Land Use and Land Cover (LULC) Change Detection in Pokhara, Nepal (2004–2024)

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1 Introduction

1.1 Background and Importance of LULC Studies

Land Use/Land Cover (LULC) change has emerged as a critical factor influencing both ecological stability and environmental sustainability. This transformation is particularly concerning in the context of climate change, where human-induced alterations to land surfaces can exacerbate the challenges posed by global warming. The extensive modifications to natural landscapes—driven by activities such as urban expansion, agricultural intensification, and deforestation—result in the disruption of ecosystem dynamics and diminish vital services that nature provides, including carbon sequestration, water purification, and soil fertility [1]. Such changes can lead to the degradation of the very resources upon which human life depends, making LULC studies essential for understanding and mitigating these impacts.

Monitoring these land use changes has gained urgency as urbanization accelerates, particularly in developing countries experiencing rapid population growth. The ability to effectively track and assess the implications of these transformations is crucial for developing sound environmental management strategies. The alteration of the Earth's surface due to human activities, such as the conversion of forests to urban areas or agricultural fields, has profound implications for biodiversity and ecological health [3, 4]. Research indicates that LULC changes can significantly affect global landscapes, contributing to habitat loss and reduced ecosystem services, particularly in areas where populations are burgeoning and resources are under increasing stress [2].

Technological advancements, particularly in remote sensing and Geographic Information Systems (GIS), have revolutionized our capability to monitor and analyze LULC changes. These tools allow researchers to gather accurate, high-resolution data on land cover transformations, making it possible to assess environmental impacts more effectively and inform policy decisions based on solid evidence [5, 6]. Remote sensing technology, in particular, enables continuous monitoring over large areas, providing insights into urban growth patterns and their subsequent environmental consequences [7]. As a result, these methodologies have become indispensable for researchers and policymakers alike, facilitating a better understanding of land use dynamics and their implications for sustainable development.

1.2 Overview of Pokhara's Geography and Socio-economic Significance

Pokhara is a prominent city located in central Nepal, distinguished by its varied topography, which includes valleys, lakes, and hills. This diverse geography not only contributes to the city's scenic beauty but also positions it as a crucial destination for tourism. Serving as the gateway to the Annapurna Circuit, Pokhara attracts trekkers and adventure enthusiasts from around the world, transforming it into a vital tourism hub [10].

The growing influx of tourists has contributed to significant population growth, as people migrate to the city seeking employment and business opportunities in the tourism sector. This demographic shift has resulted in a higher demand for housing, infrastructure, and public services, leading to the conversion of substantial areas of agricultural land into urban developments [11, 13].

However, this rapid urban expansion has raised concerns about environmental sustainability. Increased urbanization puts additional pressure on local ecosystems and natural resources. For example, Phewa Lake, a critical freshwater resource for the city, is facing pollution and sedimentation challenges linked to unregulated development and expanding human activities [12]. These challenges underscore the necessity for effective land management strategies that can balance economic growth with environmental conservation in Pokhara [9].

In addition to the threats posed to Phewa Lake, urban expansion in Pokhara has also been linked to a notable decline in forest cover. This has serious implications for ecosystem services, such as soil stability and flood prevention [8]. As forests are cleared for development, the loss of vegetation increases the risk of landslides and exacerbates the region's vulnerability to natural disasters.

1.3 Objectives of the Study

2 Study Area

2.1 Geographic Location of Pokhara

Pokhara is located in central Nepal, approximately 200 kilometers west of the capital, Kathmandu. Positioned within the Gandaki Province, the city is situated in the Kaski District. Geographically, it lies at an altitude of about 827 meters above sea level, nestled within the Pokhara Valley. The city's geographic coordinates are approximately 28°15' N latitude and 83°59' E longitude.

Pokhara's strategic location between the southern plains (Terai) and the northern Himalayan range makes it a significant center for tourism. It serves as the gateway to the Annapurna Circuit, one of the world's most popular trekking routes. The city is characterized by a diverse landscape, featuring a blend of lush valleys, rivers, and lakes like Phewa, Begnas, and Rupa, all encircled by hills and the towering Annapurna and Dhaulagiri mountain ranges to the north.

2.2 Climatic Conditions and Topography

Pokhara experiences a humid subtropical climate with four distinct seasons: spring, summer, monsoon, and winter. Due to its geographical positioning between the Himalayas and the Mahabharat range, the city enjoys a moderate climate compared to other parts of Nepal. Summers (June to September) are warm and humid, with temperatures reaching up to 35°C, while winters (December to February) are mild, with temperatures ranging between 5°C and 15°C. Pokhara receives one of the highest annual precipitation rates in Nepal, largely due to the southwest monsoon, with an average rainfall of around 3,900 mm per year.

Topographically, the city lies in a fertile valley formed by the Seti River. Pokhara's landscape is shaped by natural processes such as erosion, deposition, and tectonic movements. The city is surrounded by hills and is close to notable peaks, including Machhapuchhre and Annapurna, whose snow-covered summits create a scenic backdrop. Additionally, the Seti River has created gorges and underground flows, adding to the unique geological features of the area.

2.3 Population Growth and Economic Activities

The National Population and Housing Census 2021 indicates significant population growth in Pokhara, driven by both natural population increases and rural-to-urban migration. As of 2021, the population of Pokhara was around 513,504 people. This growth has created a high demand for housing and infrastructure, pushing urban expansion into previously agricultural areas [14]. Pokhara's economy is mainly supported by tourism, with the city serving as the gateway to the Annapurna Circuit, one of the most popular trekking routes globally [15]. Additionally, the city benefits from remittances sent by Nepali workers abroad, along with trade and services industries.

This data from the 2021 census underscores the rapid urbanization trends in Pokhara, emphasizing the need for sustainable land use management to balance economic growth with environmental preservation. For more detailed data, you can access the full census report on Nepal's National Statistics Office website [?] or Open Data Nepal [16].

2.4 Study Area Map

The map illustrates the elevation profile of the study area, highlighting the varying altitudes within Pokhara, which is situated in the Kaski District of Nepal.

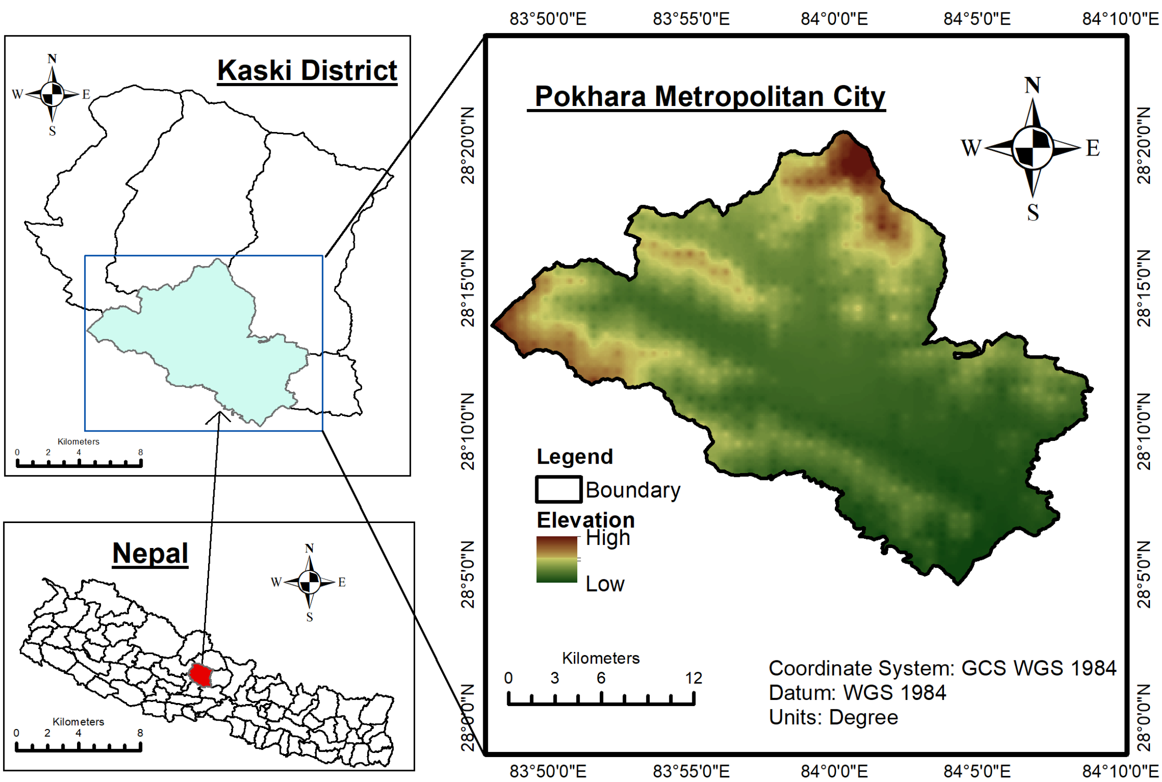

Figure 1: Study Area Map

3 Materials and Methods

3.1 Data Acquisition

In conducting this study, the acquisition of satellite imagery proved pivotal for accurately monitoring land cover changes in Pokhara, Nepal. The data were sourced from two principal satellite platforms: Landsat and Sentinel. For the years 2004, 2009, and 2014, Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) was utilized, providing high-resolution multispectral imagery with a spatial resolution of 30 meters across eight spectral bands. To ensure the reliability of the analysis, the inherent scan line error present in Landsat 7 data was addressed before proceeding with any classification processes.

For the subsequent years of 2019 and 2024, imagery from Sentinel-2B was employed. This satellite, part of the Copernicus program, offered high-resolution optical imagery with spatial resolutions ranging from 10 to 60 meters across 13 spectral bands. The advantages of using Sentinel-2B included its capability to capture high-quality images with a frequent revisit time of every five days, thereby facilitating consistent monitoring of land cover changes. In selecting images for analysis, only those with cloud cover of less than 5% were considered to ensure data quality. The satellite data were obtained from public access platforms, specifically Earth Explorer [17] for Landsat imagery and the Copernicus Open Access Hub [18] for Sentinel data. Prior to analysis, the collected images underwent necessary pre-processing steps, including atmospheric correction, geometric correction, and cloud masking, to optimize the accuracy of subsequent analyses.

3.2 Software and Tools Used

The analytical framework of this study primarily employed ArcMap, a comprehensive Geographic Information System (GIS) software. ArcMap was instrumental in facilitating data manipulation, classification, and visualization of the acquired satellite imagery. Its specialized tools for image classification and change detection proved particularly beneficial for conducting a thorough analysis of land cover transformations within the study area. Through the capabilities offered by ArcMap, the classification process incorporated supervised methodologies to accurately categorize the various land cover types present in the imagery.

3.3 Classification System

The classification system established for this study served as a critical component in the analysis of land use and land cover (LULC) changes. The land cover was systematically categorized into five primary classes, as outlined by the National Land Cover Monitoring System for Nepal. These classes included Bare Soil, representing areas with little to no vegetation cover; Cropland, encompassing cultivated agricultural areas that are vital for food production; Urban Areas, which denoted built environments such as residential and commercial spaces, thus providing insights into urban sprawl; Water Bodies, including lakes, rivers, and reservoirs critical for hydrological assessments; and Built-up Areas, reflecting the expansion of urban infrastructure.

The classification utilized a supervised approach, employing the maximum likelihood algorithm. This statistical method estimated the probability that a pixel belonged to a specific class based on training data, thereby yielding a robust classification of land cover types. To ensure the validity of the classification results, ground truth data were collected and compared against the classified outputs, with accuracy assessments conducted using Kappa statistics.

Table 1: Land cover classes and definition

Main land cover class	**Description**	**IPCC land cover class**
Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10	Forest
Cropland	This category includes arable and tillage land, and agroforestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.	Cropland
Built-up area	Built-up areas refer to artificial structures such as towns, villages, industrial areas, airports, etc.	Settlements
Water body	Rivers are natural flowing water bodies and typically have elongated shapes. Lakes and ponds are perennial standing water bodies.	Water body
Bare soil	A soil surface devoid of any plant material.	Other

3.4 Methodology Map

Methodology Map illustrating the classification and change detection processes. This map encapsulates the entire methodology employed in this study, providing a visual overview of the data acquisition, processing, classification, and change detection techniques utilized to analyze land cover changes in Pokhara, Nepal.

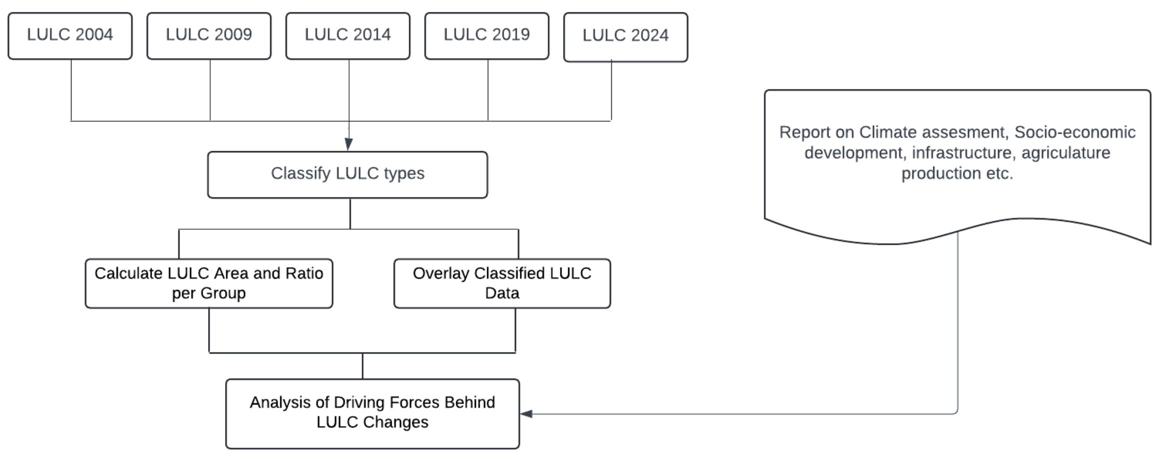

Figure 2: Methodology Map

3.5 Change Detection Techniques

The change detection analysis involved a hybrid classification technique, which facilitated the comparison of classified maps across different years. This method enabled the identification of areas experiencing significant land cover changes over time. To assess the accuracy of the change detection results, Kappa statistics and error matrices were employed, providing a quantitative measure of the classification accuracy and the reliability of the detected changes..

3.6 Accuracy Assessment

To evaluate the performance of the Land Use Land Cover (LULC) classification, an accuracy assessment was performed using a confusion matrix. This matrix allowed us to calculate several important accuracy metrics: **User's Accuracy (UA), Producer's Accuracy (PA)**, and the **Kappa Coefficient**.

3.6.1 Accuracy Metrics

The accuracy metrics were derived using the following formulas, as per the standard method described by [19]:

- **User's Accuracy (UA):** This measures the probability that a pixel classified as a particular land cover class actually belongs to that class. It is calculated using:

$$UA = \frac{TP}{TP + FP}$$

where TP is the number of true positives and FP is the number of false positives.

- **Producer's Accuracy (PA):** This reflects the probability that a reference pixel is correctly classified. The formula is:

$$PA = \frac{TP}{TP + FN}$$

where FN is the number of false negatives.

3.6.2 Kappa Coefficient

The **Kappa Coefficient** (κ) was used to assess the agreement between the classified data and reference data, accounting for chance agreement [20]. It is calculated as:

$$\kappa = \frac{p_o - p_e}{1 - p_e}$$

where p_o is the observed accuracy (i.e., the proportion of correctly classified pixels) and p_e is the expected accuracy (i.e., the accuracy due to chance). The Kappa value ranges from -1 (complete disagreement) to 1 (perfect agreement), with values above 0.8 generally considered strong agreement.

3.6.3 Confusion Matrix

A confusion matrix was generated by comparing the classified LULC data with reference data. From this matrix, we derived the UA, PA, overall accuracy, and Kappa statistic for each class.

4 Results

4.1 Accuracy Assessment

The overall accuracy for LULC classification in this study depicted variability from the year and the respective accuracy ranging from 87.15% to 97%. The Kappa indices of agreement that signal the reliability of classification varied from 0.83 to 0.95. These values show a high degree of accuracy between the classified data and reference data, as put by Congalton and Green (2019) [22] .

The results for each class and User Accuracy (UA) together with Producer Accuracy (PA) are shown in Table 2. For example, the efficiency rate was at 100 percent Producer Accuracy (PA) in the year 2024, meaning that all the reference pixels were classified accurately under the Water class. The User Accuracy (UA) for this class was found to be 0.90, meaning that 90% of the water pixels in the study area were correctly classified as water.

For the classification of Forest class they got PA 0.90 and UA 0.93 in 2024 which shows good reliability for this category in concern area but there is less than previous years, according to Foody (2002) [24]. Specifically, the Built-up class yields perfect accuracy with a UA of 1.00 in the year 2024; however, the PA of this class deteriorated from a perfect value of 1.00 in the Base year to 0.77 in the year 2014. This change indicates that there may be a variation in identifying constructed-up zones, which could be attributed to temporal differences in the aspects of the land cover. Bare Soil, and Cropland classes also had reasonably high accuracy with overall PA of 0.91 for both Bare Soil and Cropland classes showing that there was consistency of the maps in these land cover categories for the entire time period under study.

In general, the overall accuracy of each class of LULC was above the set minimum level of 85% which Anderson advocated [23]. This justify the accuracy of the LULC classifications for the analysis of gradual changes of the land covers within the specified time periods.

Table 2: Producer Accuracy (PA) and User Accuracy (UA) for LULC Classes Over the Years

LULC	2024		2019		2014		2009		2004	
	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
Water	1.00	0.90	0.90	1.00	1.00	1.00	0.83	1.00	1.00	1.00
Forest	0.90	0.93	0.87	0.97	0.93	0.95	0.85	0.92	0.95	0.95
Built-up	1.00	1.00	1.00	0.70	0.77	1.00	1.00	0.70	0.89	0.80
Bare Soil	0.90	0.93	0.82	0.96	0.96	0.82	0.66	1.00	0.69	0.82
Crop Land	0.91	0.86	0.90	1.00	0.83	0.86	0.97	0.83	0.92	0.90
Kappa	0.882		0.8715		0.8717		0.83		0.8760	

4.2 LULC Maps and Area Statistics

The LULC maps for the years 2004, 2009, 2014, 2019, and 2024 are depicted in Figure 3, with the associated area statistics for each land cover class presented in Table 3. These maps reveal significant transformations in land use over the two-decade period,

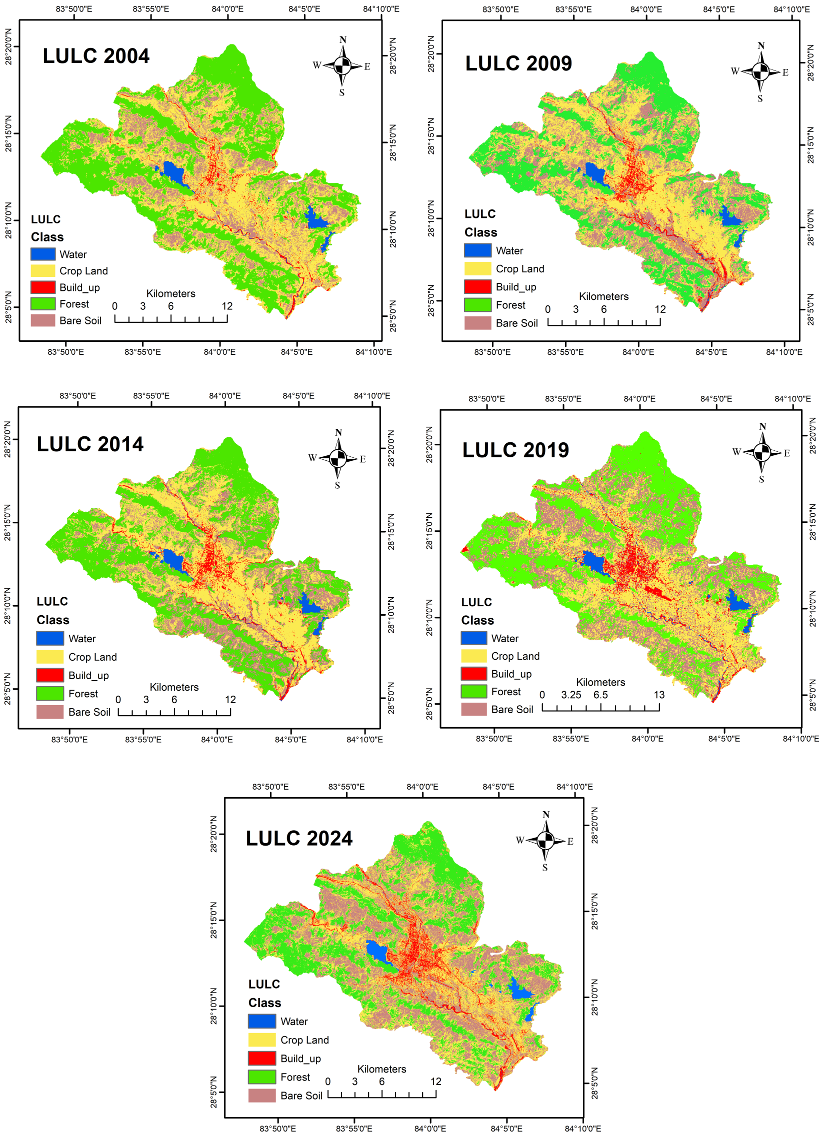

Figure 3: LULC Map of Pokhra for 2004, 2009, 2014, 2019, and 2024

particularly highlighting the substantial growth of built-up areas alongside a notable reduction in forested regions.

he changes in land cover classes are detailed in the figures and tables below, effectively illustrating the trends and the extent of each land class over time.

Table 3 also shows the areas corresponding to each of the LULC classes making it easier to interpret shifts occurring throughout the period of study. The area under Water did not change much, which suggests that its hydrological characteristic were quite preserved within the areas under analysis. However, Forest cover significantly reduced, which was at 40.25% (187.14km2) in 2004 to a 28.27% (131.48km2) in 2024). This reduction of over 56.66km^2 has evidential value on how human activities and natural disaster influences the forest resources to a level it may elicit loss in bio diversity and eco system services [25].

On the other hand, the Built up area has expanded from 2.44% (11.34 sq Km) in 2004 to 5.80% (26.96 sq Km) in 2024, as there is constant construction of structures in the study area.This urban growth is indicative of population increase and economic

Table 3: Area of LULC (Land Use and Land Cover) over the years (in percentage and km^2)

Year	2024		2019		2014		2009		2004	
	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2
Water	1.73	8.035	1.97	9.15	1.93	8.98	1.87	8.70	1.84	8.53
Forest	28.27	131.48	34.01	158.21	37.67	175.15	30.1	139.54	40.25	187.14
Built-up	5.80	26.96	4.74	22.05	4.15	19.28	3.62	16.84	2.44	11.34
Bare Soil	28.41	132.12	27.73	128.99	19.28	89.65	24.11	112.12	15.82	73.57
Crop Land	35.80	166.52	31.54	146.72	36.98	171.94	40.38	187.77	39.66	184.40

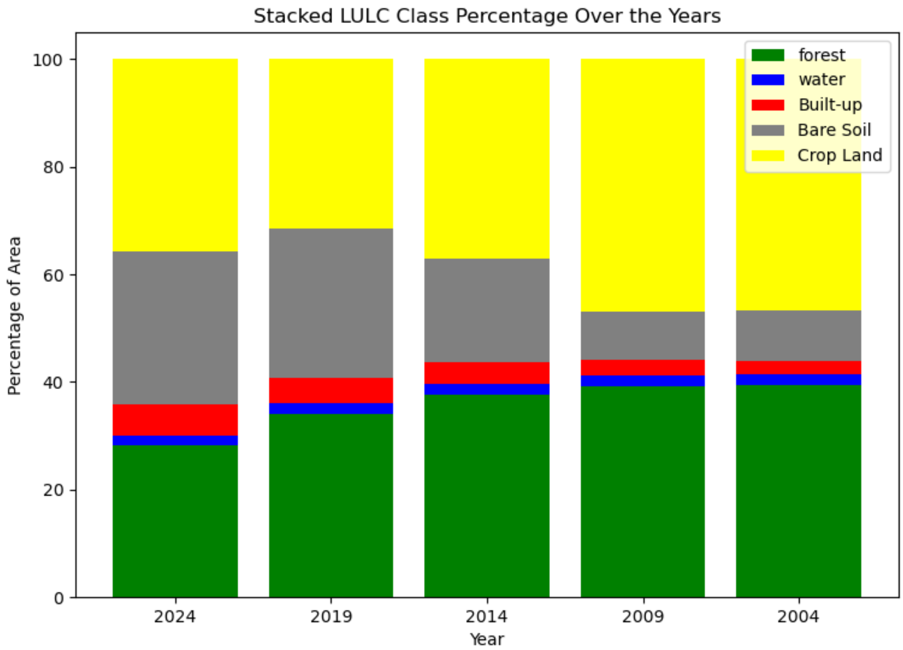

Figure 4: Percentage area change of LULC classes over time

development, leading to greater demand for residential, commercial, and infrastructure development. Such changes not only alter the landscape but may also contribute to challenges like urban heat islands, increased runoff, and pressure on local resources [26].

It is clearly discernible from the contents of the figures and the tables, that the changes in LULC are not just enormous, but are also slightly at the cost of the environment and societal structure. It is as such important to understand this dynamics especially in addressing land management and planning strategies to reducing negative impacts on land.

4.3 Land Cover Dynamics (2004–2024)

The land cover dynamics observed from 2004 to 2024 indicate significant trends, particularly in urbanization, deforestation, and agricultural land expansion. As shown in Figure 5, urban areas expanded drastically, contributing to a reduction in forested areas and cropland. The area occupied by urban land increased significantly, reflecting pressures from population growth and economic development. During this period, forest cover experienced a notable decline, suggesting possible deforestation pressures stemming from urban expansion and agricultural encroachment.

The following figure and analysis provide a quantitative breakdown of the key changes in land cover types.

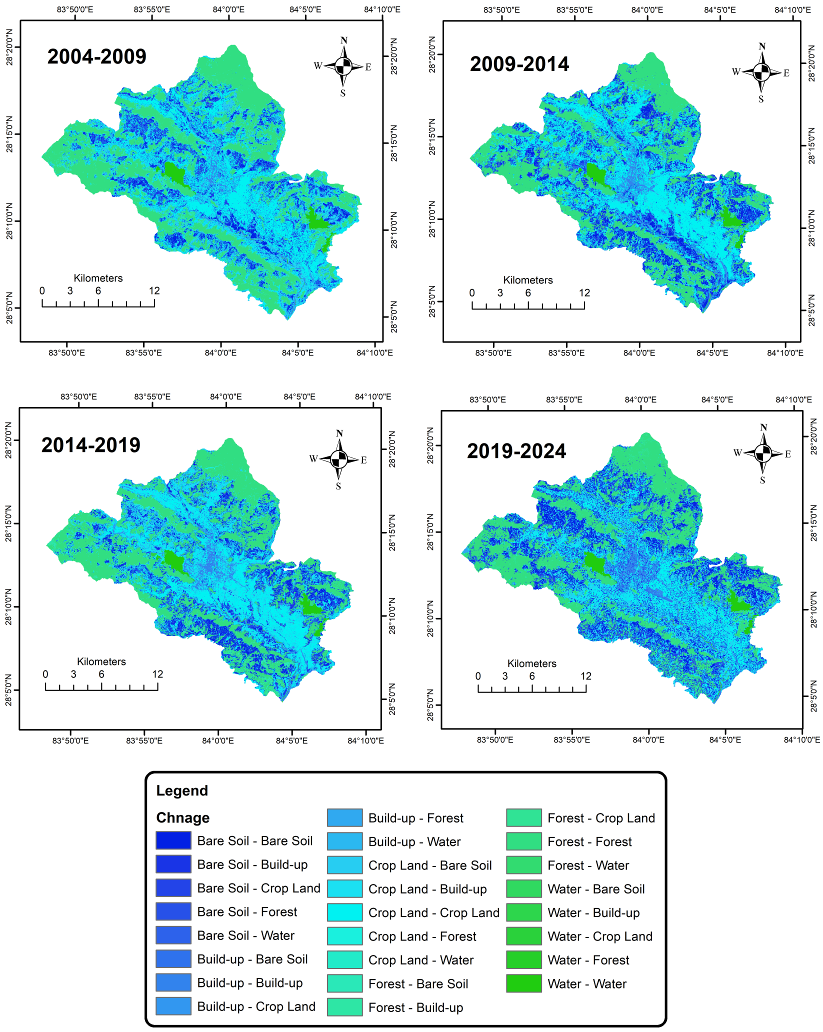

Figure 5: Land cover dynamics from 2004 to 2024, showing significant trends in urbanization, deforestation, and agricultural land expansion.

The land cover change map showing the change from one class to another of five classes for the year 2004, 2009, 2014, 2019, and 2024.9, and 2024. The map effectively conveys the distribution and trends in the changes in the land cover within the twenty-year period. For instance, the extent of the forest area declined slightly from around 40 percent of the overall landscape in the year 2004 to approximately 28 percent in the year 2024; there is still considerable work addressing difficult question of forest resource management.When urbanization and agricultural uses expand, ecosystems continue to become fragmented and species richness decreases as its habitats shrink [27].

If such trends persist, the urban areas might be expected to grow by an extra 20

4.4 Transition Matrix and Quantitative Analysis of Change

The transition matrix provides a quantitative overview of land use and land cover (LULC) changes over the past 20 years (2004-2024), offering insights into the magnitude and direction of changes between land cover categories. It highlights how different land types, such as forest, cropland, built-up areas, water bodies, and bare soil, have transitioned into other land cover categories, showing both gains and losses. The following analysis summarizes the key findings based on the transition matrix.

Table 4: Transition Matrix of Land Use and Land Cover (LULC) Changes (2004-2024) (in km^2 and %)

Land Use	Build-up (km^2/%)	Forest (km^2/%)	Water (km^2/%)	Bare Soil (km^2/%)	Crop Land (km^2/%)
Water	1.13 / 0.02	0.03 / 0.00	7.65 / 0.09	0.07 / 0.00	0.57 / 0.01
Crop Land	10.59 / 6.54	6.69 / 3.30	0.11 / 0.01	55.43 / 5.38	73.62 / 45.83
Build-up	11.13 / 8.64	0.21 / 0.17	0.39 / 0.04	2.24 / 0.82	7.87 / 6.20
Forest	0.21 / 0.01	112.20 / 82.73	0.09 / 0.05	14.43 / 10.36	30.87 / 22.50
Bare Soil	3.88 / 2.94	11.89 / 8.96	0.03 / 0.00	59.69 / 45.00	53.24 / 40.00

As seen in **Table 4**, several significant trends are evident in LULC changes between 2004 and 2024:

- **Urban Expansion (Build-up Increase):** Built-up areas saw a substantial net increase over the study period, with an increase of 11.13 km^2 (8.64%). This expansion is mainly at the expense of cropland (6.20%) and bare soil (0.82%), illustrating rapid urbanization.

- **Deforestation and Forest Stability:** Forested areas remain relatively stable, with 82.73% (112.20 km^2) of the forest cover unchanged during this period. However, there has been some deforestation, as portions of the forest were converted into cropland (3.30%) and built-up areas (0.17%).

- **Cropland Dynamics:** Cropland experienced both gains and losses. The largest increase was due to conversion of bare soil (5.38%) into cropland, amounting to a net change of 73.62 km^2 (45.83%). Some cropland was also converted into built-up areas (6.54%).

- **Bare Soil Transitions:** A significant portion of bare soil was converted into cropland (45.00%) and built-up areas (2.94%), reflecting land-use intensification during the study period.

- **Water Bodies:** Water bodies remained relatively stable, with only minimal transitions. A small portion of water was converted into built-up areas (0.02%) and cropland (0.01%).

These observations provide a comprehensive understanding of the spatial distribution of land use transitions over the 20-year study period. The dominant trends of urbanization, agricultural expansion, and deforestation underscore the pressure on natural resources in the region.

5 Discussion

5.1 Population Growth and Urban Expansion

The rapid urbanization of Pokhara, a major city in Nepal, is closely tied to significant demographic shifts and the socioeconomic dynamics that influence land transformation.

Over the past two decades, the city's population has grown by over 30

The tourism industry plays a crucial role in this transformation. As a popular destination renowned for its natural beauty and recreational opportunities, tourism has spurred investments in hotels, restaurants, and commercial spaces. Consequently, land that was once dedicated to agriculture is increasingly repurposed for tourism-related developments, intensifying urbanization.

This interaction between demographic shifts and tourism-driven land use changes creates a cycle where urban expansion fuels economic growth, attracting even more residents. However, this rapid urbanization poses challenges such as inadequate housing and environmental degradation.

To address these issues, effective urban planning and sustainable land management are essential. Policymakers must strike a balance between supporting economic growth through tourism and preserving local ecosystems and community integrity for long-term sustainability.

5.2 Environmental Impacts

This revolution from 2004 to 2024 has made considerable shifts in the environmental structure of Pokhara, including the natural resources and systems of the area. The most outstanding effect is in the decrease of the forest area from 40.25% to 28.27%. These activities have led to the fragmentation of habitats, decline in species density and the undermining of important ecosystem processes including carbon storage and constraining of soil erosion. With deforestation, the region is in a worse position to handle adverse impacts of climate change for example, landslides and floods.

Similarly, urbanisation pressures have threatened the water sources of Pokhara and Phewa Lake in particular in terms of water pollution from construction site effluence and lack of proper waste disposal systems. Vegetated degradation has hence changed natural water flow regime in that it enhances surface runoff hence soil erosion. These changes are worst during the monsoon season when floods the water bodies more and increases sedimentation and decreases water quality causing problems for local agriculture.

Further, the increase of the built up area from 2.44% in 2004 to 5.80% in 2024 has compounded on the occurrence of the Urban Heat Island (UHI) effect. This tendency, known as the Urban Heat Island Effect, is causing higher temperatures within structures and declined air quality, with consequences to community health and energy utilization.

Furthermore, the cultivation on steep, marginal slopes has increased the risks of soil erosion and landslages, especially on areas that were originally checked by plants. The challenges mentioned above show why there is the need for proper management of the land such that development is not associated with destruction of the environment.

5.3 Comparison to Similar Studies

The land use and land cover (LULC) changes observed in Pokhara from 2004 to 2024 align closely with findings from other urbanizing regions in Nepal.A research conducted by Khanal et al in 2020 showed that Pokhara Metropolitan City has recorded a lot of forest loss and urban spread from 1999 to 2019, and built up areas expanded mainly because of population and tourism activities [28]. This is evident from the findings revealed in this study where forest cover in Pokhara has reduced from 40.25% (187.14km^2) in 2004 to 28.27% (131.48km^2) in 2024 meaning a loss of more than 56.66km^2 of the forest area.

The same can be observed in the Kathmandu Valley where urbanization has entailed substantial conversion of agricultural land and forest for economic growth and rural migration to cities [29]. Facing the similar problem of expansion of built-up areas from 2.44% (11.34km²) in 2004 to 5.80% (26.96km²) in 2024, Pokhara also shares the same problem as observed in Kathmandu.

Studies conducted in the Chitwan District also show a high degree of deforestation, as well as a change of agricultural lands into built up areas [30]. Similarly, the intensity of cropland fragmentation was also high in Pokhara where, as analyzed by transition matrix, 6.54% of the cropland were changed to built-up areas.

The consistency of these trends across various studies in Nepal underscores a regional pattern of rapid urbanization and economic development reshaping landscapes. Thus, the LULC changes in Pokhara are part of a significant movement across urban areas in Nepal, highlighting the urgent need for integrated land management strategies that balance urban expansion with environmental conservation.

5.4 Driving Factors for LULC Change

Being one of the most rapidly developing cities in Nepal, Pokhara has undergone major changes in Land Use Land Cover (LULC) in recent past. Such changes occur mainly due to demographic factors, development of infrastructure, growth of population density, tourism, various kinds of commercial activities, etc, all which lead to the alteration of the city's environment.

The characteristics of LULC change in Pokhara indicated that the population growth is among the most direct causes. In the last two decades, the city has experienced demographic contraction through natural growth and rural- urban drift. Residents in the rural regions adjacent to Pokhara travel there in hope of finding better employment, education, and health care services. This population growth has led to exercise demands for shelter, amenities, and paving hence the expansion from agricultural and forest to residential, commercial and industrial zones.

Urbanization, a factor closely related to population growth, has transformed the land cover of Pokhara to a significant extent. It has grown in both human demographic size and physical structure, having annexed rural and peri-urban settings to its built-up domain. Agricultural land and areas with an abundance of free space have been gradually taken by infrastructure, such as roads, bridges, residential districts, and commercial premises. Whereas our was informed by the need for better services and transport, it has also contributed enormously to land conversion therefore enhancing the unit spread of the city.

Tourism is another key agent of LULC change, and exerts a significant influence on the landscape of Pokhara. Pokhara is one of the most popular tourists' destinations in Nepal and the main starting point to the Annapurna Trekking Region. As a result there are well established hotel and resorts, restaurants and recreational facilities within and around places like Phewa Lake and Sarangkot and other places of interest. These demands have led to changes in natural land uses with many green areas being developed to accommodate tourist accommodation and associated service facilities.

Other than tourism, economic activities also contribute to changes in LULC since economic growth leads to more land utilization. Though, Pokhara was an agricultural economy before but increase in industries and service sectors led to conversion of agricultural fields to commercial and industrial use. New growth of small and medium scale industries coupled with an enhanced concentration in trade, real estate, and construction activities has more boosted the pace of land conversion making a decline in extent of agricultural and natural lands.

Lastly, infrastructure advancement is another important cause of land cover changes. These big projects include the Pokhara International Airport, roads and bridges, highways, and transportation sectors that have physically transformed the region. First, they cater for the exploding population and primarily the growing tourism industry but second, most of these projects demand a lot of space, which in most cases translates into cutting down trees, farms and other natural resources.

6 Conclusion

There was a drastic transition of the LULC in the period of 2004 to 2024 in Pokhara through urbanization, tourism, and increase in population. From the density survey analysis it was found that forest cover reduced from 40.25% to 28.27% where more than 56 km^2 of forest has been cleared for urban and agricultural development. Urban areas developed sharply, rising from 2.44% to 5.80% per cent, indicating fast growth of urban sprawl to the detriment of cropland and other non-urban barren land. Regarding the agricultural land also, changes occurring in conversion into the urban area were depicted. However, there was not much variation on lakes such as Phewa Lake but these are currently in danger of urban pollution and sedimentation. These changes show that the pressure for development should not overwhelm the conservation of the natural systems.

The rapid urban expansion in Pokhara underscores the urgent need for sustainable urban planning to mitigate environmental degradation. Strategies such as afforestation, the protection of existing green spaces, and the integration of green infrastructure into urban design are essential. Additionally, managing waste and water pollution, especially in areas like Phewa Lake, will be critical. Urban planning must address the growing demands of tourism and population while ensuring the preservation of natural resources. By focusing on sustainable land management, Pokhara can achieve long-term economic growth without compromising its ecological integrity.

7 Recommendations

7.1 Policy Suggestions for Land Use Planning

An immediate action would be the attempt to strictly zone certain areas so that new developments cannot occur at a faster pace than the environment can handle. The pressure to develop land should shift to preserving the major natural assets including the Phewa Lake, Seti River and forested hills around which are rapidly being grabbed. The legal measures limiting construction in such areas can provide tangible outcomes when it comes to eradicating the pooreshing results of environmental deterioration including deforestation, water pollution and the severing up of large tracks of territory. The proposed zoning reforms in cities like Curitiba, Brazil have also worked harmoniously to manage the growth of urban structure and the preservation of the natural structure of geographical areas, which could be used as a model for Pokhara.

For Pokhara's unique situation, focusing on densification within existing urban areas rather than outward expansion is essential. Policies encouraging high-density, low-impact development in central and already urbanized areas would reduce the pressure on surrounding rural and agricultural lands.This may be done through incentives for vertical growth (for instance, more intensive structures with less ground area) in the core area of Pokhara. Also, creating more parks including community garden within the city, that will mitigate the effects of urbanization on the environment while at the same time enhancing the welfare of users. Singapore is one example of a city that has been able to incorporate green infrastructure in the process of development of that city's landscape, which is a possible approach that can be taken to address the problem of management of green space in Pokhara.

7.2 Mitigating Strategies for Conservation

Thus, for effectively mitigating the environmental effects of growth in built-up areas of Pokhara, few specific preservation measures for specific objects are needed. Firstly, to safeguard the watersheds and lakes including the Phewa Lake there ought to be set aside buffer zones restricting concentration of construction and agriculture. Strong regulation of water quality will eliminate water pollution by substances from the cities' drainage system and tourists littering the important ecosystems.

Therefore, the development of a comprehensive strategy of forest preservation and afforestation is an essential requirement. It would also increase the possibilities of success in eradicating deforestation around places such as Sarangkot if it involved the local community members in tree planting and restoration. This is similar to several programs observed in South Korea where environmental as well as economical benefits can be created by enhancing community involvement while availing the benefits of habitat restoration. Employment creation is also important as well as the conservation of the tourist resources through promotion of sustainable tourism. The positive approach is to set up standards of sustainable tourism, and avoid construction in critical locations to reduce impact. This development means that promoting responsible trekking and tourism at community level will benefit both conservation and people's income.

Finally, the plan of establishing of new corridors to overcome the disruptions of wildlife due to urban sprawl. These corridors may consist of elements that can connect broken up land, also helping local ecosystems and offering people recreational areas. The application of the above mentioned strategies will welfare facilitate City Command's efforts to ensure that the growth of Pokhara cannot be wished to be at the expense of Nature resources.

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