Assessing the Impact of Urban Expansion on Forest Cover using LULC Maps, NDVI, and NDBI: A Case Study of Kathmandu District.

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KEYWORDS

NDVI, NDBI, LULC, Urbanization, Deforestation

ABSTRACT

Rapid urbanization poses significant challenges to the delicate balance between urban development and environmental conservation. This study investigates the impact of urban expansion on forest cover in the Kathmandu District, employing a comprehensive approach that integrates Land Use/Land Cover (LULC) maps, Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-Up Index (NDBI). The aim of the study area is to provide insights into the dynamic interplay between urban growth and its consequences on the region's ecological landscape. LULC maps derived from remote sensing data offer a spatially explicit representation of land-use changes over time, enabling the identification of areas where urbanization has encroached upon forest area. The NDVI, a vegetation health indicator, serves as a quantitative measure of changes in the density and health of vegetation cover, aiding in the assessment of ecological impacts. Complementing this, the NDBI highlights intensity of built-up areas, allowing for a nuanced understanding of the urbanization process. This study employs NDBI and NDVI to dynamically assess urban growth and land use cover change, enhancing analytical accuracy. Findings reveal a substantial 89.9 km² increase in built-up areas between 2013 and 2016, coupled with a minor 18.4 km² increase between 2016 and 2021, reflecting continuous urban expansion driven by population growth and development initiatives. Concurrently, forest area marginally increased by 2.3 km² in 2016, suggesting reforestation and conservation efforts, yet a subsequent 23.5 km² decline by 2021, due to deforestation, urban encroachment, and natural disasters such as wildfires. Notably, vacant land decreased by 92.3 km² in 2016, absorbed by built-up areas and forest expansion, underscoring the urgent need for spatial planning to accommodate the growing population and its evolving needs.

1. INTRODUCTION

Everyday everything around us is changing, it is an inevitable process. Among the different changes, Land Use Land Cover Changes (LULC) is the one that don't just reflect natural features like geology and topography; they're also influenced by social and economic conditions (Rai et al., 1994). Population is the main factor that determines the changes in the environment. The growth in population and economic activities are closely linked to the expansion of urban areas, resulting in growth of urbanization which has the close relation with the LULC changes (Yasin et al., 2022) . Urbanization is the major cause that has resulted in fast evolution in the land use and land cover leading to forest deforestation and transformation of fertile land into other activities and demand for food and land (Krishna, 2021) .Due to improper and unmanaged urbanizations, deforestation is increasing daily which can cause soil erosion, flood, fewer crops, extinction of flora and fauna, the health of humans and wildlife and many more (Chaudhary et al., 2015). Urban heat islands, air pollutant emission, ecological injury, and urban climatic alteration are some other environmental problems related to rapid urbanization. Therefore, an accurate urban data, including NDVI and NDBI, is essential for understanding environmental issues and urbanization. This data offers insights into land changes and vegetation, aiding in effective land management and environmental monitoring. This understanding is important for investigating land use and land cover change that provides vital input in making better decisions on management. Analyzing land use changes over time is key for managing forests sustainably. It helps balance protection, conservation, and production, ensuring resources are utilized sustainably in temperate ecosystems. Understanding evolving land patterns informs informed forest management decisions. Additionally, in urban settings, the relationship between land use and land cover patterns and the resulting thermal characteristics of the environment has gained significant attention. Urbanization influences these dynamics, leading to alterations in the thermodynamics of the air within cities. Studying these spatial dynamics is crucial for comprehending the impact of urban growth on the thermal environment and can guide strategies for urban planning and management to mitigate adverse effects associated with these changes. The study of the changes due to urbanization is essential to study the land use land cover change and for the information for appropriate decision making (Deng et al., 2009).

2. STUDY AREA

The study area for this study is the Kathmandu District situated in the central part of the country. Kathmandu District covers an area of approximately 395 km². It is one of the three districts located in the Kathmandu Valley. It is located from 27°27′E to 27°49′E latitude and from 85°10′N to 85°32′N longitude. It is surrounded by Bhaktapur and Kavrepalanchowk in the east, Dhading and Nuwakot in the west, Nuwakot and Sindhupalchowk in the north, and Lalitpur and Makwanpur in the south. It is the most densely populated district in Nepal, with a population of over 2.04 million residents as of the most recent data available (NSO, 2021). The main reason to choose Kathmandu as the study area is that it is the most developed district among others in Nepal. A huge number of people have migrated from rural to urban areas, and the rapid increase in population has resulted in challenging problems such as crowding and land use conflicts, environment and problems in urban planning and management The district is characterized by rapid urban growth and environmental changes . Hence, this research project is centered in the Kathmandu District, Nepal, with a focus on LULC change detection, urbanization trends, and forest dynamics.

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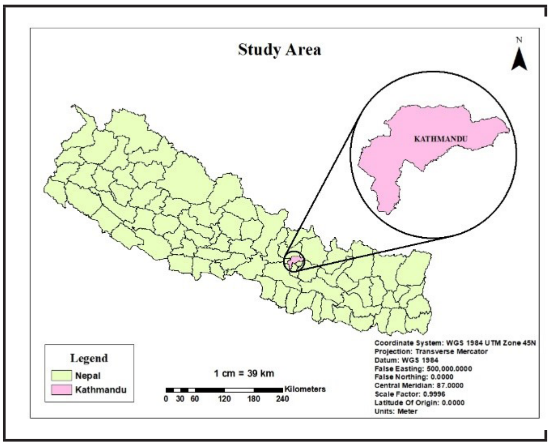

Figure 1: Study Area Map.

3. METHODOLOGY

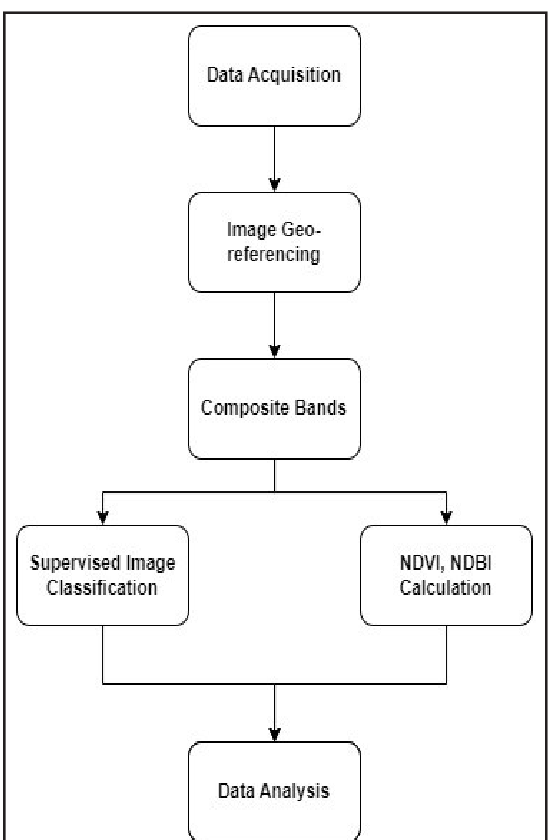

Figure 2: Workflow of Project.

3.1. Data acquisition

Landsat 8 with Operational Land Imager (OLI) sensor was acquired. Satellite image with spatial resolution of 30m was used of the time of 2013, 2016 and 2021. The detail of satellite data is given as:

- Satellite: LandSat 8
- Sensor: Operational Land Imager (OLI)
- Path and Row: 141 and 041
- Date: 2013/11/02, 2016/10/25, 2021/11/08
- Resolution: 30m
- Bands: 1-8

3.2. Image geo-referencing

Satellite information which acquired in raster image format was geo-referenced to WGS-84 datum.

3.3. Composite bands

Landsat 8 images were used to create a composite that consists all the necessary required for this study. Composite Images for 2013, 2016 and 2021 of Kathmandu District was created with the help of GIS Environment Composite Band Toolbar.

3.4. Supervised image classification

Supervised image classification is a fundamental technique used to categorize land cover and land use in remote sensing and GIS applications. In this study, we employed supervised image classification to create LULC maps.

At an initial step, we selected some of the training data. Representative samples of various land cover and land use classes within the study area were identified. These samples were collected based on multi-spectral satellite images. After training data, Maximum Likelihood Classification (MLC) Algorithm was used for categorizing the land cover classes based on the extracted features. The algorithm utilized the spectral information of the training samples to establish decision boundaries in feature space. Once trained, the classifier was applied to the entire study area to classify each pixel into one of the predefined land cover classes. Finally, the LULC maps were generated based on the classification results, with each pixel assigned to a specific land cover or land use category.

3.5. NDVI, NDBI calculation

To quantitatively assess vegetation and built-up areas within the study area, we calculated NDVI and NDBI. These indices are derived from remote sensing data and provide valuable information about land cover and land use. The following steps were taken to compute NDVI and NDBI:

- Band Selection: Since Landsat 8 OLI imagery has been used for this study, Band 4(Red), Band 5(NIR) and Band 6(SWIR) were used for the calculation of NDVI and NDBI. These bands were chosen due to their sensitivity to vegetation and built-up features.
- NDVI Calculation: This index measures the presence, density and health of vegetation, with higher values indicating healthier vegetation cover which is calculated by:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- NDBI Calculation: This index is used to assess the distribution of built-up or urban areas, with higher values indicating a greater extent of built-up features which is calculated by:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

- Mapping NDVI, NDBI: Hence, the map is prepared from NDBI and NDVI calculations.

3.6. Data analysis

We represented and interpreted all the collected data using bar diagrams in MS Excel 2016 and created maps using a GIS environment.

Numerous efforts have been made to extract information from remotely sensed images, with quantitative analysis being a key approach. Image Classification, a powerful digital technique, is commonly used for information extraction. We have utilized image classification to extract following data:

Table 1: Extracted Data from Digital Interpretation.

Classification Category	2013		2016		2021	
	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
Built-Up Area	126.7	31	216.6	52	235	57
Forest Area	192.7	47	195	47	171.5	41
Vacant Land	94.2	22	1.9	1	7	2

Table 1 explains the area covered in km² and percentage of each classification categories in different time periods of Kathmandu District.

4. RESULT AND DISCUSSION

Table 1 and the Figure 3, 4, 5 clearly explains that the capital city of Nepal has become increasingly congested, and the city has expanded outwards depleting the forest or vegetation area. From the classification of imagery of 3 different years i.e., 2013, 2016 and 2021, LULC map has been prepared for the following study area.

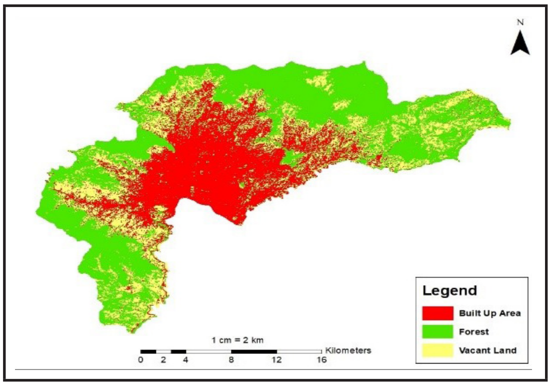

Figure 3: LULC Map of Kathmandu (2013).

Figure 3 shows the LULC map of Kathmandu District for the year 2013 reveals a dynamic distribution of land across various categories. Notably, the built-up area encompasses 126.7 km², constituting 31% of the district's total land. A significant portion of the landscape is dominated by lush forest cover, covering 192.7 km² and representing 47% of the district. Complementing these urban and natural landscapes is the presence of vacant land, accounting for 94.2 km², equivalent to 22% of the total area. This comprehensive breakdown provides valuable insights into the spatial composition of the district, reflecting the interplay between urban development, environmental preservation, and open spaces within the Kathmandu region in 2013.

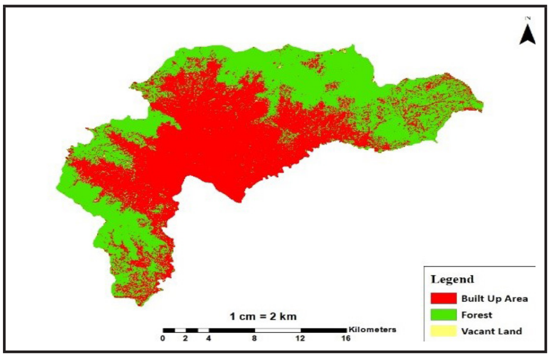

Figure 4: LULC Map of Kathmandu (2016).

Figure 4 shows the LULC map of Kathmandu District for the year 2016 reveals that built-up area has undergone a substantial expansion, surging from 126.7 km² in 2013 to 216.6 km² in 2016. This signifies a remarkable increase of 89.9 km², reflecting a substantial 71% growth over the three-year period, indicative of intensified urban development. In contrast, the forested area has seen a marginal decline, decreasing from 192.7 km² in 2013 to 195 km² in 2016, representing a modest reduction of 2.7 km² or a 1.4% decrement. The most significant transformation is observed in vacant land, which has experienced a drastic reduction from 94.2 km² in 2013 to 1.9 km² in 2016. This translates to a substantial decrement of 92.3 km², highlighting a notable 98% decrease over the three-year span. These shifts underscore the dynamic interplay between urbanization, environmental conservation, and evolving land use patterns within the Kathmandu District during this period.

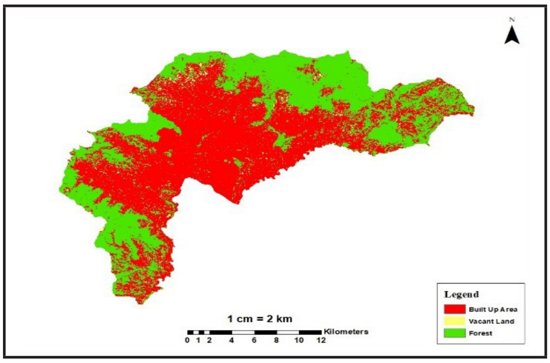

Figure 5: LULC Map of Kathmandu (2021).

Figure 5 shows the LULC map of Kathmandu District for the year 2021. Over the span of five years, from 2016 to 2021, reveals noteworthy shifts in the distribution of land across key categories. The built-up area has demonstrated a consistent expansion, increasing from 216.6 km² in 2016 to 235 km² in 2021, marking an 8.5% growth over this period. Conversely, the forested area has experienced a more pronounced reduction, diminishing from 195 km² in 2016 to 171.5 km² in 2021, representing a 12% decrease. A compelling observation is the notable rise in vacant land, escalating from 1.9 km² in 2016 to 7 km² in 2021, signaling a substantial 268% increase. These trends underscore the ongoing transformation in land use patterns, emphasizing persistent urbanization, a significant decrease in forested areas, and a notable increase in vacant land within Kathmandu District during the five-year period. The intricate dynamics reflect the evolving balance between urban development and environmental conservation in the region.

The overall changes seen over time from 2013 to 2021 is tabulated below:

Table 2: Change Detection in Land Use Land Cover.

Classification Category	2013/2016		2016/2021	
	Change in area (km²)	Change in area (%)	Change in area (km²)	Change in area (%)
Built-Up Area	89.9	21	18.4	5
Forest Area	2.3	1	-23.5	-6
Vacant Land	-92.3	-22	5.1	1

Above tabular data can be visualized in bar chart diagram as follow:

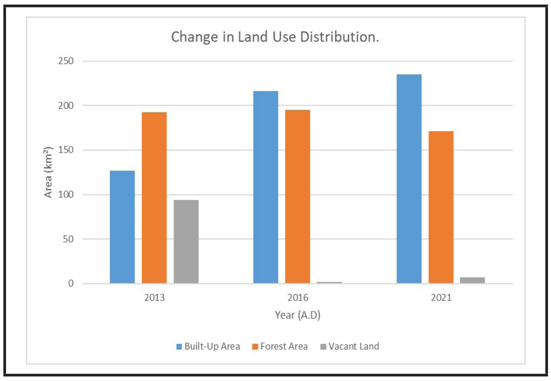

Figure 6: Change in Land Use Distribution.

Table 2 and Figure 6 clearly show that the built-up areas have been increased by around 89.9 km² in between 2013 & 2016 while 18.4 km² in between 2016 & 2021. Similarly, Forest area has been increased by 2.3 km² in 2016 while decreased by 23.5 km² till 2021. Talking about the vacant land, it has been decreased by 92.3 km² in 2016 which was utilized by built-up areas and forest to some extent while increased by 5.1 km² by 2021.

Thus, from 2013 to the end of 2021 the changes seen in built-up areas, forest area and vacant land is increased by 108km², decreased by 21.2km² and decreased by 87.2km² respectively. Similarly, we have calculated the indexes like NDVI and NDBI which resulted the following maps:

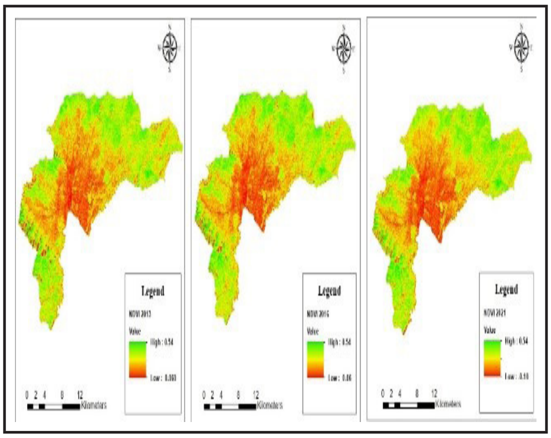

Figure 7: NDVI Map of Kathmandu District.

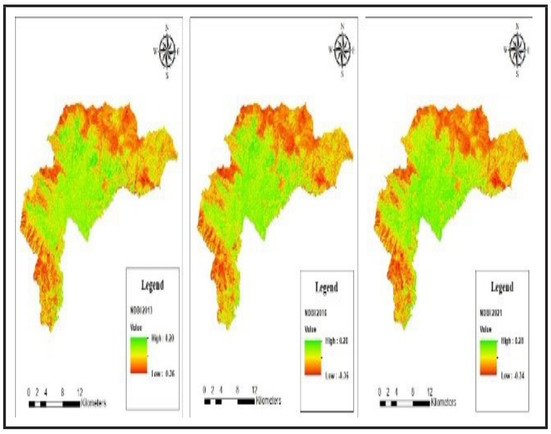

Figure 8: NDBI Map of Kathmandu District.

The above map resulted from NDVI and NDBI shows the increment in the built-up area that has an adverse effect on forest area. This result expected a linear trend as follows:

Table 3: Linear Trend and Future Expectation.

Classification Category	Generated Equation	Estimated Area by 2024
Built-up Area	y = 12.532x - 25079	285.8km²
Forest Area	y = -2.8592x + 5952.4	165.3km²

This estimated trend shows the built-up area to be increased to about 285.8 km² in 2024 while the trend line shows the decrement of forest area to 165.3 km² in 2024 which can be shown through the linear graph.

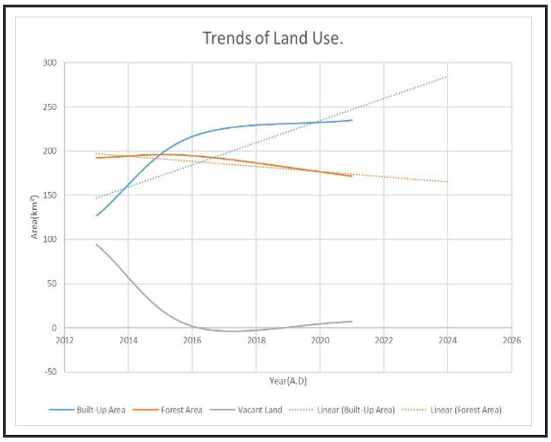

Figure 9: Estimated Linear Trend.

5. CONCLUSION

As a result of this study, it has been revealed that NDBI and NDVI provide a dynamic view of urban growth and may significantly improve the accuracy of analyses of land use cover change due to their dynamic nature. Also, it reveal significant transformations in the Kathmandu District over the study period, with a notable increase in built-up areas at the expense of forested regions and vacant land. The rapid urban expansion observed underscores the urgent need for sustainable land management practices and effective urban planning strategies.

Despite the valuable insights gained from the study, certain limitations were identified, including the spatial resolution of satellite imagery and the focus on a limited number of land use categories. Future research endeavors should address these limitations and incorporate additional factors to provide a more comprehensive understanding of land use dynamics and their implications.

In conclusion, the study contributes to the existing body of knowledge by shedding light on the complex interplay between urbanization, land use changes, and environmental conservation in the Kathmandu District. The findings underscore the need for collaborative efforts among policymakers, land-use planners, and stakeholders to promote sustainable land management practices and safeguard vital ecosystems for future generations.

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