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Spatio-Temporal Analysis of Land Use and Land Cover Change in Makwanpur District, Chure Region, Nepal

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Abstract

The research is outlined within the spatio-temporal dynamics of Land Use and Land Cover (LULC) in Makwanpur District, adjacent to the ecologically sensitive Chure (Churia) region.We quantify and interpret changes across eight land-use categories based on remote-sensing data from 2000, 2010, and 2019, obtained from Landsat imagery, and analyzed in a GIS platform. Findings reveal that built-up areas (+0.55%) and forest cover (+6.2%) have increased significantly, with slight reductions in cropland (-5.28%), grassland (-1.21%), and riverbeds. The paper addresses the need for integrated land-use planning and conservation practices in the Chure region to mitigate ecological degradation and promote sustainable development. The study aims to detect and quantify land-cover changes and analyze the driving forces and consequences of these changes. It provides critical data for resource management and environmental protection in the geologically fragile Chure Hills. Methods include remote sensing (e.g., Landsat imagery) and geographic information systems (GIS) for data processing, image classification, and spatial analysis. Specific techniques include supervised classification using platforms such as Google Earth Engine (GEE) and ArcGIS, followed by spatial analysis to map temporal changes and to identify factors such as deforestation and soil erosion.

Keywords: GIS, land use and land cover change, spatial, temporal, driver, urbanization, Chure

Spatio-Temporal Analysis of Land Use and Land Cover Change in Makwanpur District, *Chure* Region, Nepal

Change in Land Use and Land Cover (LULC) is a dynamic process that indicates human-environment interactions. Land use and land cover change are significant global phenomena driven primarily by human activities, including population growth, urbanization, and agricultural expansion. This accelerates the transformation of the Earth's surface and has significant environmental, social, and economic consequences (Moïse et al., 2022). Urban population growth, particularly in developing nations, is a primary driver of LULC change. Urban expansion often occurs at the expense of arable land and natural ecosystems, leading to habitat loss and environmental degradation (IOF, 2019).

This is a human environmental impact, with arable land for agriculture making up a significant portion of the earth's surface. Expansion of agricultural land often results in deforestation and conversion of natural grasslands (Moïse et al, 2022). Overgrazing and under-draining, resource extraction without planning, are unsustainable practices that are contributing to land degradation, desertification, and increasing soil erosion worldwide. While the general trends in global LULC change are consistent, there are notable discrepancies in specific land-change estimates across global datasets. These discrepancies may arise from different classification methods, spatial scales, and data sources.

There are a variety of factors influencing LULC changes that are complex and interrelated, from local to global scales. A growing population directly leads to higher demand for food, housing, and other resources, conversion of land for agriculture and settlement (IOF, 2019). Ultimately, this includes changes in agricultural practices, real estate booms, urban migration for economic opportunities, and infrastructure development. Government policies on land use and management play a major role in shaping land use patterns. Advances in remote sensing and geographic information systems (GIS) have provided effective methods for monitoring and analyzing LULC change, helping to inform land management strategies.

Lack of comprehensive studies that integrate local community perceptions with empirical data inspired this research. There is a need for more detailed, evidence-based case studies of debris reduction and a deeper understanding of the relationship between specific land use changes, local human activities (such as illegal extraction), and environmental impacts such as groundwater depletion and landslides. Specific to the case of C*hure* in Nepal, this study is an important case study to understand the complex environmental and socioeconomic issues of the region. The focus of this work is to use remote sensing and geographic information systems (GIS) tools to map and quantify how the landscape has changed over a period of time. This involves comparing satellite images from different years to identify and measure changes in key LULC categories. The study aims to determine the root causes behind the documented landscape changes.

The *Chure* hills function as an important transitional space between the *terai* and the central hills and thus provide important ecological services such as soil stabilization, water recharge, and conservation of biodiversity (Ghimire, 2017). Nowadays, the region is continuously affected by encroachment of forest area, infrastructure development, and vulnerable land conversion (IOF, 2019). Due to its geographical fragility, ecological importance, and increasing human pressure, the land use and land cover (LULC) in the *chure* region is growing sensitive. Also known as the Shivaliks, the Chure Hills are highly susceptible to erosion because they are composed of fragile, unconsolidated sedimentary rocks, and increased deforestation for agriculture, settlement, and infrastructure development destabilizes the slopes and accelerates soil erosion (Joshi & Paudel, 2024).

Chure plays an important role in recharging the water in the plains of the *terai*. Changes in LULC, especially deforestation, disrupt this hydrological function. As a result, groundwater levels decrease and natural springs, the main source of water for local communities, dry up (IFO, 2019). Rapid erosion and subsequent sedimentation in the rivers flowing through the C*hure* have increased the river banks. This increases the risk of frequent and catastrophic floods in the downstream *terai* region, which has devastating effects on agricultural lands and settlements (Pokharel, 2013). Habitat fragmentation due to deforestation, encroachment, and unplanned development directly threatens the rich biodiversity of the *Chure* forest. The loss of forest cover puts immense pressure on wildlife and contributes to human-wildlife conflict as animals compete for dwindling resources (Joshi & Poudel, 2024).

Widespread problems have arisen due to illegal and haphazard mining of sand, gravel and stones from the *Chure* river banks. This mining activity increases river cutting, alters river characteristics, and depletes water resources (Pokharel, 2013). Overlapping claims and regulatory roles among different stakeholders, including the government's conservation board, community forest user groups, and private companies involved in extractive industries, create conflicts and impede effective conservation.

Strong techniques for detecting, analyzing, and visualizing such transformations are offered by remote sensing and geographic information systems (GIS). They also enable multi-temporal evaluations of landscape dynamics, which are of great importance in making informed decisions. This paper assesses LULC dynamics of the Makwanpur district from 2000 to 2019, with a focus on the demography, to get some insights into land management and planning. Similarly, we examine the dynamics of population with changing land use and land cover and evaluate the ecological and planning context of the change, especially in the *Chure* region of Nepal.

Theoretical Overview

For this, the most appropriate approach is to combine theories from Land System Science and Political Ecology because these approaches complementarily address our research gaps and help to crystallize the concept of the research theme. Land System Science (LSS) provides the framework for understanding how coupled social and environmental systems interact to drive changes on the land. It examines the "why, how, and where" human activity affects the Earth's surface, whereas Political Ecology (PE) provides a critical lens for understanding the social, economic, and political power dynamics behind land change (Song et al, 2018), which is especially relevant given the socio-ecological fragility and contestations in Nepal's *chure* region. The fusion of these theories allows for a robust and comprehensive analysis that accounts for both the spatial patterns and underlying causes of land change.

Land systems science is an integrative framework that is directly related to the development of earlier land-use and land-cover change (LUCC) approaches and focuses on the complex interactions within social-ecological systems. The interaction between human decisions and biophysical characteristics is explored. In the case of Makwanpur, the interaction focuses on the role of population growth, migration, agricultural expansion, and urbanization to determine the nature and pattern of interaction with the fragile geology, vegetation, and hydrology of the area. Methodologically, it integrates the multiple disciplines, combining remote sensing and GIS data with social science research to quantify spatial and temporal change to explain the drivers behind it.

Political ecology is a theory that addresses the deep relationship between political and economic factors as driving forces shaping land use in the *Chure* region (Osborne et al., 2021). It examines how power relations affect who has access to and control over resources such as land and forest products. This theory is suitable for explaining conservation policies and land tenure issues, and the "chain of explanations" approach within political ecology links local land-use practices to broader regional, national, and global processes. For Makwanpur, this means connecting local decisions to factors such as national conservation policies, infrastructure projects, and market demands. It also prioritizes understanding the justice implications of environmental change, investigating how marginalized communities are disproportionately affected by land degradation and conservation efforts.

Except for these forest transitions, urban ecological theories are appropriate to find out the interplay between land use and land cover in the study area. Here, we have presented how the theories work to visualize the various issues and factors in land use and land cover in the *Chure* of Makwanpur.

Summary of Theories and Application to Makwanpur *Chure*

Theory / Approach	Primary Focus	Application in Makwanpur *Chure*
Land System Science (LSS)	Holistic view of coupled social-environmental systems.	Analyses the interplay of human activities (e.g., population growth, agriculture, urbanization) and biophysical processes (e.g., erosion, forest change).
Political Ecology (PE)	Power dynamics, inequality, and their role in environmental change.	Investigates the socio-political drivers of land degradation, including resource access, tenure rights, and the impact of conservation policies.
Forest Transition Theory	Long-term, non-linear shifts between deforestation and reforestation.	Models and explains historical forest dynamics, particularly the regrowth linked

		to out-migration and community forestry initiatives.
Urban Ecology / Bid-Rent Theory	The effect of urbanization on land use and land value.	Explains the expansion of built-up areas, especially near Hetauda, at the expense of agricultural land.
Agent-Based Modelling (ABM)	Simulating land change by modelling the behavior of individual decision-makers.	It could be used to understand how household decisions on migration, farming, and resource extraction collectively drive landscape changes over time.

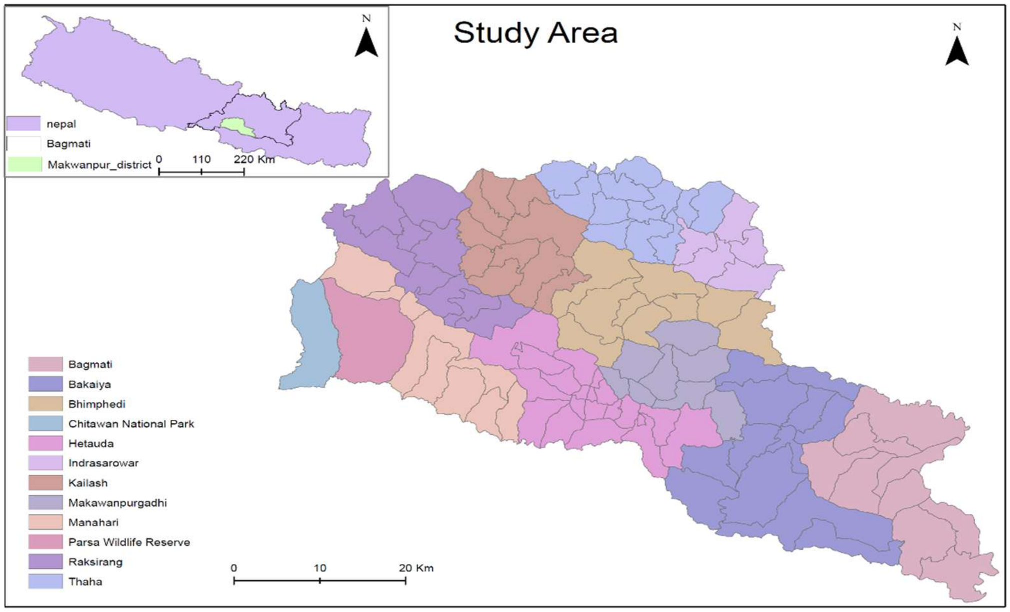
Methods and Materials

Study Area

Makwanpur district, located in a part of the *Chure*, can serve as an example of such troubles.Due to strategic connectivity with Kathmandu along the Hetauda and other trade route nodes, the district has been facing high rates of urbanization, influx of people into the areaafter the earthquake, and the transformation of lifestyle patterns.The trends have resulted in land cover changes between agricultural and forest land and built-up land, raising questions on sustainability, availability of water, and the stability of the environment.

Figure 1

Location Map of the Study Area, Local Level of Makwanpur District



Makwanpur District lies in 27°20′ to27°50′ North latitude, 84°40′ to 85°20′ East longitude of Bagmati Province and is situated some 42 km southeast of Kathmandu.It covers 2,426 km^2, with a range of altitudes between 166 and 2,584 meters above sea level.The area comprises a large urban center of Hetauda and the small towns of Palung and Bhimphedi.The district has a climate that is subtropical in the lower terrain and temperate in the higher altitudes. The yearly subdivision of precipitation is 1,751.5 mm, and its temperatures have a range of 2.7°C to 37 °C. It has a wide range of landscapes that are forested, cultivated, riverbeds, and large tracts of built-up countries (National Statistics Office, 2023).

The study area was chosen in Makwanpur because of its ecological and socioeconomic importance, besides being sensitive to rapid changes in its land use and land cover (LULC). Makawanpur is located at the border of the *Chure* Hills, the Mahabharata Range, and the Terai Plain. The district acts as a transition region and is extraordinarily susceptible to critical environmental degradation. It is also a trade route between Kathmandu and the southern plains and India. Nevertheless, these processes together with unstable geology, climate fluctuations, and poor governance prevailing through the federal restructuring of Nepal, make Makwanpur a perfect site to observe the factors and consequences of LULC change (IOF, 2019).

Data Sources and Processing

This study has employed a mixture of geospatial and demographic information to examine the transformation of land use and land cover (LULC) through time. The images of the

Landsat 5 TM (2000), Landsat 7 ETM+ (2010), and Landsat 8 OLI (2019) with the 30 m spatial resolution have been used in the paper, which were obtained from (https://rds.icimod.org/Home/DataDetail?metadataId=1972729) ICIMOD regional data-based system. The other data were administrative boundaries, infrastructure layers, and population data, which were acquired at the National Statistics Office (2001, 2011, and 2021). The geo-referencing of data was done in the UTM Zone 45N, WGS84 datum, and processed in ArcGIS 10.8. To validate the samples, field verification was conducted in February 2024 in the Hetauda, Bhimphedi, and Manahari municipalities.

Classifying and Assessing the Accuracy of Images

The Maximum Likelihood Classifier (MLC) aided in the supervised classification that described eight LULC types: forest, cropland, grassland, riverbed, other woodland (OWL), built-up area, reservoir, and bare soil. Post-classification visual corrections were performed in order to mitigate spectral confusions between cropland classes, bare soil classes, and built-up classes. The accuracy measure was a confusion matrix and Kappa coefficient, having the overall accuracy of 87.5% (2000), 89.2% (2010), and 90.1% (2019), and a Kappa coefficient of 0.85-0.88 that indicated a high degree of agreement. Ground-truth reference points on both a 1:100,000 scale and high-resolution Google Earth imagery to assess classification accuracy. Moreover, demographic analysis by using MS Excel was also carried out to observe the growth of the population and household pattern, as well as possible connection with LULC dynamics.

Change Detection Analysis

The post-classification comparison was a quantitative approach of the change in percentage and area during three periods (2000-2010, 2010-2019 and 2000-2019). To get the rate of change (r) per annum, the following formula was applied:

$$r = \frac{A_2 - A_1}{A_1 \times t} \times 100$$

Where A_1 and A_2 denote land cover area at time t 1 and t 2, respectively, and t denotes years. This enabled the visualization of dynamics of gain and loss as transition matrices and arrow plots.

Results and Discussion

Compilation of the Land Use and Land Cover Change (2000-2019)

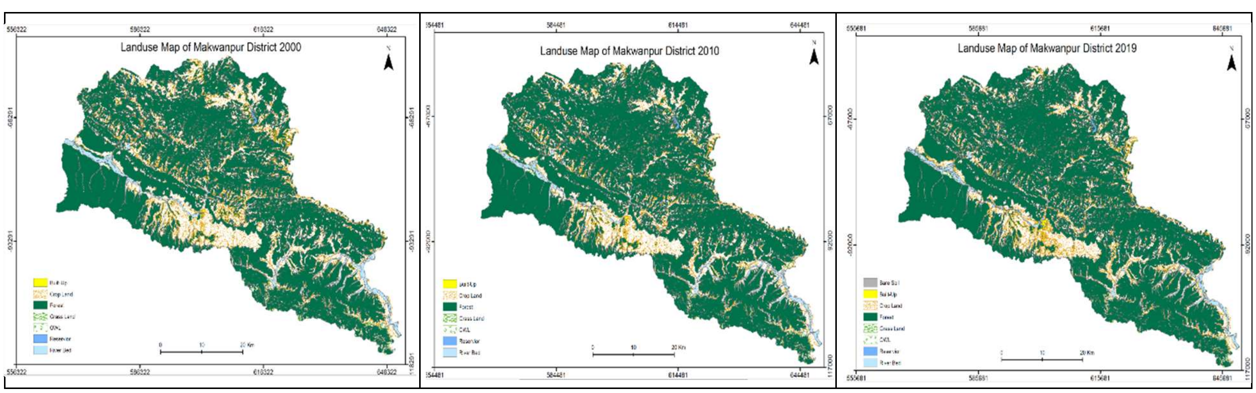
The Makwanpur district land use map 2000 indicates that the landscape of Makwanpur district is mainly composed of forests, particularly in the highlands in the north and south, and the central valleys and the lower hills are covered with croplands due to the topography being gentle. There was very little urban development, with built-up areas being minimal and far in between. The hydrological network of the district is composed of riverbeds and small reservoirs, which are transitional areas between forests and croplands, which were occupied by grasslands and other woodlands.

By 2010, the district was in the ecological and spatial transition. Coverage of the forest marginally improved, probably through the regeneration of the forests and community forestry initiatives, and the croplands in the valleys exhibited some premature signs of neglect or deterioration. The development of urban sprawl around Hetauda and road corridors was a sign of the onset of urban sprawl. Hydrological characteristics like riverbeds and reservoirs were still noticeable, and the grasslands and other woodlands were on the marginal and transitional lands.

In 2019, the land use map also shows a very different landscape. It displays a slight rise in forest cover and significant growth in the built-up areas, especially around Hetauda and transport corridors, due to urbanization following the earthquake. Croplands were still facing downwards, indicating movement and low farming. The emergence of bare soil indicates increased construction, soil erosion, and land degradation. Transitional woodlands also got divided, and the increasing encroachment in the riparian zone is an indication of the risks to the integrity of the watershed.

Figure 2

Spatial Distribution of Land Use and Land Cover Change in the Years 2000, 2010 &2019



On the whole, the three maps are evidence of the obvious change in the agrarian-forest landscape to a semi-urbanized ecosystem, regulated by human settlement, the expansion of infrastructure, and ecological restoration, which is an indication of the socio-environmental revolution that occurs in the *Chure* and the mid-hills of Nepal.

Land Use Land Cover Change Assessment from the Year 2000, 2010, and 2019

Makwanpur district has witnessed a remarkable change in its land use land cover (LULC) within two decades. The district that endows some areas of Nepal's sensitive ecology, the *Chure* region, is a depiction of how environmental processes and socio-economic change co-exist in a blended form.

Table 1 clearly indicates that forest cover was the prevailing land use in 2000, 2010, and 2019, with a steady increase from 67.31 to 73.51 per cent. This extension of more than 15,000 hectares is attributed to effective community forestry programs in Nepal, regrowth of forests through land abandonment, and growing environmental consciousness. The forest growth rate has, however, slowed since 2010, possibly because reforestation was limited or land was increasingly competing with other uses. Croplands, on the other hand, reduced steadily from 25.23 per cent in 2000 to 19.95 per cent in 2019. The massive loss of about 13,000 hectares indicates a shift in the forms of livelihood without streamlining, low productivity in the hill farming, and demand for land in the growing city, leading to the agricultural land change. The other vital ecological and livelihood resource, grasslands, decreased by a large margin, namely, 2.97 to 1.76 per cent, limiting livestock grazing opportunities and signifying ecological changes such as succession or conversion to forest and settlement.

Table 1

Comparison of Land Use Land Cover Change in Makwanpur District (2000-2019)

LULC Cover Type	2000 Area (ha)	2000 %	2010 Area (ha)	2010 %	2019 Area (ha)	2019 %	Change (2000-2019)	% Change	Rate (%/yr)	Change (2010-2019)	% Change	Rate (%/yr)	Overall Change (2000-2019)	% Change	Rate (%/yr)
Forest	164,403.40	67.31	175,668.27	71.92	179,552.88	73.51	+15,149.48	+6.20	0.48	+3,884.61	+1.59	0.25	+15,149.48	+6.20	0.48
Crop Land	61,628.39	25.23	53,026.39	21.71	48,728.79	19.95	-12,898.60	-5.28	1.10	-4,296.60	-1.76	4.90	-12,898.60	-5.28	1.10
River Bed	8,666.21	3.55	8,264.81	3.38	7,606.51	3.11	-1,059.70	-4.43	4.64	-658.30	-4.27	4.89	-1,059.70	-4.43	4.64
Grass Land	7,251.33	2.97	5,112.90	2.09	4,293.86	1.76	-2,957.47	-1.21	2.15	-819.04	-4.34	1.78	-2,957.47	-1.21	2.15
OWL	1,554.08	0.64	1,354.00	0.55	1,729.74	0.71	+175.66	+0.07	0.59	+375.74	+0.15	3.08	+175.66	+0.07	0.59
Built-Up	339.42	0.14	463.30	0.19	1,686.86	0.69	+1,347.44	+0.55	20.89	+1,223.56	+0.50	29.34	+1,347.44	+0.55	20.89
Reservoir	422.64	0.17	375.37	0.15	643.60	0.26	+220.96	+0.09	2.75	+268.23	+0.11	7.94	+220.96	+0.09	2.75

Bare Soil	0.00	0.00	0.00	0.00	21.89	0.01	+21.89	+0.01	100.00	+21.89	+0.01	100.00	+21.89	+0.01	100.00
Total	244,265.46	100.00	244,265.05	100.00	244,265.13	100.00	-	-	-	-	-	-	-	-	-

The built-up area witnessed the most dramatic change in relative terms, expanding from just 0.14% in 2000 to 0.69% by 2019, a fivefold increase. This reflects the accelerated urbanization, particularly in the post-2010 period, driven by factors such as rural-urban migration, post-earthquake reconstruction, and the expansion of infrastructure and markets in and around Hetauda Sub-Metropolitan City. The emergence of bare soil in 2019, absent in earlier years, likely signals the effects of ongoing construction, land clearance, and soil erosion, particularly in marginal or sloped areas.Meanwhile, riverbed areas slightly declined, possibly due to changes in river course, encroachment, or sedimentation linked to upstream land use practices.Reservoirs, which declined slightly by 2010, saw a notable rise by 2019.These hydrological changes underline the importance of understanding water-land interactions, especially in the *chure* region, where river systems are critical for downstream agriculture, drinking water, and ecological balance.

The period between 2000 and 2010 recorded the largest growth in forested space, whereas both cropland and grassland declined sharply, which demonstrates thatthe land use is shifting to more natural vegetation or abandoned land in the traditional pattern.The spread of built-up areas being the most critical tendency of the upcoming decade (2010 - 2019) implies a high rate of creeping urbanization.The land types, such as the forest and the built-up area, grew in the total time that the study was conducted (2000-2019), and, conversely, there were decreases incropland, grassland, and riverbeds, which indicates the impact of both changes in the environment and human activity.

Land Use and Land Cover Individual Categories of the Years 2000, 2010 and 2019

Land Use and Land Cover Individual Categories of the Years 2000, 2010 and 2019 show fairly pronounced trends of change. The area of forests also remained on an upward trend, which was a result of effective conservation and reforestation efforts. Conversely, the cropland continued to fall at a steady rate, which was probably attributed to land abandonment, urban growth, and low dependence on agriculture. The level of built-up areas has increased drastically between 2010 and 2019, which is a key indicator that the area is getting urbanized around Hetauda. Some insignificant changes were found in the riverbed, grasslands, OWL, and reservoir zones, whereas the bare soil was only detected in 2019, which is an indication of land disturbance or construction.

In addition to this, four individual line graphs show some important dynamics: a positive rate of forest change, a negative trend of cropland and grassland, and the fast rate of change in the built-up areas on an annual basis. In sum, these visualizations serve as highlights of the two-fold procedure of ecological restoration and urban pressure and emphasize the necessity of a coherent land use strategy and environmental planning in the district.

Figure 3

LULC Matrix of Individual Categories from the Years 2000, 2010, and 2019

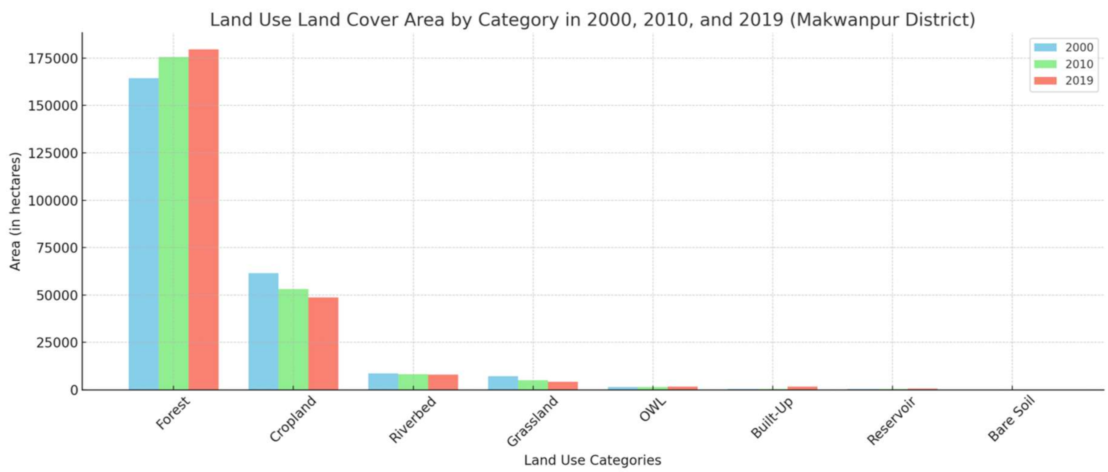
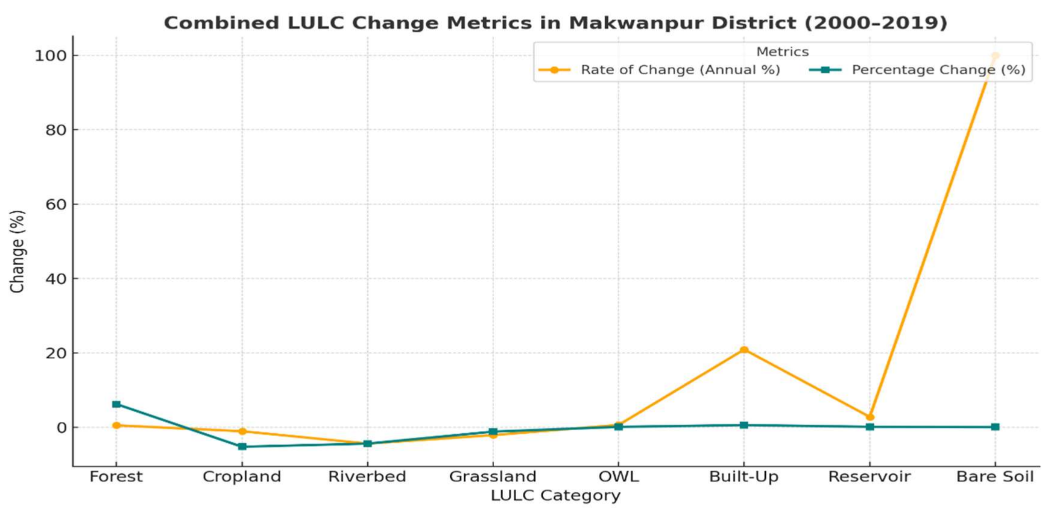


Figure 4

Combined LUCC Change Metrics (2000-2019)



The aggregate LULC change indicators point out a clear trend of forest increase and agricultural loss, and fast urbanization in Makwanpur District. The community forestry and regeneration saw a moderate improvement in forest cover, whereas the cropland and grassland showed continuous degradation, which means land abandonment and livelihood change. The urbanization and development of infrastructures were captured in the built-up areas, which registered the greatest growth rate per year. Taken altogether, these indicators demonstrate a radical change between agrarian and mixed urban-forested landscapes, and they both show ecological regeneration and developmental stress.

Findings

Trend and Magnitude of Land Use and Land Cover Change

The Land Use Land Cover (LULC) change analysis of Makwanpur District in 2000-2019 indicates unique trends in the intensity, pattern, and spatial distribution of land transformation. During the 20-year durability, forest cover demonstrates a net increase (+15,149.48 ha, 6.2%), whereas cropland is losing a significant part (-12,898.60 ha, 5.28%). The development of built-up areas grew sharply by 339.42 ha to 1,686.86 ha (0.55%), which is more than five times. Grassland and riverbed areas decreased by a small percentage (1.21% and 0.44%), whereas OWL (Other Woodland Land) and reservoirs grew by a small percentage (0.07% and 0.09%). Only in 2019, bare soil was observed, and it is new or disturbed land, probably related to construction, mining, or erosion. These movement tendencies reflect a two-sided process of ecological recovery in the form of forest growth and agricultural lands turned into cities.

Table 2

Summary of LULC Change (Year 2000-2019)

Land use class	2000 %	2010 %	2019 %	Net change 2000-2019	Direction
Forest	67.31	71.92	73.51	+6.20%	↑Gain
Cropland	25.23	21.71	19.95	-5.28%	↓Loss
Grassland	2.97	2.09	1.76	-1.21%	↓Loss
Built up	0.14	0.19	0.69	+0.55%	↑Rapid gain
Riverbed	3.55	3.38	3.11	-0.44%	↓Loss
Reservoir	0.17	0.15	0.26	+0.09%	↑Gain
OWL	0.64	0.55	0.71	+0.07%	↑Slight gain
Bare soil	0.00	0.00	0.01	+0.01%	↑New class erupt

These gain and loss arrows, in contrast, show an evident change of agro-based landscapes to urban and semi-forest landscapes, which can be conceived with the socio-economic transition which was taking place in the mid-hills of Nepal.

Comparative Analysis of the Other Studies

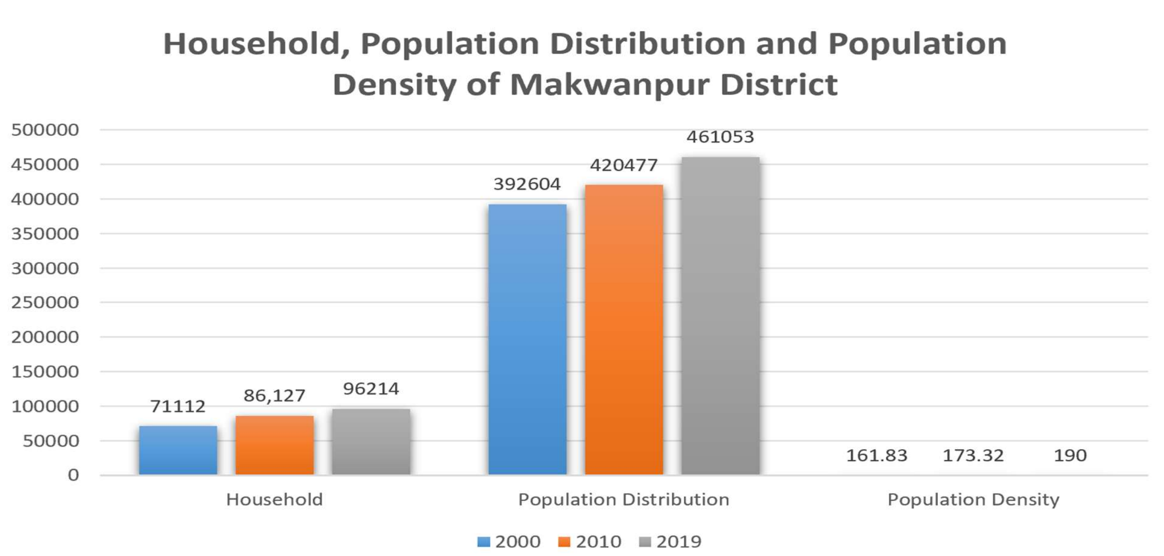
The recorded increase in the forest and decrease in cropland in Makwanpur are similar to the national trends in the Himalayas and the mid-hills districts. Uddin et al. (2014) have reported that the forested region in central Nepal has been growing as a result of a growing community forestry program and the reduction in reliance on traditional agriculture. Equally, Chapagain et al. (2018) found that the area of forests increased and agricultural land was reduced by outmigration and low productivity of farms in Panchthar district. Virgo and Subba (1994) found this recovery of forests in rural depopulated areas of Dhankuta District, in the same direction as in the mid-hill villages of Makwanpur. According to Khanal (2002) and Paudel et al. (2016), subsistence farming was also replaced by forest and settlements in the eastern and western Himalayas.

Dynamics of Population and Land Use Interdependence

The concepts of population increase and migration are directly connected to the concept of the transformation of land in the area of study. The census results show that Makwanpur expanded by between 392,604 and 464,579 people in 2001 to 2021 in terms of population, which resulted in a higher density of 133 to 169 people per hectare. This population growth is associated with a sharp rise in developed land surrounding Hetauda, Manahari, and Bhimphedi, in which migrants living in the countryside established themselves in the years after internal migration escalated.

Figure 5

Population Distribution of Makwanpur District, 2000-2019



The correlation of population and land use indicates that densely populated areas are associated with areas of decreasing arable land and the rising impervious covers. This connection assists in the Land Change Science (LCS) theory, in which demographic forces are regarded as central antecedent causes of LULC. Movement of labourers out of agriculture to the construction and service industry also contributes to the agricultural land abandonment and forest regeneration, as in the case of the mid-hill slopes.

Trend of LULC Change in Space and Altitude

The analysis of the space indicates that the build-up expansion and the loss of the crop land are concentrated in low-altitude areas (less than 600 m) such as Hetauda and Manahari municipalities. The regions are typified by smooth slopes and connectivity by road, which promotes urbanization and industrialization. On the other hand, natural regeneration and community forestry intervention are evidenced in mid-altitude areas (800-1500 m) where forest is recovered on former agro-terraces and infertile slopes.

At elevations (>1500 m) above, the land use is not that dynamic and is mainly forest and sparsely covered grasslands. The spatial process reflects a north-south gradient of change: the southern area of the foothills of the *Chure* is full of urbanization and infrastructural encroachment, whereas ecological restoration typifies the northern part of the mid-hill area.

Compared on a municipality basis, it is: Hetauda Sub-Metropolitan City: fast built-up growth and disappearance of agricultural land. Manahari Rural Municipality: ambivalent trend- forest increase and highway settlement.Bhimphedi Rural Municipality: regeneration of forests in the abandoned terraces. These trends indicate that land change is topographically stratified and socio-economically differentiated; thus, it is important to account for spatial heterogeneity in land-use planning.

Factors Driving LULC Change

The research has come up with five key categories of LULC change drivers that are supported by past literature on Nepal and the Himalayas:

Demographic Drivers

The direct causes of land conversion are population growth, rural-urban migration, and household expansion (Ning et al., 2023). Build-up area growth was aggravated by the post-earthquake resettlement.

Economic Drivers

Road widening, industries, and trade centers around Hetauda encourage the conversion of agricultural land into commercial and residential ones. The agricultural economy changes to a service economy, making the croplands less important.

Drivers of Policy and Institutional Level

The community forestry initiatives promote the regeneration of forests (Uddin et al., 2014). Lack of planning in zoning and irregular regulation of land use in cities helps promote unplanned sprawl.

Environmental Drivers

Riverbed erosion, slope instability, and sedimentation change the land use patterns (Ghimire, 2017). The change in rainfall due to climate change increases land degradation in areas that are in the lowlands.

Technological and Infrastructure Drivers

Technological and infrastructure drivers have enabled the company to enhance its profitability and quality of life. Market connectedness and access to transport via highway activities concentrated urbanization.

The interaction between these influences is consistent with the Land Change Science framework, insofar as both direct (proximate land conversion) and indirect (demographic, economic, policy) factors contribute to the problem's development. Moreover, the Political Ecology governance perspective helps explain how institutional restructuring and land tenure issues shape transformations, whereas Landscape Ecology can be used to explain their spatial and ecological consequences.

Overall, Makwanpur district has experienced a twofold change: urban growth in the lowlands and forest recovery in the mid-hills. Such a trend results from demographic pressure, economic diversification, and changing land governance within Nepal's federal system. Population dynamics, multi-scalar drivers, and spatial patterning are combined to provide a more comprehensive picture of LULC change, thereby achieving the study's aim of relating spatial, demographic, and institutional variables to a single analytical unit.

Conclusion

This study shows that Makwanpur district has experienced a different spatial and temporal change due not only to ecological regeneration, but also to urban growth. The increase in forest cover between 2000 and 2019 was 6.2, and this was due to the success of community forestry and natural regeneration, with a total decline in cropland and grasslands amounting to 5.28 and 1.21, respectively. On the other hand, urban areas increased fivefold (0.14-0.69), which means that the pace of urbanization increased along Hetauda and transport corridors. The spatial pattern evidences the intensification of lowlands and the success of mid-hill forests, which illustrates the process by which topography and accessibility influence the dynamics of land-use.

The use of the Land Change Science (LCS) as the main framework in cooperation with Political Ecology and Landscape Ecology facilitated the understanding of the complicated interaction of human activity with the processes of institutional and ecological structures. These results highlight the importance of combining spatial planning and environmental management in order to develop a balance between development and conservation. The policies focusing on zoning, watershed conservation, and sustainable settlement design are important to reduce land degradation in the delicate C*hure* landscape.

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