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# Urban Growth Analysis Using Multi- Temporal Remote Sensing Image and Landscape Metrics for Smart City Planning of Lucknow District, India

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## Introduction

- Urbanization is considered as a pivotal feature of modern society, deeply affecting the land use and environmental conditions followed by socioeconomic development of a region.
- The analysis of urban growth and its pattern is also vital for understanding complex interactions between anthropogenic activities and environmental changes from global to local scale.
- In recent years, the availability of space-borne remote sensing (RS) images and Geographical Information System (GIS) brought more opportunities in the study of changing land-scape spatial patterns.
- The objective of present study was to investigate the spatial and temporal changes in LULC using landscape metrics with respect to urbanization from year 1999 to 2023 in Lucknow district of Uttar Pradesh state, India.

## Study Area and Datasets

Lucknow district is the capital of Uttar Pradesh state, India. It is located between latitudes 26°30' N and 27°10' N and longitudes 80°30' E and 81°13' E covering a total geographical area of 2525.61 sq. km (**Figure 1**).

Multi-temporal Landsat images acquired from TM, ETM+, and OLI/TIRS sensors for the period of 1999–2023 were used in this study that is downloaded from the USGS Earth Explorer.

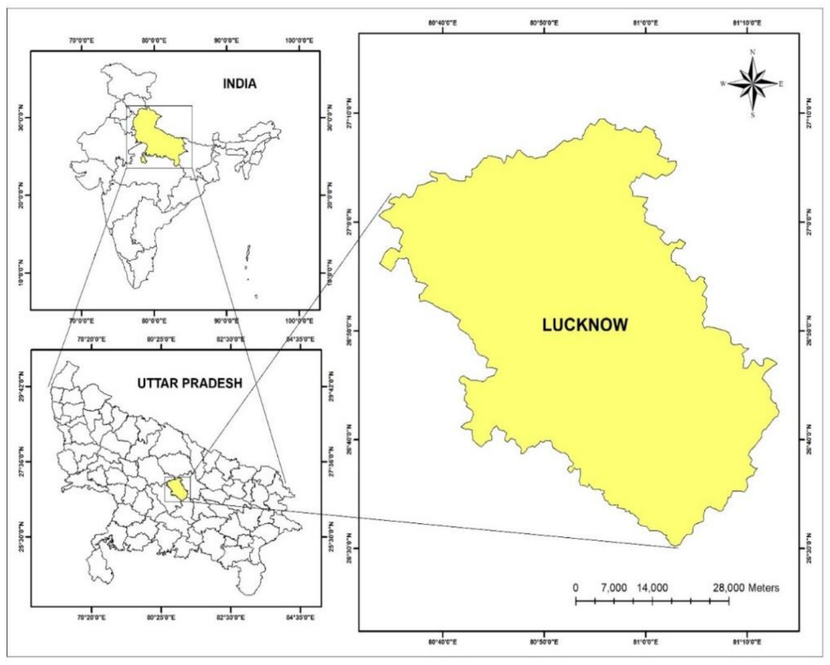


**Figure 1.** Location map of study area

## Methodology

**Image pre-processing:** The ArcMap 10.8 was used to perform intensive pre-processing on the Landsat satellite images including mosaicking, layer stacking, and sub-setting of study area. An appropriate band combination was chosen to produce FCC for all the images. It is used further for analyzing and creating the training signatures of specific LULC type.

**LULC classification:** Five major LULC categories like built-up, water body, vegetation, fallow land, and cropland were identified corresponding to the landscape of Lucknow district. The LULC maps of the years 1999, 2008, 2015, and 2023 were produced by applying supervised classification method on pre-processed Landsat images. The accuracies of LULC maps were assessed by overall accuracy and kappa coefficient. The random points were generated using the stratified random sampling method to examine the accuracy of LULC classified maps

**Calculation of Landscape Metrices:** Landscape metrics were calculated to quantify the changes in the structure of landscape under investigation (**Table 1**). FRAGSTATS (v. 4.3) tool was used to measure the ongoing spatial and temporal changes in the landscape patterns.

**Table 1.** Landscape metrics used at class level

| Metrices | Symbol | Description of the metrices |
|---|---|---|
| Number of patches | NP | It is the total number of patches present in a class |
| Patch Density | PD | It is the ratio between the total patches and the area |
| Edge Density | ED | Total edge length involving the respective land use/land cover class divided by total area. |
| Total edge | TE | The total length of all edge segments in the class. |
| Largest patch index | LPI | The ratio between the biggest patch area and the area under the study. |
| Landscape shape index | LSI | The average complexity of the entire landscape. |
| Percentage of Landscape | PLAND | It is the percentage of the landscape that consists of the specific patch type. |

## Results & Discussion

### LULC Maps and Change Analysis

In this study, LULC maps are derived using multi-temporal Landsat images for years 1999, 2008, and 2015, 2023 respectively. The spatial distribution of LULC categories are shown in **Figure 2**. The overall accuracy of LULC maps for years 999, 2008, and 2015, 2023 are 86.00, 85.00, 86.00, and 88.50%, respectively. The kappa coefficient for respective years is found to be 0.83, 0.82, 0.83, and 0.86. Analysis of multi-temporal LULC maps revealed significant urban growth in Luck-now over the specified time frame. The area statistics for LULC classes are given in **Table 2**. A key factor driving this urban expansion in the Lucknow district is the alteration of its municipal boundary, which has been revised three times, progressively encompassing more villages and expanding service coverage.

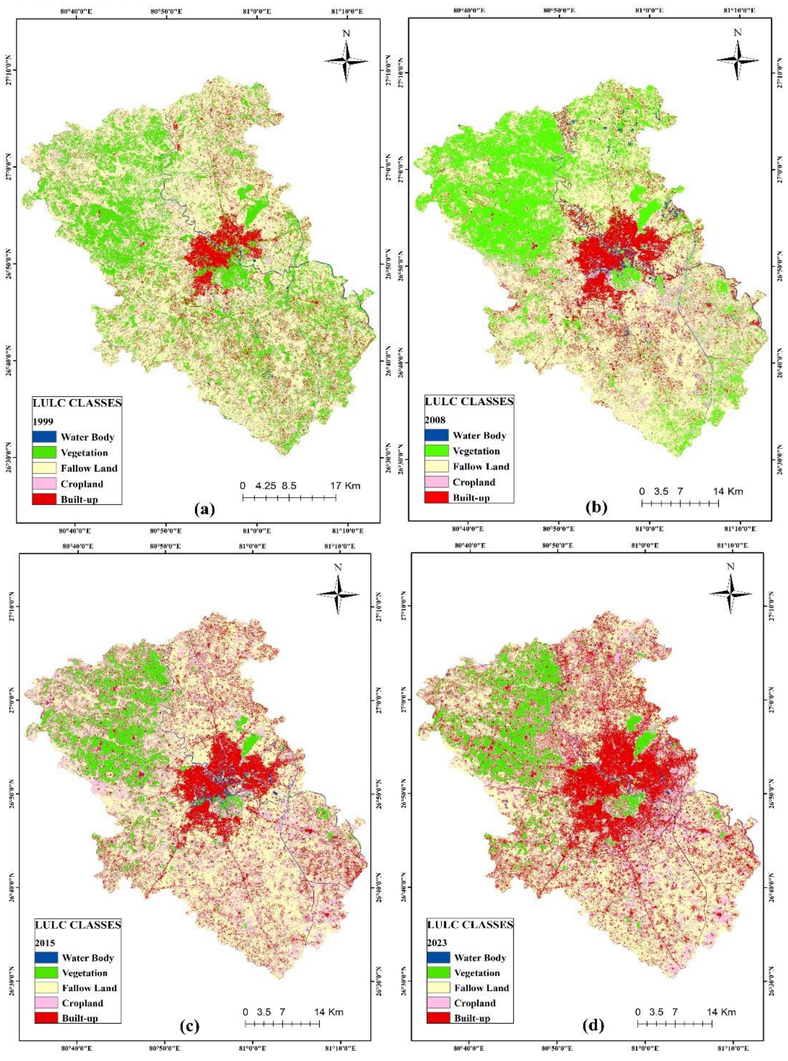


**Figure 2.** LULC classified maps for years (a) 1999, (b) 2008, (c) 2015 and (d) 2023

**Table 2.** Area statistics of LULC during 1999-2023

| LULC Category | 1999 | | 2008 | | 2015 | | 2023 | |
|---|---|---|---|---|---|---|---|---|
| | Area (sq.km.) | Area (%) | Area (sq.km.) | Area (%) | Area (sq.km.) | Area (%) | Area (sq.km.) | Area (%) |
| Built-up | 228.477 | 9.046404 | 299.696 | 12.866 | 455.134 | 18.024 | 654.468 | 25.9133 |
| Vegetation | 656.889 | 26.00916 | 692.377 | 24.919 | 300.735 | 11.9078 | 295.798 | 11.7119 |
| Fallow Land | 1212.62 | 48.01287 | 1211.6 | 48.969 | 1121.78 | 44.4162 | 949.056 | 37.5773 |
| Cropland | 407.282 | 16.12608 | 296.423 | 11.796 | 622.951 | 24.6609 | 609.223 | 24.1218 |
| Water Body | 20.3436 | 0.805493 | 25.5097 | 1.45 | 25.0055 | 0.9911 | 17.0631 | 0.6756 |
| Total | 2525.608 | 100 | 2525.608 | 100 | 2525.608 | 100 | 2525.608 | 100 |

### Quantification of Landscape Metrices

The landscape fragmentation analysis indicates modest alterations in the Lucknow district, prompting a deeper understanding of the resulting LULC patterns. Landscape metrics analysis, encompassing metrics such as PLAND, NP, LSI, ED, PD, and TE, was employed to discern changes in these metrics and their impact on landscape patterns over four years. **Figure 3** illustrates the changes in all landscape metrics over time (1999-2023) for different LULC classes.

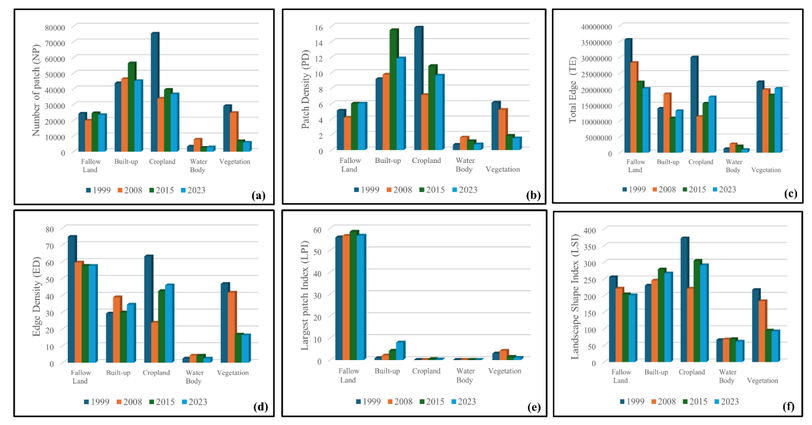


**Figure 3.** Changes in landscape metrics during 1999-2023

Additionally, **Figure 4** shows the PLAND that quantifies the class area in four different years. It represents the proportion of the respective patch type in the landscape, providing a relative measure of landscape composition significant in ecological applications.

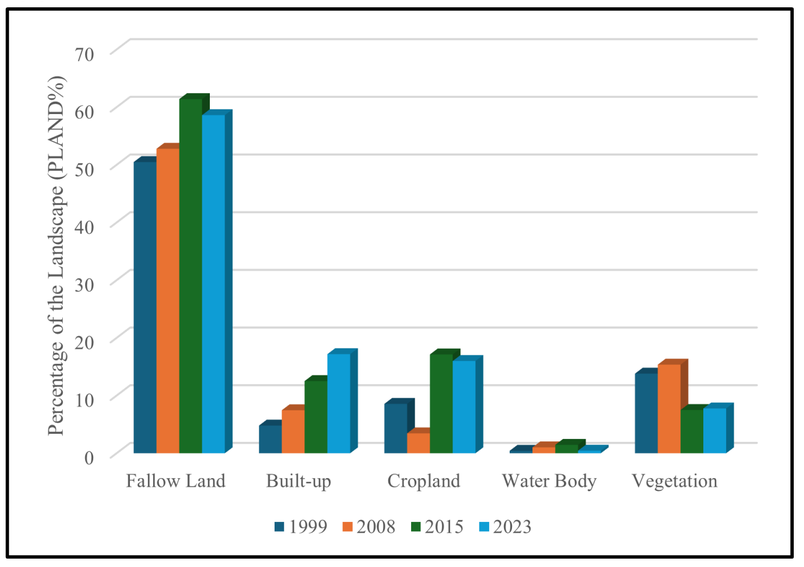


**Figure 4.** Changes in PLAND during 1999-2023

The study employs the SHDI and SHEI to explore point diversity and dispersion in the area over time. This index provides numerical insights into the diversity of points within a landscape or scene.

**Figure 5.** Changes in (a) SHDI and (b) SHEI during 1999-2023




The decline observed in the first two time periods suggests that the landscape is becoming more isolated, potentially due to hu man activity. Notably, the significant development of built-up areas has notably impacted the calculated SHEI values, particularly contributing to the decline observed in the earlier time periods.

## Conclusion

The present study analyzed the spatial and temporal urban growth in Lucknow district of India over a 24-year (1999-2023) period through landscape fragmentation. It provides significant insights into urban dynamics and LULC changes, underpinned by meticulous analysis with the help of remote sensing images and landscape metrics.