# Urban Expansion and Its Consequences: Impacts on Food Security and Environmental Sustainability

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**Key words**: Urban Expansion, Food Security, Environmental Sustainability

## SUMMARY

Understanding the effects of urbanization and developing sustainable planning strategies necessitates a comprehensive analysis of urban growth patterns across different spatial and temporal scales. Urbanization is a rapidly evolving phenomenon, particularly in developing countries, where it often leads to significant changes in land use and land cover. This study investigates the spatial and temporal patterns of urban expansion in Godawari Municipality, located in the Lalitpur District of Kathmandu Valley, over a period of twenty years, from 2000 to 2019. Using land cover data sourced from the International Centre for Integrated Mountain Development (ICIMOD) and advanced GIS analysis techniques, this study quantifies the changes in key land cover categories such as built-up areas, forests, and croplands. The findings of this research reveal a dramatic increase in built-up areas, which expanded from 95 ha in 2000 to 650 ha in 2019. This expansion has predominantly occurred at the expense of forests and croplands. Forest areas, after an initial increase, ultimately decreased from 5690 ha in 2000 to 5642 ha in 2019. Similarly, cropland areas experienced a reduction, declining from 3824 ha in 2000 to 3318 ha in 2019. The implications of these changes are profound. The conversion of croplands to urban areas poses a significant threat to local food security, as the reduction in agricultural land limits the capacity for food production. Additionally, the loss of forest areas affects biodiversity and the provision of essential ecosystem services, contributing to environmental degradation. This paper underscores the critical need for sustainable urban planning strategies that balance development with environmental conservation. By highlighting the adverse impacts of unchecked urban expansion, to the outputs from this research inform policymakers and urban planners about the necessity of integrating sustainable practices to mitigate the negative consequences on natural resources. The findings emphasize the importance of a holistic approach to urban development that ensures economic growth while preserving vital ecological and agricultural landscapes

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## 1. INTRODUCTION

Urbanization is a transformative process that reshapes social and cultural relationships, including demographics, economy, political structures, and ideology, creating new identities, economic relationships, materialities, and social realities. It extends beyond mere population growth and nucleation, encompassing the emergent properties that redefine human interactions and environments (Love, 2021). The United Nations' World Urbanization Prospects reports that 55% of the global population lived in urban areas in 2021, a figure expected to rise to 68% by 2050(United Nations Habitat, 2022). Developing countries in Asia and Africa are anticipated to see substantial growth in their urban populations (Manna et al., 2024). Each country defines urban and rural areas based on its own criteria, and in Nepal, these definitions have frequently changed over the past six decades, with varying requirements for urban classification across different geographic regions ( Bhattarai et al., 2023). The shift from a rural to an urban economy in Nepal has been driven by government decisions to merge rural administrative units and designate them as municipalities (Joshi, 2023). Rural-to-urban migration significantly drives urban growth in Nepal, resulting in unplanned land use, reduced open spaces, haphazard construction, and inadequate services, reflecting global urbanization trends (Timsina, 2020). Nationally, the urban population increased from 2.9% with 10 urban centers in 1952/54 to 17.1% with 58 urban centers in 2011, and exceeded 50% population growth with 293 urban centers by 2017 (Rijal et al., 2020). The latest report of the National Statistical Office shows 66.17% urban population in 2021 (NSO, 2023). Understanding the impacts of urbanization and developing sustainable planning strategies starts with analyzing the dynamics of urban growth across different spatial and temporal scales (Bulti & Eshete, 2023). This study aimed to examine the spatiotemporal pattern of urban growth and its agricultural and environmental impacts in Godawari Municipality, Nepal, by analyzing land cover data from 2000 to 2019, focusing on the conversion of agricultural and forest land into urban built-up areas.

Remote sensing and geographical information system (GIS) have become popular tools for providing scientifically credible insights and policy recommendations that aid sustainable development, particularly in fast-growing urban areas, by enhancing the understanding of spatiotemporal and spectral land use and cover changes (Wang et al., 2020). Change detection techniques are broadly categorized into two methods: Pre-Classification, which analyzes changes without classifying image values like Normalized Difference Vegetation Index (NDVI) and Change Vector Analysis (CVA), and Post-Classification, which evaluates land cover changes based on detailed classified images using methods like comparison, aerial difference calculation, and image differencing(Haque & Basak, 2017). For this study the post-classification techniques were used.

Urban land-cover growth leads to various impacts, including economic opportunities destruction in agriculture and forest (Chughtai et al., 2021), environmental degradation, pollution, loss of water bodies and farmland, rising temperatures, informal settlements, and food scarcity (Bhatta et al., 2010). This study concentrates on deforestation and the loss of cropland due to the expansion of the urban built-up. The findings indicate a significant reduction in both cropland and forest land, primarily due to the expansion of urban built-up areas. This trend suggests not only environmental degradation but also potential challenges to local food security, as vital agricultural and forest resources are being diminished.

## 2. MATERIALS AND METHODS

In developing countries like Nepal, the absence of proactive urban planning hinders systematic growth in rural-urban fringes, making dynamic monitoring of urban expansion crucial for optimizing spatial structure, guiding sustainable development, and enhancing urban competitiveness (Xie et al., 2020). Time series analysis using GIS and remote sensing techniques efficiently reveals the rate and pattern of urban expansion and its impact on other land covers (Wang et al., 2020). This study attempts to investigate the impact of the urban dynamics in the fringe of the metropolitan area of the Kathmandu valley by analyzing time series land cover data in GIS environment.

### 2.1 Study Area

To look into the rate and pattern of growing urbanization in the fringes of the metropolitan area of Kathmandu valley the Godawari Municipality was selected as the study area. This municipality, located in Lalitpur District of Bagmati Pradesh, Nepal, was established on December 2, 2014, by merging the former Village Development Committees of Godawari, Badikhel, Bisankhunarayan, Godamchaur, and Thaiba (Bista et al., 2023). The Municipality area was again expanded in March 2017 to include in total 12 previous VDCs. The six VDCs added were Devichaur, Dukuchhap, Chhampi, Thecho, Chapagaun, Jharuwarasi and Lele, covering a total area of 96 square kilometers (N. R. Bhattarai & Pasa, 2021). The population of Godawari Municipality has grown rapidly, increasing from 66,240 in 2001 to 80,376 in 2011 and 97,633 in 2021(Brinkhoff, 2023).

Godawari Municipality is bordered to the east by Panauti Municipality of Kavrepalanchok District, to the west by Bagmati Rural Municipality, Dakshinkali Municipality of Kathmandu District, and Indrasarovar Rural Municipality of Makwanpur District. To the north, it is bordered by Lalitpur Metropolitan City and Mahalaxmi Municipality, while to the south, it is bordered by Konjyosom and Bagmati Rural Municipalities. Geographically, it extends from 85°15'8" E to 85°24'57" E longitude and from 27°31'40" N to 27°38'57" N latitude. Godawari Municipality is located in the southern part of Lalitpur District. The municipality spans 8.2 km from north to south and 13.3 km from east to west, covering a total area of 96.11 square kilometers. It has a temperate climate, with elevations ranging from approximately 457 meters to 2,831 meters above sea level(Godawari Municipality, 2021).

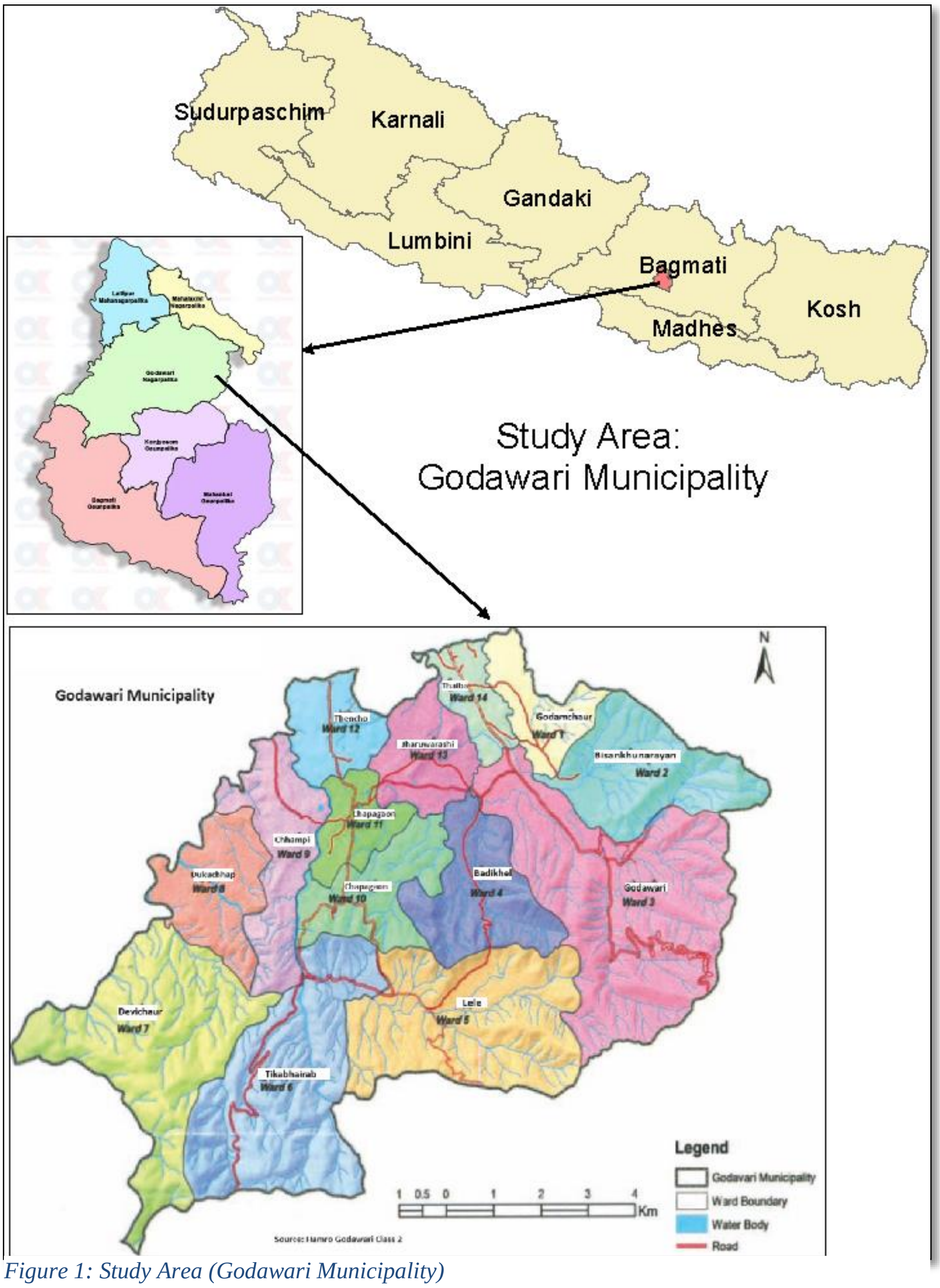


*Figure 1: Study Area (Godawari Municipality)*

### 2.2 Data acquisition and preparation

The annual land cover data for Nepal (2000–2019) is available in the Regional Database System (RDS) portal developed by International Centre for Integrated Mountain Development(ICIMOD, 2019). This dataset, created through the National Landcover Monitoring System, uses a standardized classification system for consistent land cover change assessment. The data was generated using openly accessible Landsat imagery and a cloud-based machine learning framework on the Google Earth Engine (GEE) platform (ICIMOD, 2022).

The RDS portal provides free downloads of data in GeoTIFF format with GCS_WGS_1984 (Geographic Coordinate System-World Geodetic System 1984) coordinate systems. Land cover data for Nepal from the years 2000, 2005, 2010, 2015, and 2019 was downloaded from this portal.

The administrative boundary data, freely accessible through the National Spatial Data Center (Geoportal) of the Survey Department, was downloaded in shapefile format (.shp) with the GCS_WGS_1984 coordinate system. This dataset includes the administrative boundaries of Local Governments (Municipalities and Rural Municipalities) in accordance with the updated administrative structure of Nepal (Survey Department, 2024). From this dataset, the boundary of Godawari Municipality was specifically selected and exported as a separate polygon shapefile, representing the municipality's administrative boundary.

Since both datasets were based on the same spatial reference system, the land cover raster data for the years 2000, 2005, 2010, 2015, and 2019 were spatially clipped to conform to the administrative boundaries of Godawari Municipality. This process was performed to create smaller subsets of land cover data specific to the municipality. A batch processing model was developed using the Clip tool from the Data Management toolbox in ArcGIS software. The worksflow and it's implementaion are illustrated in Figures 2 .

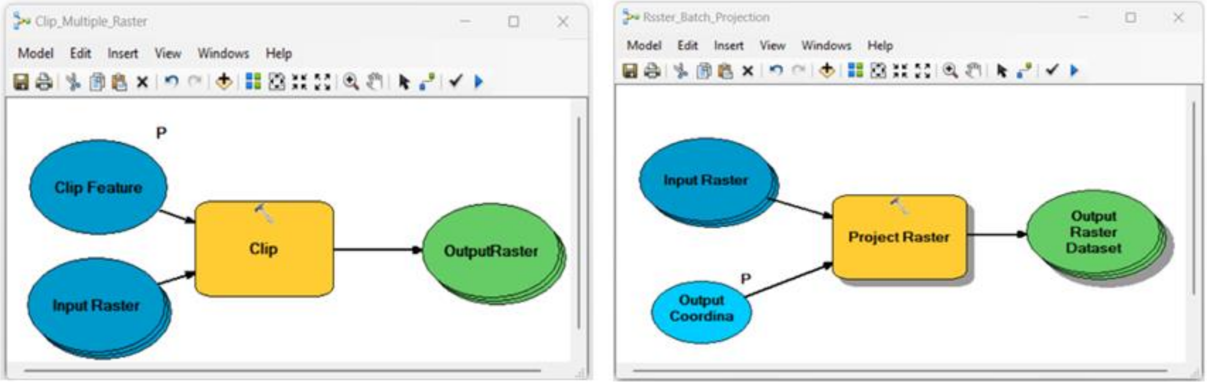


*Figure 2 Raster Clip and Projection Models for Multiple Roasters*

The land cover data was subsequently projected to the UTM (Universal Transverse Mercator) projection system to calculate the area of each land cover class in a more comprehensible unit, specifically square meters with WGS_1984_UTM_Zone_45N because the location of Godawari municipality lies between “ 85°15'8" E to 85°24'57" E longitude and UTM 45 N zone covers 84°E to 90°E (Carnes, 2011). Instead of manually processing each dataset individually, a model for batch processing was created using the Project Raster tool from the Data Management toolbox in ArcGIS. This approach streamlined the projection process across all datasets.

To simplify the analysis, land cover classes with insignificant coverage were merged into relevant categories, resulting in the reclassification of each dataset into only three classes: built-up, cropland, and forest.

To calculate the area of each land cover class, an 'Area' field was added to the attribute tables of the classified land cover data for each year. The area was then computed using the Field Calculator with the formula: Area = Count×(grid size squared). This method provided both attribute information and spatial information for the land cover classes across all five years (2000, 2005, 2010, 2015, and 2019).

According to the "Data Description" accompanying the land cover classification data provided by ICIMOD, the following grid values are assigned to their respective land cover classes:

| Grid value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Land cover class | Waterbody | Glacier | Snow | Forest | Riverbed | Built-up area | Cropland | Bare soil | Bare rock | Grassland | Other wooded land (OWL) |

However, not all of these classes were present in the study area; only the following classes were found, as a reference, their coverage in the year of 2000 was as follows:

| Value | Count | Land Cover | Area | % Coverage |
|---|---|---|---|---|
| 1 | 27 | Water | 22014 | 0.02 |
| 4 | 68312 | Forest | 55696147 | 57.95 |
| 6 | 1166 | Built-up | 950663 | 0.99 |
| 7 | 46914 | Cropland | 38249927 | 39.80 |
| 10 | 606 | Grassland | 494084 | 0.51 |
| 11 | 852 | OWL | 694653 | 0.72 |

To simplify and clarify the study, the similar classes—OWL, Grassland, and Water, which had negligible coverage—were merged into the Forest category, resulting in three consistent land cover classes: Built-up, Cropland, and Forest, across all datasets from 2000, 2005, 2010, 2015, and 2019.

### 2.3 Methodological work flow

Choosing methodologies for analyzing the spatiotemporal expansion of built-up areas is a complex process, shaped by factors such as data availability, study area characteristics, and research objectives. This complexity creates challenges for researchers and practitioners in making well-informed decisions (Bulti & Eshete, 2023). It highlights the importance of thoroughly understanding the available approaches, including their strengths, limitations, and suitability for different contexts. This knowledge is essential for choosing the most appropriate methodology that aligns with research goals and ensures the robustness of the analysis results (Chughtai et al., 2021).

Change detection is widely used in environmental monitoring, land use and land cover (LULC) studies, urban planning, disaster management, and more. It enables researchers and analysts to understand the dynamics of the Earth's surface, detect patterns, and make informed decisions based on temporal changes (Manna et al., 2024). There are several approaches to change detection, with the most widely used being pre-classification and post-classification methods. Each approach has distinct applications depending on the objectives of the study(Haque & Basak, 2017).

1. Pre-Classification Approach
The pre-classification approach involves analyzing the raw or pre-processed images directly before any classification is applied. This method is particularly useful for detecting areas of change and quantifying the rate of change over time. It often includes the following techniques (Chughtai et al., 2021):

Change and No-Change Detection: This technique is primary focus on identifying whether a change has occurred between two or more images taken at different times. It distinguishes areas that have undergone changes from those that have remained constant. Techniques such as image differencing, image ratioing, and image regression are commonly used.

Rate of Change Analysis: This technique helps in quantifying the magnitude or extent of change over a specified period. It is particularly useful in environmental studies, where researchers may be interested in understanding the rate of deforestation, urban expansion, or glacier retreat.

Image Enhancement: Image enhancement techniques are applied to improve the visual interpretation of changes. This includes contrast stretching, edge enhancement, and principal component analysis (PCA). These methods help in highlighting subtle changes that may not be immediately visible in the original images.

The pre-classification approach is advantageous because it can quickly identify changes without the need for detailed classification, making it efficient for large-scale or preliminary studies. However, it is less effective in determining the nature or type of changes, which is where the post-classification approach becomes relevant (Haque & Basak, 2017).

### 2. Post-Classification Approach

Post-classification comparison is one of the most widely used methods for detecting changes in land cover. This approach involves independently classifying each image in the dataset, ensuring that each land cover type is accurately identified for each time period. After the individual classifications are completed, the corresponding pixel signatures from each image are compared. By analyzing these signatures, researchers can pinpoint specific areas where changes have occurred between the different time periods, providing a clear and detailed picture of how the landscape has evolved over time (Rana & Sarkar, 2021).

From-To Change Analysis: This technique tracks changes from one land cover class to another (e.g., from forest to urban, or from agricultural land to barren land). The advantages of From-To Change Analysis include its ability to identify the specific areas where changes have occurred, provide detailed "from-to" information on land cover transitions, and avoid the challenges typically associated with analyzing images taken at different times, such as the need for radiometric normalization (Karsidi, 2004).

Comparison of Individually Classified Images: In this method, each image from different time periods is classified independently, and then the results are compared both quantitatively and qualitatively. Quantitative comparison involves calculating the area of each class and determining the extent of change, while qualitative comparison involves assessing the accuracy and reliability of the classification.

The post-classification approach is highly suitable for change detection because it minimizes the effects of atmospheric conditions, sensor variations, and other factors that may influence raw images. This method is particularly effective for detecting changes in different types of land use by comparing individually classified land use maps. A key advantage of this approach is its ability to provide detailed information on the nature of changes that occur over the study period. Additionally, GIS capabilities facilitate the comparison of post-classification results and support qualitative calculations (Nasar-U-minallah et al., 2021).

Although, it is more time-consuming and requires a higher level of expertise in image classification and this procedure relies heavily on the accuracy of the classifications in all the images, this method was chosen because the study utilized pre-classified land cover data prepared by ICIMOD. It was assumed that the land cover data developed by the National Landcover Monitoring System, which utilizes Landsat imagery and a cloud-based machine learning framework on Google Earth Engine (GEE) to ensure consistent land cover change assessments with a standardized classification system(ICIMOD, 2022) has sufficient accuracy for this study.

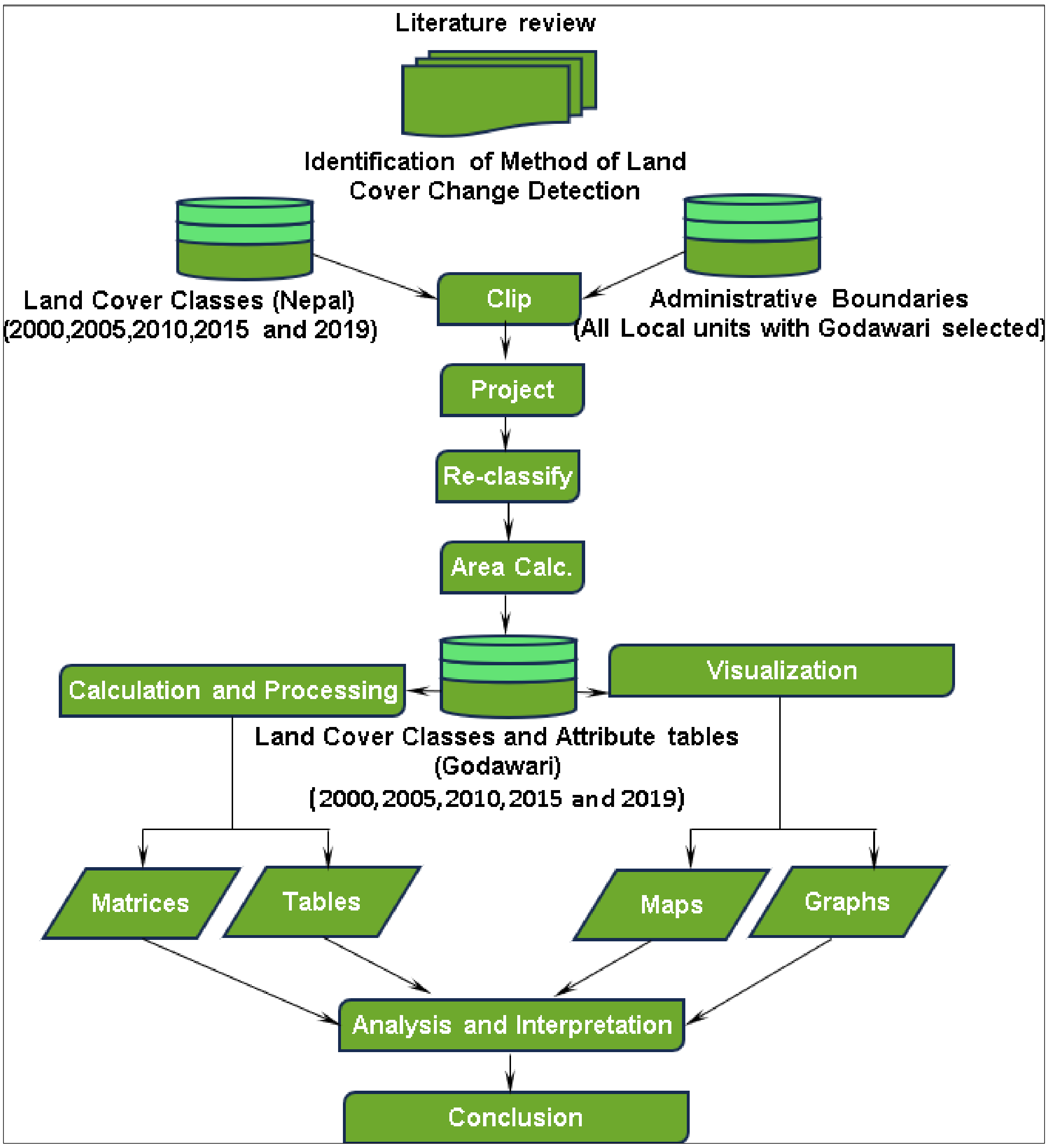


*Figure 3: Workflow Diagram of the Study*

## 3. RESULTS AND DISCUSSION

### 3.1 Comparison of Individually Classified Images

The corresponding land cover areas for Built-up, Cropland and Forest in square kilometer for each year were obtained as follows:

| LandCover | LC_2000 | LC_2005 | LC_2010 | LC_2015 | LC_2019 |
|---|---|---|---|---|---|
| Built-up | 0.95 | 1.51 | 1.83 | 2.12 | 6.50 |
| Cropland | 38.25 | 31.31 | 33.62 | 35.24 | 33.18 |
| Forest | 56.91 | 63.08 | 60.46 | 58.55 | 56.42 |

The following graphs show the trend of changes of these three land cover classes:

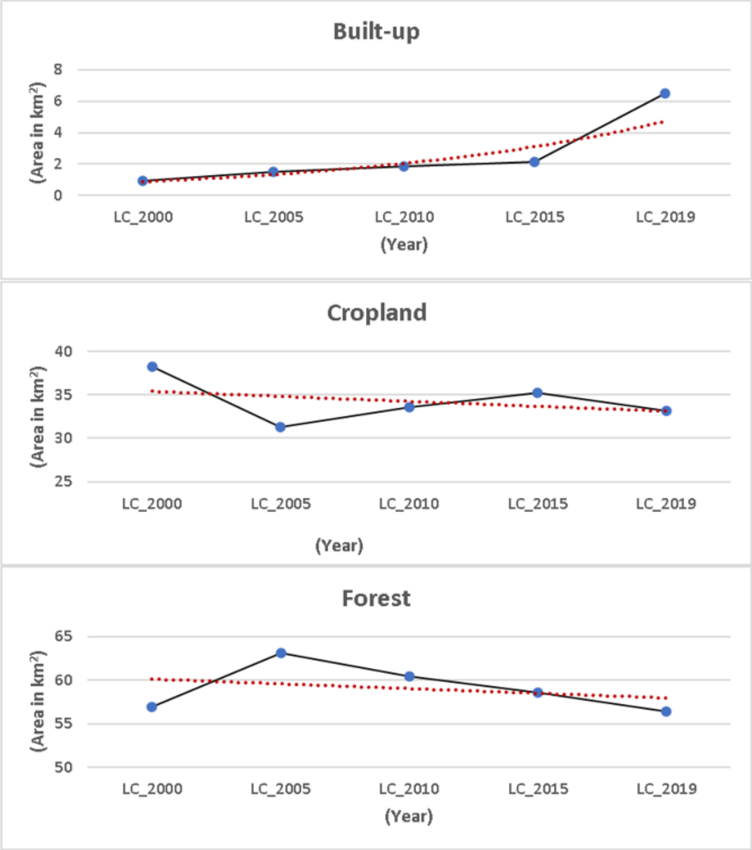


*Figure 4: Trends of Land Cover Change*

In the initial period from 2000 to 2005, both built-up and forest cover seemed to increase at the expense of cropland, while from 2005 to 2015, both cropland and built-up areas appeared to grow at the expense of forest cover. However, the overall trend indicates an increase in built-up areas alongside a decrease in both forest and cropland. The overall expansion of built-up areas at the expense of cropland and forest from the year of 2000 to 2019 is illustrated in the following pie charts:

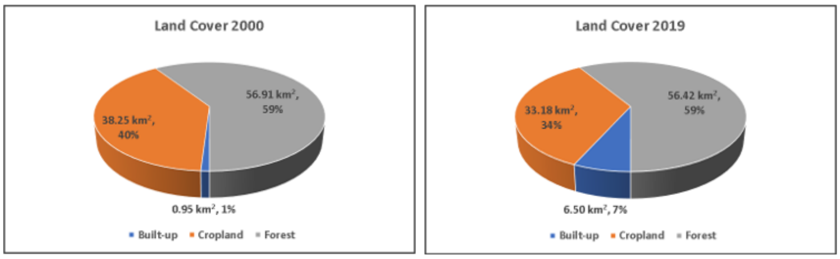


*Figure 5: Overall Changes of Land Covers*

These charts indicate that the conversion of forest land into built-up areas is less significant in percentage compared to the conversion of cropland into built-up areas.
We can see the land use change patterns by comparing the individual classified images as follows

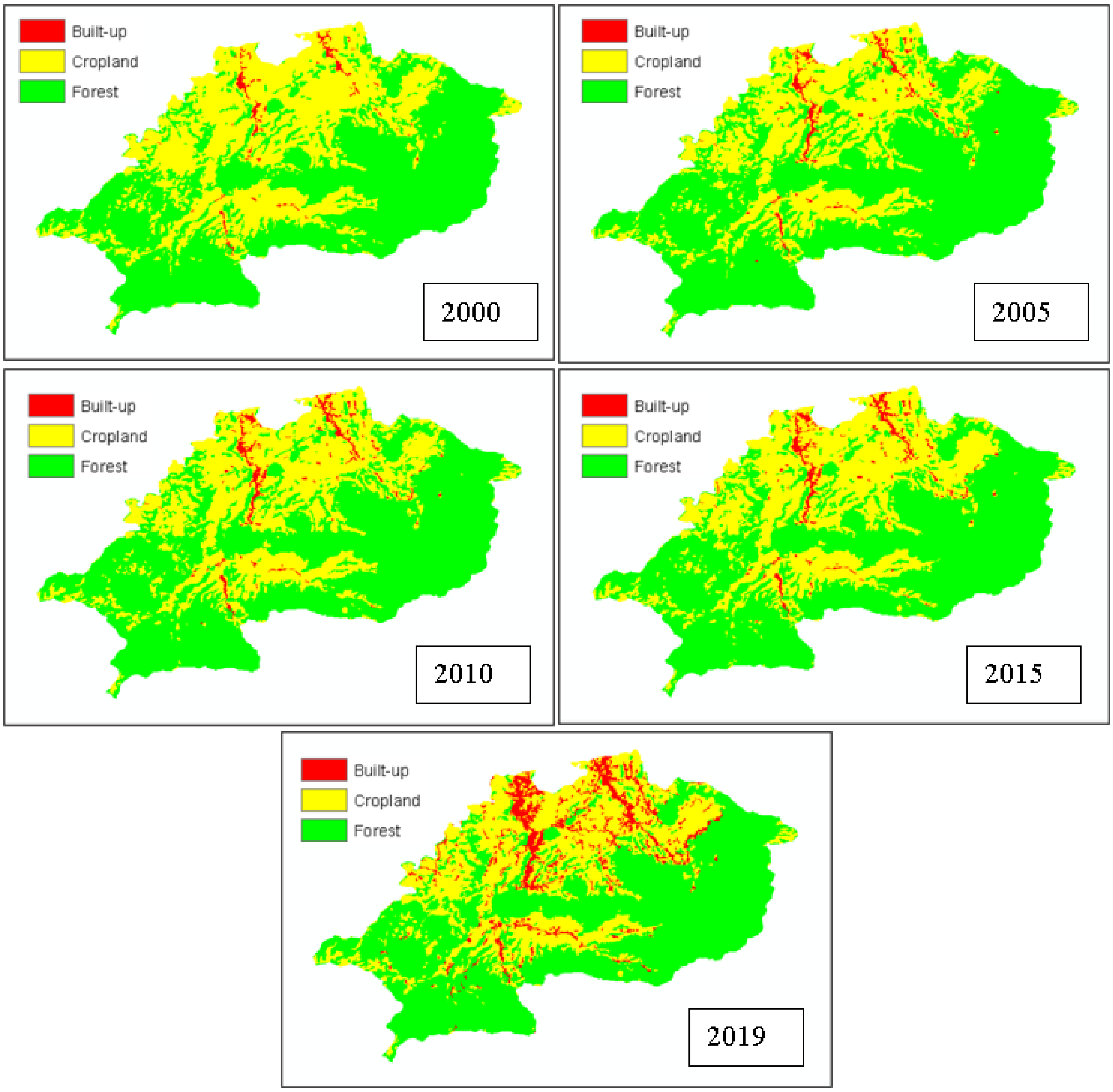


*Figure 6 Land Cover Change Patterns*

The visual analysis of the classified maps clearly shows that urban built-up expansion consistently leads to a reduction in both cropland and forest cover. Notably, the expansion of urban areas encroaches more significantly on cropland than on forest cover, suggesting that agricultural lands are more vulnerable to urban development pressures. This reduction in cropland could have profound implications for food security, as it diminishes the area available for food production.

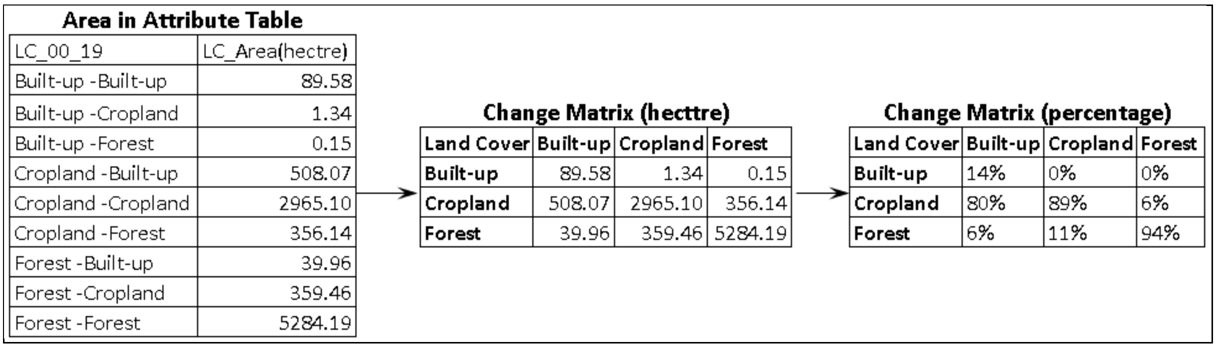
Moreover, the analysis also reveals evidence of interconversion between forest and cropland. This suggests that in some cases, forested areas are being converted into agricultural land, and vice versa, as land use demands shift over time. This interconversion indicates a dynamic landscape where land cover types are not only being lost to urbanization but are also being transformed into one another, reflecting the complex interactions between different land uses in response to economic, social, and environmental factors.

This pattern of land cover change highlights the ongoing competition among urbanization, agriculture, and forest conservation, revealing the complex interplay between these competing land uses. As urban areas expand to accomodate growing populations and economic development, agricultural land are increasingly encroached upon, leading to the displacement of vital cropland. Simultaneously, forests, which play a crucial role in maintaining ecological balance and providing ecosystem services, are at risk of being converted to either urban or agricultural uses. This dynamic not only threatens biodiversity and the integrity of natural ecosystems but also raises concerns about food security and sustainable resource management. The intensifying competition among these land uses highlights the urgent need for integrated land use planning strategies that can effectively balance the demands of urbanization, agriculture, and forest conservation..

When compared with the actual ground situation, it becomes evident that urban expansion is somewhat influenced by real estate developments, including settlement planning initiatives such as Guided Land Development (GLD), land pooling, plotting, and housing projects. However, a comprehensive study is needed to fully substantiate this interpretation.

### 3.2 From-To Change Analysis:

Although several tools are available for conducting from-to change analysis in different software, a manual approach was employed in this study to compare the overall land cover changes from 2000 to 2019. The process began by converting the raster land cover data into polygon format. The 2000 land cover polygons were then clipped with those from 2019 to identify areas where a change from one land cover category to another had occurred. A new field was added to the attribute table to document the specific land cover changes, indicating which category in 2000 had transitioned into which category by 2019. The added field lc_00_19(text) was computed using formula lc_00_19= [LC_2000] + "-" + [LC_2019] in field calculator. Polygons that represented the same type of change were subsequently dissolved to create a single area for each specific change. Finally, a change matrix was derived from the attribute table to summarize the results as follows:



Area in Attribute Table

| LC_00_19 | LC_Area(hectre) |
|---|---|
| Built-up -Built-up | 89.58 |
| Built-up -Cropland | 1.34 |
| Built-up -Forest | 0.15 |
| Cropland -Built-up | 508.07 |
| Cropland -Cropland | 2965.10 |
| Cropland -Forest | 356.14 |
| Forest -Built-up | 39.96 |
| Forest -Cropland | 359.46 |
| Forest -Forest | 5284.19 |

Change Matrix (hecttre)

| Land Cover | Built-up | Cropland | Forest |
|---|---|---|---|
| **Built-up** | 89.58 | 1.34 | 0.15 |
| **Cropland** | 508.07 | 2965.10 | 356.14 |
| **Forest** | 39.96 | 359.46 | 5284.19 |

Change Matrix (percentage)

| Land Cover | Built-up | Cropland | Forest |
|---|---|---|---|
| **Built-up** | 14% | 0% | 0% |
| **Cropland** | 80% | 89% | 6% |
| **Forest** | 6% | 11% | 94% |

This change matrix reveals that there was an almost negligible (close to zero) transfer of built-up areas to cropland and forest. However, the built-up area saw a significant increase, growing nearly sevenfold (6.84 times) from 2000 to 2019. Of the approximately 650 hectares of built-up land in 2019, a substantial 80% was converted from cropland, while 6% was converted from forest. Only 14% of the built-up area in 2019 was already classified as built-up in 2000. During this period, the conversion between cropland and forest was nearly balanced, with about 356 hectares of cropland being converted to forest and 359 hectares of forest being converted to cropland.

## CONCLUSION

The study reveals significant land cover changes, primarily driven by urban expansion, which has increasingly encroached upon both cropland and forest areas. The rapid growth of built-up areas, largely at the expense of cropland, poses serious concerns for food security, as it reduces the availability of arable land necessary for agricultural production. Additionally, the conversion of forest areas into urban spaces threatens environmental sustainability, potentially leading to a loss of biodiversity, disruption of ecosystems, and increased vulnerability to natural disasters.

The balance observed in the interconversion between cropland and forest suggests a dynamic but fragile equilibrium that could easily be disrupted by ongoing urbanization trends. This highlights the urgent need for careful urban planning and land use policies that prioritize both food security and environmental sustainability. Without such measures, the long-term consequences of these changes could be detrimental to the region's ecological balance and its capacity to support its population.

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