

4.4.1 Climate Variability and Change

Climate variability and change are highly noticeable in the Himalayan region. The river valleys and middle altitudes are experiencing warming trends, impacting Himalayan glaciers and land use patterns. Temperatures are increasing, and rainfall is decreasing with high variability. Monsoon rains are more intensive, but the duration of rain has decreased. During

the offseason, mainly in the months of February, March, and April, the rate of rainfall has increased. Figure 9 depicts the 161-year average seasonal rainfall in the Central Himalaya.

Climate variability and change have impacted land use and cropping patterns. The warming of river valleys and middle altitudes has caused pine forests to shift to higher altitudes, encroaching on mixed-oak forests. Consequently, mixed-oak forests have been shrinking. Furthermore, climate change has increased the rate of glacier melting.

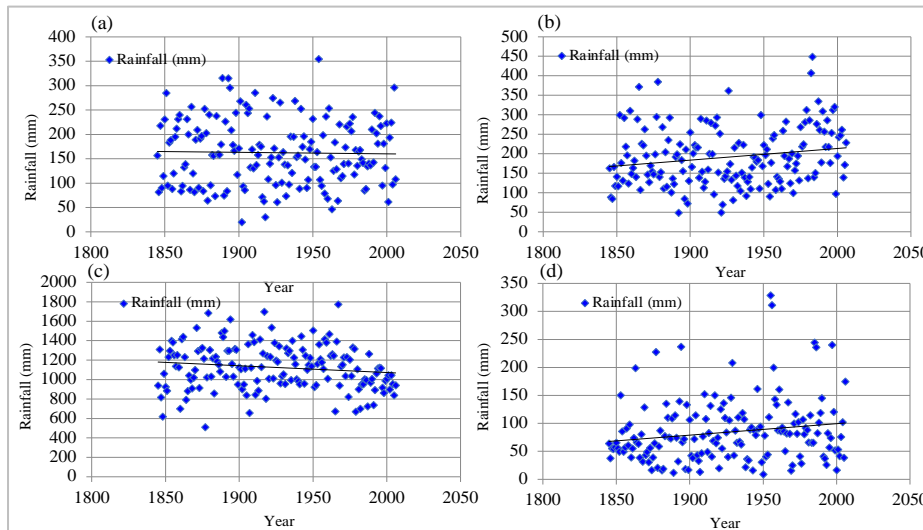


Figure 9: Seasonal average rainfall (mm) in the Central Himalaya (a) January and February (b) March, April, and May (c) June, July, August, and September, and (d) October, November, and December.

4.4.2 Out-Migration and Land Abandoned

Due to many factors affecting lives and livelihoods, the Central Himalaya is experiencing exodus out-migration - from rural to urban areas and from mountain regions to plain regions. Moreover, due to extensive out-migration, arable land has been abandoned, and more than 1500 villages have become ghost villages (Sati, 2023). Approximately 10% of villages have fewer than 10 households. This has resulted in significant changes in both sending and receiving areas. We have observed that the increase in the built-up area in the Doon Valley and Haridwar was due to in-migration.

4.4.3 Construction of Hydropower Project

The Central Himalaya is known as the Urja State due to the construction of more than 200 hydropower projects - both large and small. Many have been completed and many are currently under construction or proposed. This has resulted in significant changes in the land use pattern. In the Tehri high dam reservoir, a total of 114 villages were fully or partially submerged (Sati, 2014). Additionally, Tehri town and some other towns were fully submerged. Vast agricultural and forest lands were also submerged into the dam reservoir, which is 76 km long and on average 3 km wide. The affected households were rehabilitated in other places, mainly in the Doon Valley, further changing the land use pattern. Water bodies also emerged in the highland due to the melting of glaciers.

4.4.4 Increasing Natural Hazards

Natural hazards such as landslides, debris flows, floods, and mass movements triggered by cloudbursts and glacier-bursts are common phenomena in the Central Himalaya. In the recent past, their intensity and frequency have increased multi-fold. Between 2020 and 2023, 183 incidents of natural hazards occurred in the Central Himalaya (Sati, 2023). This has led to a large-scale change in land use patterns and land cover changes.

4.4.5 Development of Infrastructural Facilities

The Central Himalaya has been undergoing transformations in terms of economic development. Many infrastructural development projects are under construction, leading to significant land use changes. The construction of all-weather roads to the four highland pilgrimages (Char Dhams), simple roads to rural areas, the development of railway lines, economic avenues, helipads, and the installation of electric and pipeline systems in urban and rural areas have altered the land use patterns. In urban areas, the construction of multi-storied buildings has encroached on arable lands, thereby changing land use patterns.

4.5 Discussion

This study elucidates land use and land cover dynamics in the Central

Himalayan region, based on Landsat imagery and the observations of the authors. For analyzing land cover change, Landsat data from 1991 and 2021 were collected. The study elaborates on eight categories of land uses. Among the major land uses—snow cover, alpine pasturelands, forest land, agricultural land, built-up area, barren land, and water bodies—are prominent. The largest area is covered by forest, accounting for more than 60%. Forest land is categorized mainly into two types—temperate forests, and subtropical forests. The highest area is under subtropical forests, followed by temperate forests and alpine pastureland. Snow cover also occupies a substantial area. The other land use categories cover less than 10% of the area.

Land cover changes were analyzed, and the findings of the study depict that all categories of land uses changed in the past three decades. The two categories of land uses—snow cover and alpine pastureland—decreased. Snow cover decreased by 21.59% in the last three decades. Similarly, there was a decrease of 7.28% in alpine meadows. Meanwhile, a slide increase was noted in temperate forests whereas subtropical forests increased by 2.64%. The highest increase was observed in water bodies followed by water bodies. Built up area also increased by 6.30%.

The major drivers of LULCC were examined, and changes in each category of land use were separately discussed. One profound driver of LULCC was noted as high climate variability and change, with the most significant impact observed on snow cover and alpine pasturelands. Numerous published documents highlight the impact of climate change on Himalayan glaciers, leading to a decrease in snow cover and alpine pasturelands. Climate change has also influenced the expansion of pine forests, shifting towards higher altitudes and encroaching into the territory of mixed-oak forests, therefore, the rate of increase in subtropical forests is higher than temperate forests. Warming of the river valleys and middle altitudes also led to decrease in snow cover area, area under alpine pasturelands, and expansion of pine trees towards higher elevation. Many crop varieties have vanished, and others are on the verge of disappearing. Citrus and apples have been shifted to higher altitudes due to warming in the lower altitudes and many areas, they are disappeared. The production and productivity of traditional crops mainly millets have decreased.

Built-up areas are primarily increasing in plain regions and along river valleys. The Doon Valley and the Haridwar district have transformed into a concrete jungle due to natural population growth and large-scale immigration. Large-scale land use change is also occurring due to the construction of infrastructural facilities. Increasing number of large scale hydropower projects led to increase in dam reservoirs and thus, the size of water bodies increased. Out-migration from rural and mountainous regions to urban areas within and outside the state has led to a significant change in land use patterns. The Central Himalaya is facing a tremendous impact from natural hazards, with high intensity and frequency leading to changes in land use cover, mainly an increase in barren land.

## 5. CONCLUSIONS

This study revealed that the rate of changes in land use patterns is higher during the recent past. More or less, all the land uses were affected. Two land uses – snow cover and alpine pasturelands decreased largely, which is critical to fragile ecosystems of the Himalaya. This has also led to changes in river ecosystems. Warming of the Himalayan region has noticed decrease in snow cover. On the other hand, land under water and barren land increased enormously. In the recent past, many river valley hydropower projects were constructed, which increased the number of water reservoirs. Significant increase in barren land was due to exodus out-migration from the Himalayan region to other parts of India. Built up area and agricultural land increased with small proportion. Increase in population led to increase in built-up area mainly in the plain regions, whereas, agricultural land is spanning towards forest area. This study suggests sustainable land use pattern and management in the Himalayan regions. Forest lands need to be conserved, which will assist in maintaining a cooler climate and, thus, decrease the rate of snow melting. Agriculture, being the major occupation and source of livelihood, should be practiced sustainably using both traditional and modern methods. Suitable policy measures need to be framed and implemented for sustainable rural development that will reduce the rate of out-migration and maintain a balance between rural and urban populations. There is a need to reduce the intensity of natural disasters in the fragile Himalayan landscapes through the landscape vulnerability analyses and disaster risk management.

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