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Urban Sprawl and Sustainable Development: A Geospatial Analysis of LULC Changes in Lucknow City and Its Peri-Urban Areas (2003–2023)

Ayushi Sharma[1]*, Kh. Moirangleima[2] and Gururaj[3]

Abstract

Lucknow has witnessed rapid urbanization, transforming into a key economic and educational hub. This study analyzes the spatiotemporal dynamics of land use and land cover (LULC) changes in Lucknow and its peri-urban areas, focusing on Sarojini Nagar and Chinhat, between 2003 and 2023. Landsat-7 ETM (2003), Landsat-8 OLI (2013), and Landsat-9 OLI (2023) satellite imagery were classified using Maximum Likelihood Classification (MLC) to assess urban sprawl. The results indicate a 44.33% expansion in built-up areas, primarily due to the conversion of barren land into urban settlements, particularly in peri-urban zones. Meanwhile, vegetation cover increased by 73.12%, driven by afforestation programs and urban greening initiatives. However, water bodies declined by 81.29%, indicating severe hydrological disruptions, loss of wetland ecosystems, and increased urban runoff. These trends underscore the growing environmental challenges posed by unchecked urban expansion. The study highlights the urgent need for sustainable urban planning, including integrated water resource management, green infrastructure development, and stringent land-use policies to mitigate ecological degradation. Addressing these concerns is critical to ensuring environmentally resilient urban growth in Lucknow's rapidly expanding metropolitan landscape.

Keywords

Ecological Degradation, Land Use and Land Cover (LULC) Change, Peri-Urban Areas, Sustainable Urban Planning, Urban Sprawl

* *Corresponding Author*
[1]*Research Scholar, Department of Geography, School of Earth Sciences, Banasthali Vidyapith, Rajasthan, India-304022. Email- sharma.ayushi1993@gmail.com*
[2]*Assistant Professor, Department of Geography, School of Earth Sciences, Banasthali Vidyapith, Rajasthan, India- 304022. Email: mkhundrakpam@banasthali.in*
[3]*GIS Expert and faculty, Chandrapur Forest Academy of Administration, Maharashtra, 442401. Email: gururaj.sugure.2016@gmail.com*

Introduction

Urbanization is a dynamic socio-economic process that has transformed landscapes globally, shifting societies from predominantly rural to increasingly urban. By 2050, nearly 70% of the global population is projected to reside in cities (World Bank Group, 2023). Asia and Africa are expected to witness the most significant urban expansion, driven by economic growth and demographic shifts (UNFPA, 2024). In India, the urban population has increased from 28.53% in 2001 to 31.16% in 2024, reflecting an accelerating trend in urban sprawl (Town & Country Planning Department, U.P., 2024). However, rapid and often unplanned urban expansion has resulted in sprawling, unregulated peri-urban growth, contributing to land-use conflicts, environmental degradation, and resource depletion (Spence et al., 2008).

Patel and Teli (2019) examined urban sprawl in Lucknow, identifying key challenges such as migration, congestion, environmental degradation, and the rise of informal settlements. Tiwari and Singh (2020) explored peri-urban growth near Lucknow and Varanasi, emphasizing infrastructure deficits and governance challenges. In recent years, urban expansion in Lucknow has extended beyond its core into peri-urban areas like Chinhat and Sarojini Nagar, which have experienced rapid land conversion. Despite these developments, systematic studies analyzing the spatiotemporal dynamics of land use and land cover (LULC) changes in the peri-urban regions of Lucknow remain scarce.

This study addresses that gap by utilizing Landsat satellite imagery and GIS-based classification techniques to assess urban sprawl trends over the past two decades. The findings aim to provide evidence-based insights to inform sustainable urban planning, infrastructure development, and ecological conservation policies, helping to mitigate the adverse effects of unregulated urban expansion.

Aims and Objectives

Research Aim

This research aims to examine the extent of urban sprawl in Lucknow city and its peri-urban areas—specifically Sarojini Nagar and Chinhat—over the period from 2003 to 2023, and to evaluate its implications for sustainable development.

Objectives

To achieve the stated aim, the following broad objectives have been set:

1. To analyze land use and land cover (LULC) changes in Lucknow city between 2003 and 2023.
2. To assess LULC changes in the peri-urban areas of Lucknow, with a focus on Sarojini Nagar and Chinhat, from 2003 to 2023.
3. To evaluate the environmental implications of urban sprawl and underscore the importance of sustainable urban development practices.

Study Area

Lucknow, the capital of Uttar Pradesh, lies between 26°30'N to 27°10'N latitude and 80°30'E to 81°13'E longitude, with an average elevation of 110 meters above mean sea level. The Lucknow Urban Agglomeration (LUA) comprises the Lucknow Municipal Corporation (LMC) and the Lucknow Cantonment Board (CB). According to the 2011 Census of India, the LMC spans 348.80 km² and had a population of 2,817,105, with projections estimating an increase to

4,589,826 by 2031 (Lucknow Municipal Corporation, 2015).

Recent urban expansion has led to peri-urban growth, forming transitional zones around the city's core (Aijaz, 2019; Singh, 2021). Sarojini Nagar and Chinhat are two prominent peri-urban areas undergoing rapid land conversion due to Lucknow's outward growth. Sarojini Nagar, located southwest of the city, covers 322.51 km and has a population of 246,857, while Chinhat, situated in the northeast, spans 125.65 km² with 137,251 residents. These areas serve as critical sites for analyzing urban sprawl and land-use transformation, making them focal points of this study.

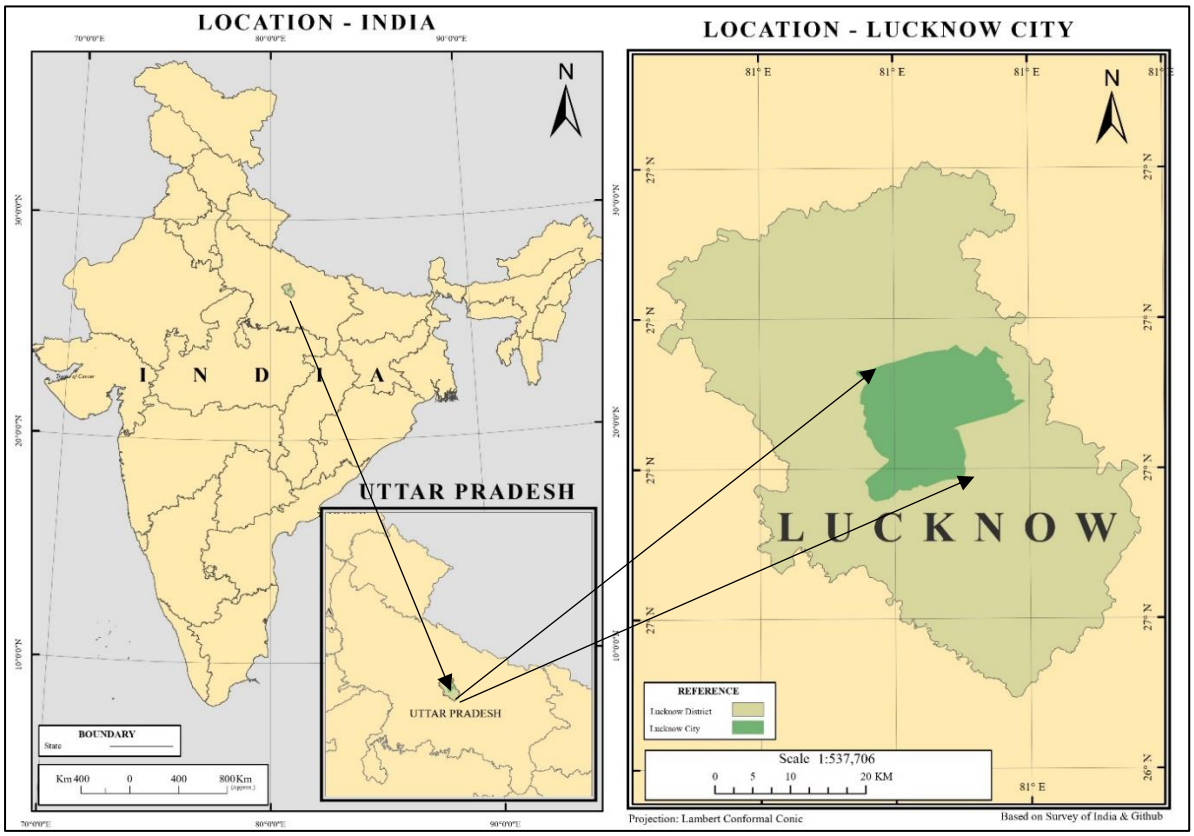


Figure 1 Location Map of Study Area

Data Sets and Methods

The present study utilized a variety of secondary datasets. Landsat satellite imagery, acquired from the USGS Earth Explorer portal, served as the core dataset for analyzing Land Use and Land Cover (LULC) changes. A detailed list of the datasets employed in the study is provided in Table 1. Geographic Information System (GIS) tools were used to generate visually appealing and information-rich maps with ArcGIS software.

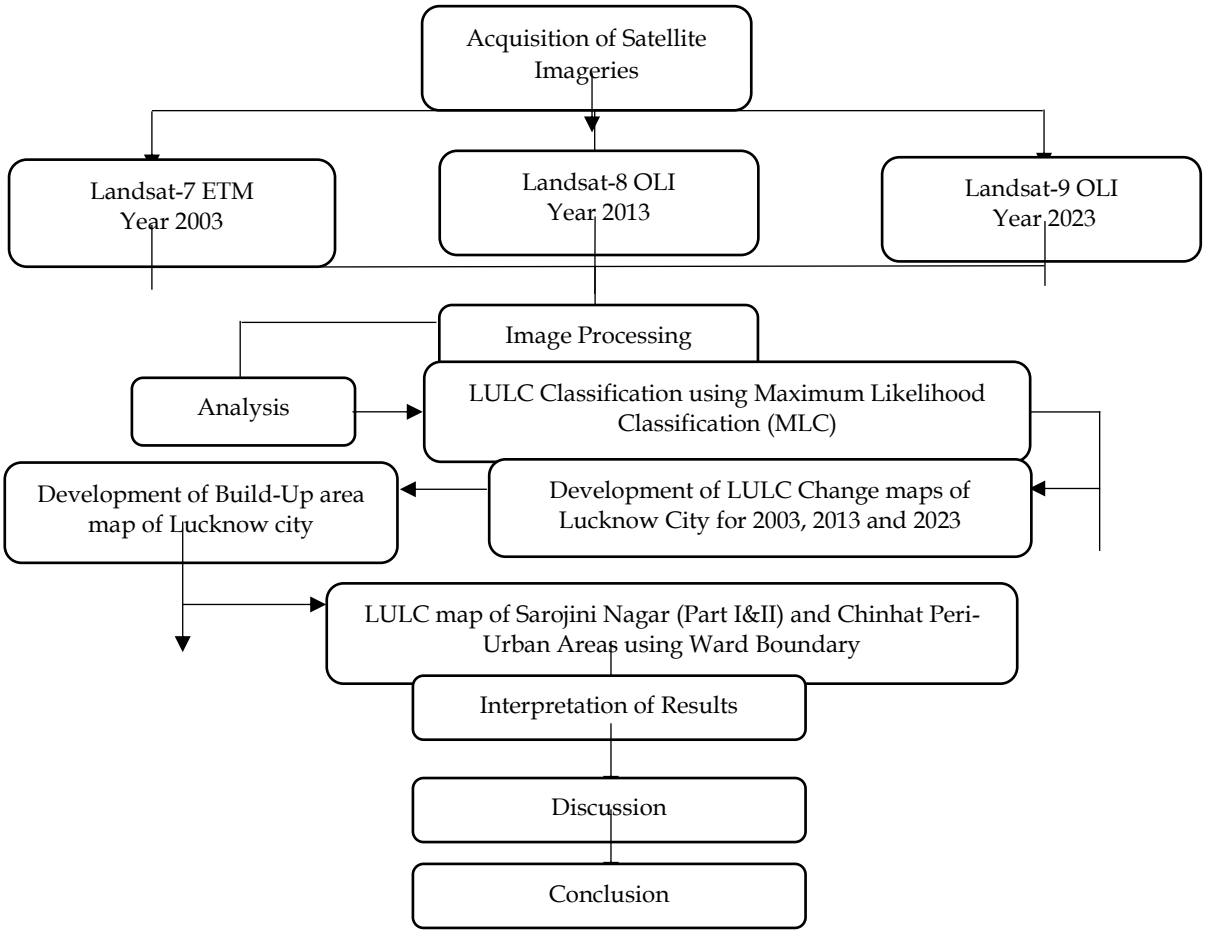
LULC classification was carried out using the Maximum Likelihood Classification (MLC) method for the years 2003, 2013, and 2023. Separate LULC maps for the selected peri-urban areas—Sarojini Nagar (Parts I & II) and Chinhat—were developed using ward boundaries for spatial reference. A specialized Built-Up Area map was created to analyze and illustrate the spatial changes

and spread of urbanized regions across Lucknow during the selected years. By extracting and visualizing Built-Up areas from the LULC datasets for 2003, 2013, and 2023, the study highlights expansion patterns and the dynamics of urban sprawl in both the city and the selected peri-urban areas.

Table 1 Data Sets Used

Sr. No.	Satellite Used	Resolution	Date	Time
1	Landsat-7 ETM Level 1 Tier 1	30 m	10/04/2003	04:55
2	Landsat-8 OLI Level 2 Tier 1	30 m	09/12/2013	05:08
3	Landsat-9 OLI Level 2 Tier 1	30 m	10/10/2023	05:06

Methodology Flow Chart



Results

The spatiotemporal analysis of Lucknow City's LULC between 2003, 2013, and 2023 reveals significant land transformation driven by rapid urban expansion, infrastructure development, and environmental changes. The results indicate a substantial increase in built-up areas, a drastic reduction in barren land and water bodies, and a notable increase in vegetation cover, reflecting both planned urbanization and ecological interventions.

Table 2 Change in Land use and Land cover of Lucknow City (2003-2023)

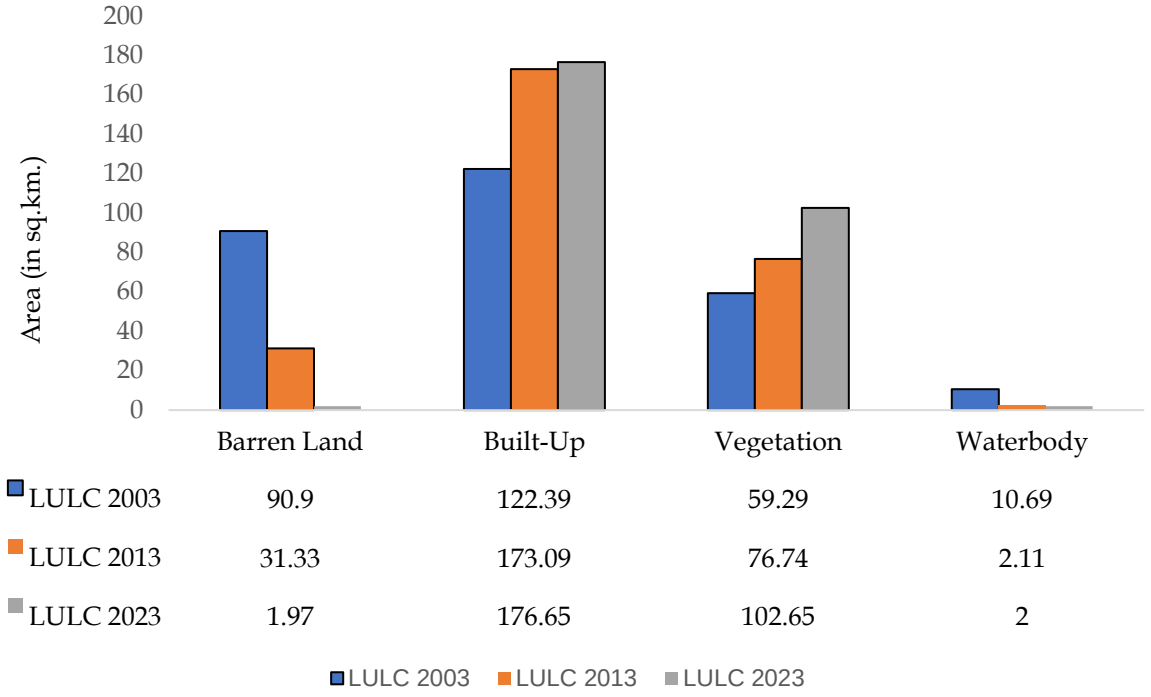


Table 2.1 Percentage Change in LULC of Lucknow City from 2003-2023

LULC	2003	% Change	2013	% Change	2023	% Change	Average % Change from 2003-2023*
Barren Land	90.9	-	31.33	-65.52	1.97	-93.71	−97.83
Built-Up	122.39	-	173.09	+41.45	176.65	+2.05	+44.33
Vegetation	59.29	-	76.74	+29.45	102.65	+33.74	+73.12
Waterbody	10.69	-	2.11	-80.28	2.00	-5.21	−81.29

**Formula Used- Percentage Change= (New Value−Old Value/Old Value) ×100*

3.1 Land Use and Land Cover (LULC) Changes in Lucknow City (2003–2023)-

Built-up areas expanded by 44.33% (from 122.39 km² in 2003 to 176.65 km² in 2023), with the most rapid growth occurring between 2003 and 2013 (+41.45%), reflecting intensified urbanization and infrastructure development. However, between 2013 and 2023, growth slowed to +2.05%, suggesting a shift from outward sprawl to urban densification and redevelopment. Meanwhile, barren land declined by 97.83%, from 90.9 km² in 2003 to just 1.97 km² in 2023, as vacant plots were rapidly converted into residential and commercial zones, driven by population influx and real estate expansion (as shown in Figures 2, 3, and 4). Vegetation cover increased by 73.12%, reaching 102.65 km² by 2023, likely due to afforestation efforts, roadside plantations, and the integration of green spaces in urban planning. However, the 81.29% reduction in water bodies (from 10.69 km² to 2.00 km²) signals severe hydrological stress, wetland encroachment, and poor stormwater management, increasing urban flood vulnerability.

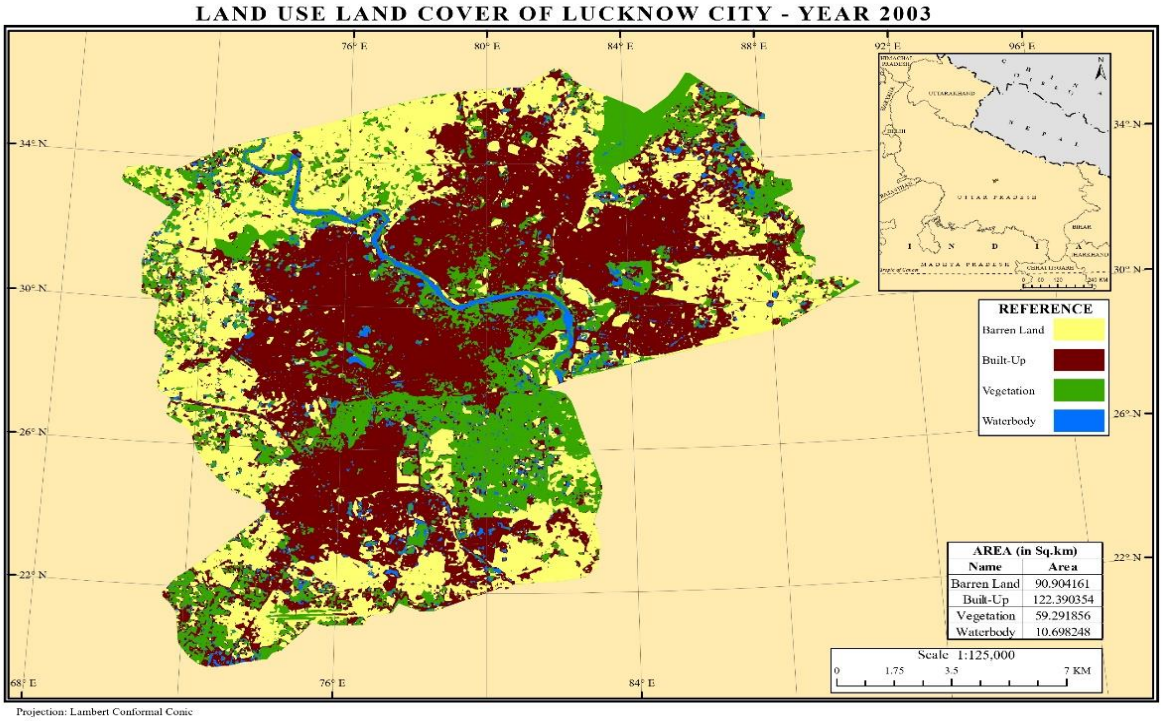


Figure 2 LULC Classification Map of Lucknow City for the year 2003

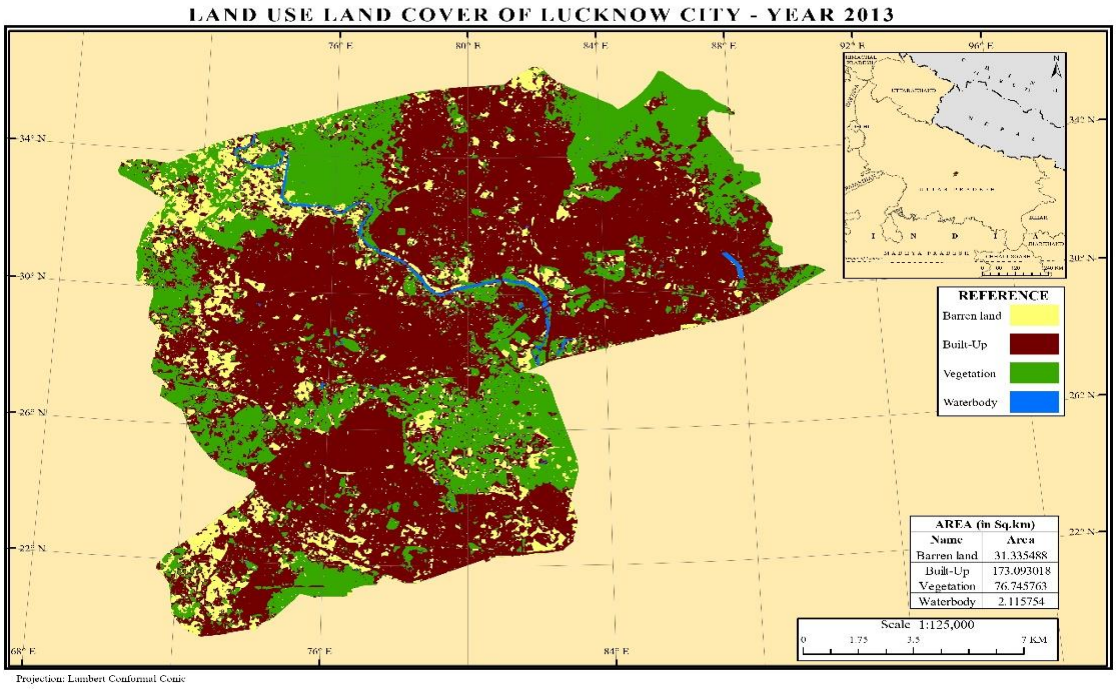


Figure 3 LULC Classification Map of Lucknow City for the year 2013

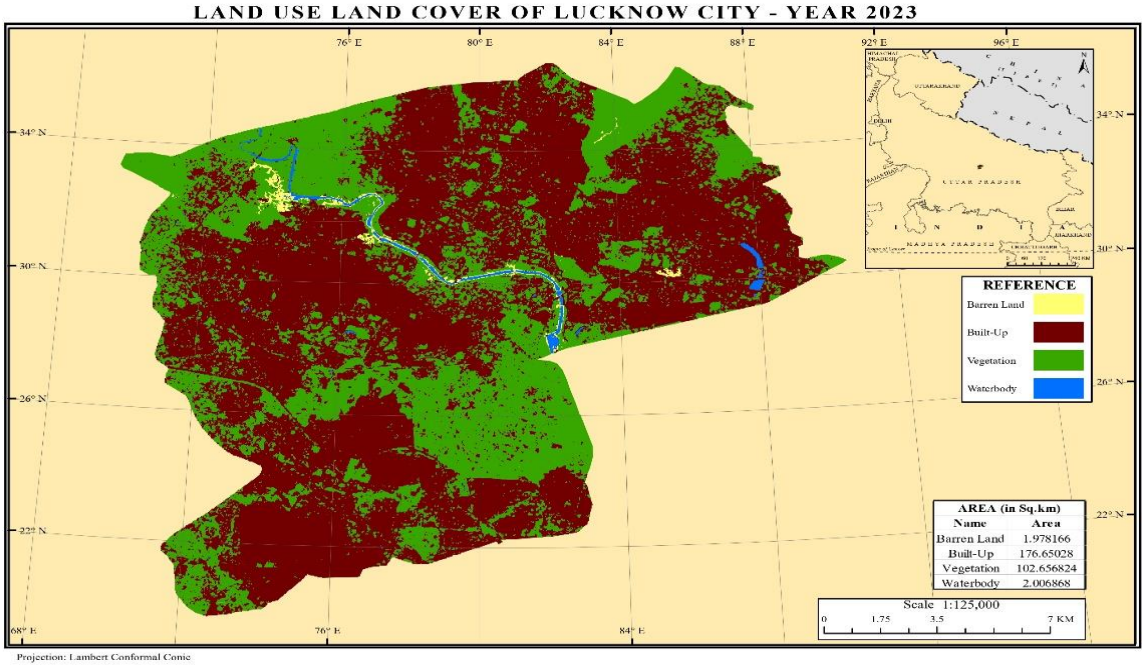


Figure 4 LULC Classification Map of Lucknow City for the year 20

3.2 LULC Changes in Chinhat and Sarojini Nagar Peri-Urban Areas (2003–2023)

The urban sprawl of Lucknow City towards the peri-urban areas has shown a high rate of development in built-up areas from 2003 to 2023. Chinhat has witnessed a significant shift from agricultural and barren land to high-density residential and commercial developments, driven by increasing housing demand, private real estate expansion, and the establishment of commercial hubs. However, vegetation cover has increased due to planned green spaces and buffer zones in new developments, contributing to better urban landscaping, as shown in Figure 5.

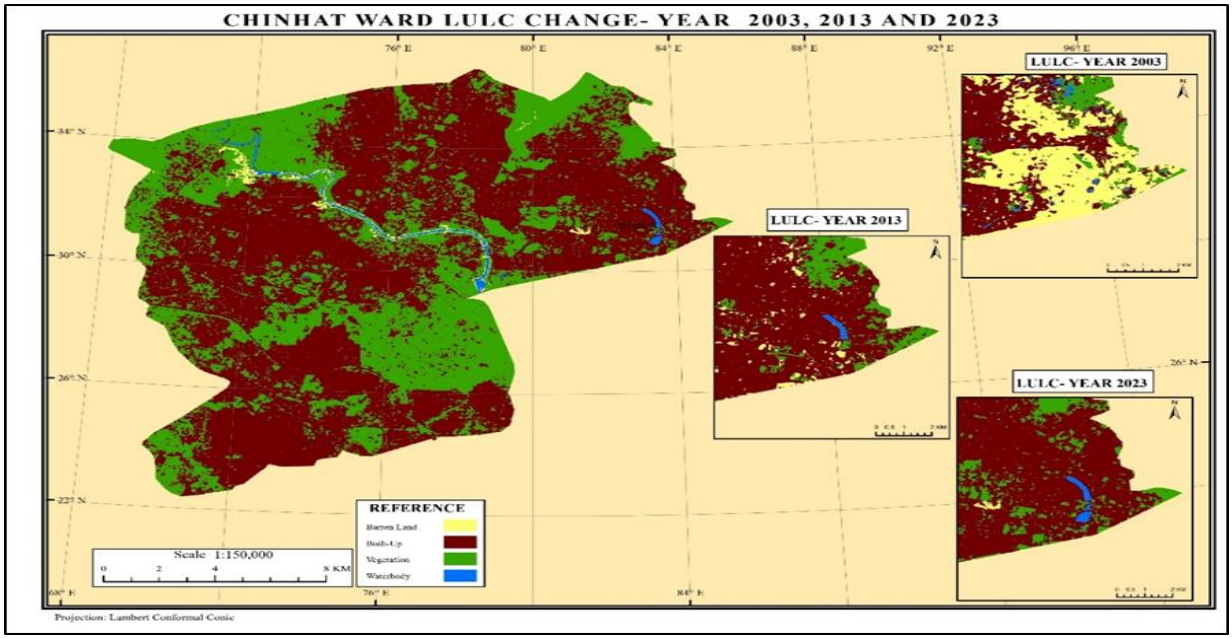


Figure 5 LULC Map of Chinhat Peri-Urban Area of Lucknow City

In contrast, Sarojini Nagar has experienced a more industrial and infrastructure-led transformation, with large portions of barren land converted into industrial zones, logistics hubs, and commercial centers, making it a key economic corridor. Although built-up expansion in Sarojini Nagar is moderate compared to Chinhat, industrial activities have led to environmental concerns, including air and water pollution risks.

Both areas have lost significant water bodies, while planned afforestation efforts have increased vegetation cover (+73.12%). These transformations underscore the need for sustainable land-use planning, stricter environmental regulations, and integrated urban policies to balance urban expansion with ecological resilience.

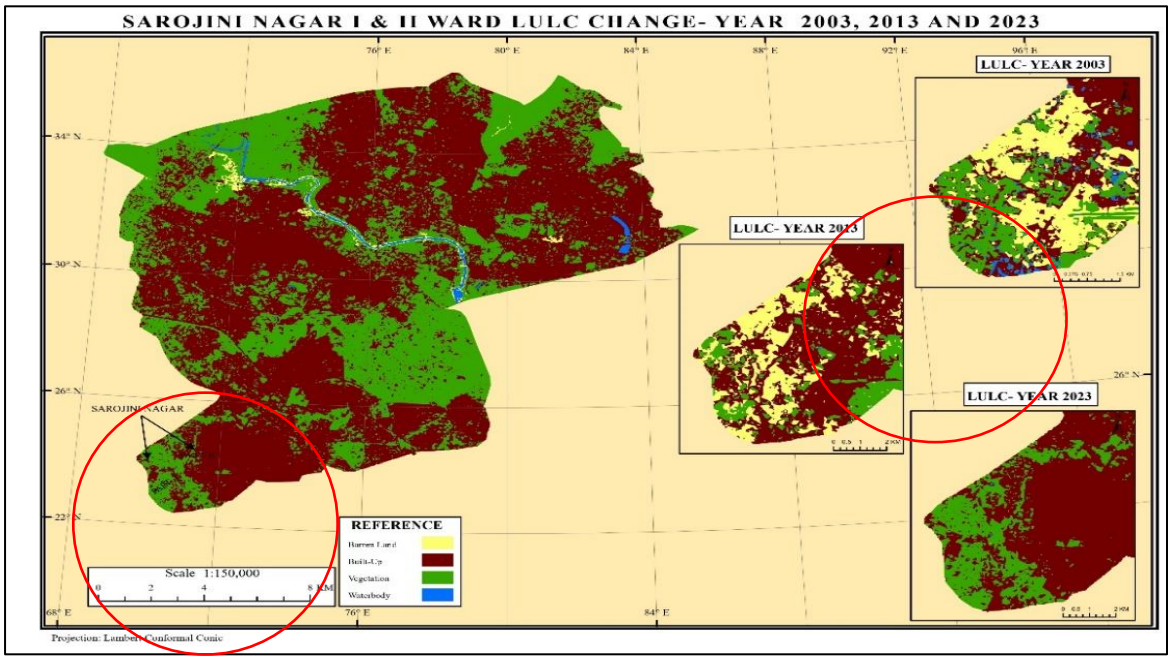


Figure 6 LULC Map of Sarojini Nagar Peri-Urban Area of Lucknow City

Discussion

The results indicate rapid urban expansion in Lucknow City, with built-up areas increasing by 44.33% from 2003 to 2023 (from 122.39 sq. km to 176.65 sq. km). The most significant surge occurred between 2003 and 2013 (+41.45%), driven by increasing population pressure, infrastructure projects, and commercial development. However, between 2013 and 2023, growth slowed to just 2.05%, indicating a shift toward urban densification rather than outward sprawl. As shown in Figure 7, the spatial distribution of built-up expansion highlights a concentrated transformation along major corridors and peri-urban areas. Meanwhile, the 81.29% reduction in water bodies presents serious environmental concerns, while the 73.12% increase in vegetation cover suggests targeted afforestation and urban greening initiatives. These changes align with broader urbanization trends observed in Indian metropolitan regions but also present unique sustainability challenges that require careful analysis.

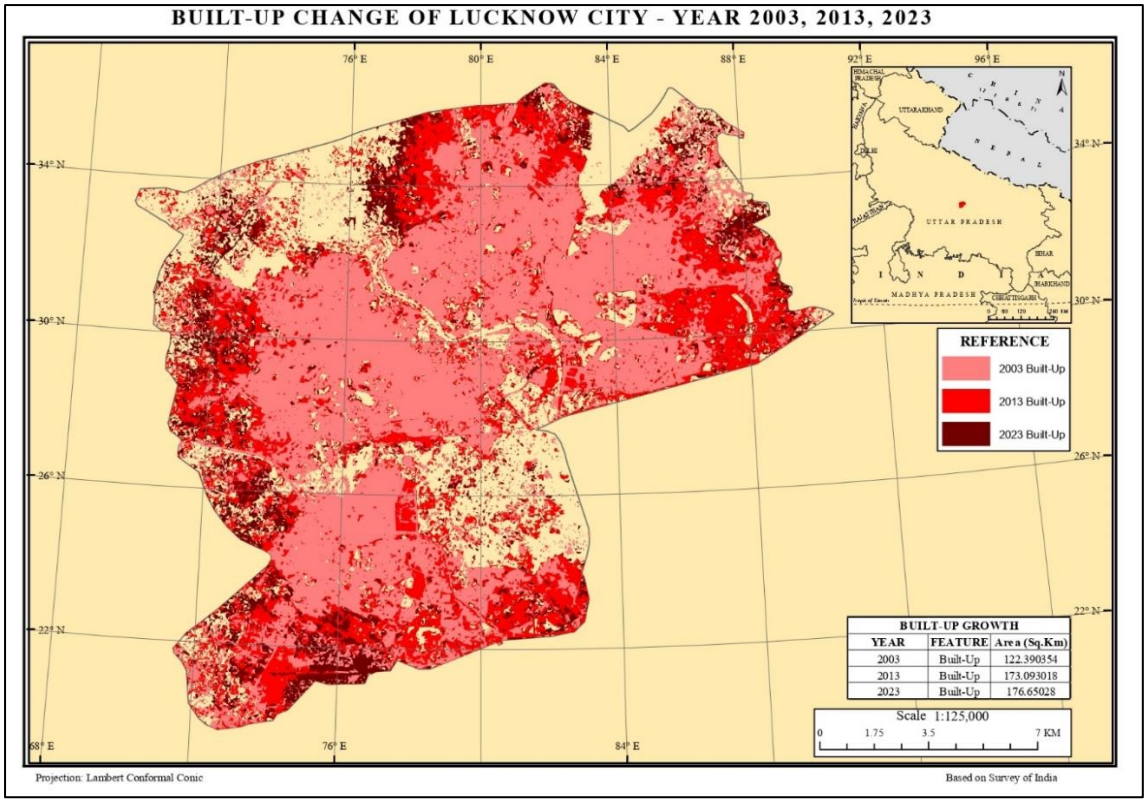


Figure 7 Change in Build-Up Area of Lucknow City

Drivers of LULC Change

The urban expansion observed in Lucknow is a result of several interlinked factors:

- Population Growth and Migration: Lucknow's population has surged from 2.2 million in 2001 to 3.8 million in 2021, leading to increased demand for housing, commercial spaces, and transport infrastructure.
- Infrastructure and Economic Growth: Government-led projects, including the Lucknow Metro (2017), Gomti Riverfront Project (2018), and Smart City Mission (2020), have accelerated land-use transitions, particularly in peri-urban areas.
- Real Estate and Industrial Development: The private sector has played a significant role in transforming Chinhat into a residential-commercial hub and Sarojini Nagar into an industrial zone.
- Urban Greening Policies: The National Green India Mission and local afforestation programs have contributed to the increase in vegetation cover, contrasting with trends observed in cities like Delhi, where there has been a -22.4% decline in vegetation.
- Lack of Waterbody Conservation: Unlike vegetation, wetland conservation policies have been ineffective, leading to unchecked encroachments and the loss of urban lakes and ponds.
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Environmental & Sustainability Implications

The findings of this study align with global sustainability goals but also highlight key challenges:

- Urban Heat Island (UHI) Effects: The rise in built-up areas and the loss of water bodies could exacerbate temperature increases, requiring green infrastructure solutions.
- Groundwater Depletion and Flooding Risks: The loss of over 80% of water bodies raises concerns about groundwater recharge failure, flash floods, and urban droughts.
- Sustainable Development Goals (SDGs) Alignment: The study's results correspond to:
  - SDG 11 (Sustainable Cities): Densification post-2013 suggests a transition towards compact city planning.
  - SDG 15 (Life on Land): Vegetation growth enhances urban biodiversity but requires sustainable land-use strategies.
  - SDG 6 (Clean Water and Sanitation): The sharp decline in water bodies necessitates urgent conservation efforts.

Policy Recommendations for Sustainable Urban Planning

To mitigate the negative impacts of rapid urbanization, the following strategies should be implemented:

- Water Body Protection and Restoration: Strengthen wetland conservation laws and implement integrated urban water management systems to prevent further encroachments.
- Green Infrastructure and Climate Resilience: Expand urban forests, vertical gardens, and permeable surfaces to combat urban heat island effects and improve air quality.
- Smart Zoning and Mixed-Use Development: Promote high-density, mixed-use planning to reduce unnecessary land conversion and encourage efficient land utilization.
- Hydrological Restoration Programs: Encourage rainwater harvesting, groundwater recharge initiatives, and flood control mechanisms to restore urban hydrological balance.
- Eco-Friendly Peri-Urban Development: Introduce green belts, low-carbon housing projects, and sustainable transport systems in peri-urban areas like Chinhat and Sarojini Nagar.

Conclusion

This study highlights the rapid transformation of Lucknow's urban and peri-urban landscapes over the past two decades, emphasizing the significant expansion of built-up areas and the alarming decline in water bodies. While the increase in vegetation cover reflects positive afforestation efforts, the loss of wetlands and conversion of barren land raise critical concerns about hydrological sustainability and ecological resilience. To ensure sustainable urban development, future planning should incorporate integrated land-use policies that balance expansion with environmental conservation, and implement enhanced wetland protection measures to prevent further degradation. Smart urban infrastructure should be prioritized—favoring vertical growth over uncontrolled horizontal sprawl—and community-driven green initiatives should be promoted to support afforestation and urban greening.

By adopting a data-driven, policy-oriented approach, policymakers and urban planners can mitigate the adverse impacts of rapid urbanization while fostering a more

environmentally resilient metropolitan landscape.

Conflict of Interest

No conflict of interest was reported by the authors.

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