



Analyzing the Evolution of Urban Sprawl in Lucknow City: A Comprehensive Study (1992-2022)

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Abstract

This Research provides a thorough examination of the changes in Land Use and Land Cover (LULC) in Lucknow City from 1992 to 2022. This study divides the urban landscape into five separate groups using sophisticated Support Vector Machine (SVM) classification inside the ArcGIS Software 10.7.1 Environment: Water Bodies, Vegetation, Built-up Areas, Barren Land, and Agricultural Land. The SVM classifier was chosen for its capacity to handle complicated and high-dimensional datasets, and it proved to be reliable in defining these classes and tracking their progress over time. The findings reveal major shifts in Lucknow City's LULC trends. In 1992, barren land dominated at 37.57%, while built-up areas and vegetation covered 23.27% and 34.95%, respectively. Over the decades, urban expansion became evident, with built-up areas increasing to 50.77% by 2022, signalling rapid urbanization. Concurrently, barren land reduced to 11.70% and agricultural land declined to 13.42%, emphasizing the conversion of land for urban development. Vegetation, which accounted for 34.95% in 1992, decreased to 22.72% in 2022, raising environmental concerns about reduced green spaces. Similarly, water bodies decreased from 1.43 % to 1.36 %, emphasizing the importance of sustainable water resource management in an urbanizing setting. Furthermore, the research assesses the LULC classification's accuracy, revealing high agreement between observed and anticipated accuracy with Kappa Coefficients of 0.8183 in 1992 and 0.840 in 2022. Finally, this study uncovers considerable urban expansion dynamics, with urbanized areas increasing from 1992 to 2022. These findings highlight the need of educated urban planning and sustainable development methods in dealing with the consequences of urbanization while protecting the city's natural balance and long-term resilience.

Keywords: Lucknow city, LU/LC, Landsat (TM, OLI/TIRS), SVM classifier, Change analysis, Urban Sprawl.

1. Introduction

Rapidly spreading and pervasive urban expansion has significant economic and social repercussions. Fundamental changes brought about by the speed and scope of urban growth have a variety of repercussions on the composition and functionality of landscapes at different scales [1]. Construction of vital infrastructure, including industries, industrial facilities, and roads, as well as the availability of service amenities like hotels and hospitals, are necessary for the advancement of regional development. These variables operate as catalysts to promote urbanization [2]. Most of the world's population now prefers to live in urban regions because of factors including higher living standards and more lucrative employment prospects. 54.5 per cent of the world's population chose metropolitan areas as their primary residence in 2016. By 2030, it is predicted that this number will rise to 60% of the overall population based on current trends [3].

India, which is acknowledged as one of the nations in the world that is changing the fastest, has seen substantial changes to the features of its land, especially in the last 50 years. In recent years, a great deal of research has been done to examine how different Indian cities are changing. For instance, studies have examined Mumbai [4], Chennai [5], Kolkata [6], and Delhi [7] to comprehend the spatial changes and land dynamics in these urban areas. By 2050, 416 million more people are anticipated to live in urban areas across India because of the country's continuous urbanization trend. Concern needs to be expressed about the nation's urban areas' quick growth.

Urban areas are encroaching on environmentally sensitive areas or on rural and agricultural land to make room for the expanding population. As a result, metropolitan areas and impermeable surfaces are rapidly replacing agricultural land, waterways, and flora, with negative effects on the environment. For instance, India has seen a rise in summer temperatures of nearly 1°C over the past 60 years, and hot days are more frequent across the peninsula's interior as well as on its eastern and western coasts [8]. The increasing heat negatively affects human health, which lowers productivity and increases the number of cooling degree days [9].

To support the objective of sustainable development in cities, urban vegetation has emerged as one of the most significant potential solutions to a variety of urban difficulties [10]. Given this, researching urban vegetation provides advantages for both the environment and socio-economic advancement. While conventional data can be used to calculate urban environmental indicators, these data are sometimes insufficient due to generalization, datedness, or a lack of availability. Earth observation, on the other hand, has shown itself to be a reliable alternative source of geo-information for environmental monitoring and urban development. By providing the geographical data necessary to carry out urban planning projects, Earth observation contributes to scientific understanding. The real benefit of satellite technology above conventional approaches is that urban geospatial data can provide useful alternative planning methods and tools by assisting in the creation of affordable, accurate, and quick urban environmental indicators [11]. The focus of this study is Lucknow city, which is situated in the Uttar Pradesh state in North India. The urban environment of Lucknow has seen considerable changes because of its fast growth. This study's main goal is to analyze trends to determine the degree of urban sprawl and its effects on the ecology of the city over 30 years.

2. Materials and Methods

2.1. Study Area

Lucknow City, the capital of Uttar Pradesh, has been chosen as the study region due to its geographic location and size (436.4 sq. km). The city is located between latitudes 26° 44' 08" and 26° 57' 57" north and longitudes 80° 49' 50" and 81° 03' 14" east (Figure.1). Gomti River, which runs through the city's centre and runs from north to south, intersects it. It is estimated that the city is 123.00 m above sea level. Lucknow has a humid subtropical climate, and it rains an average of 904 mm/yr. The temperature range varies significantly between seasons, with the coldest winter months typically falling within the 5-15 °C range and the hottest summer days soaring to temperatures between 40-45 °C [12]

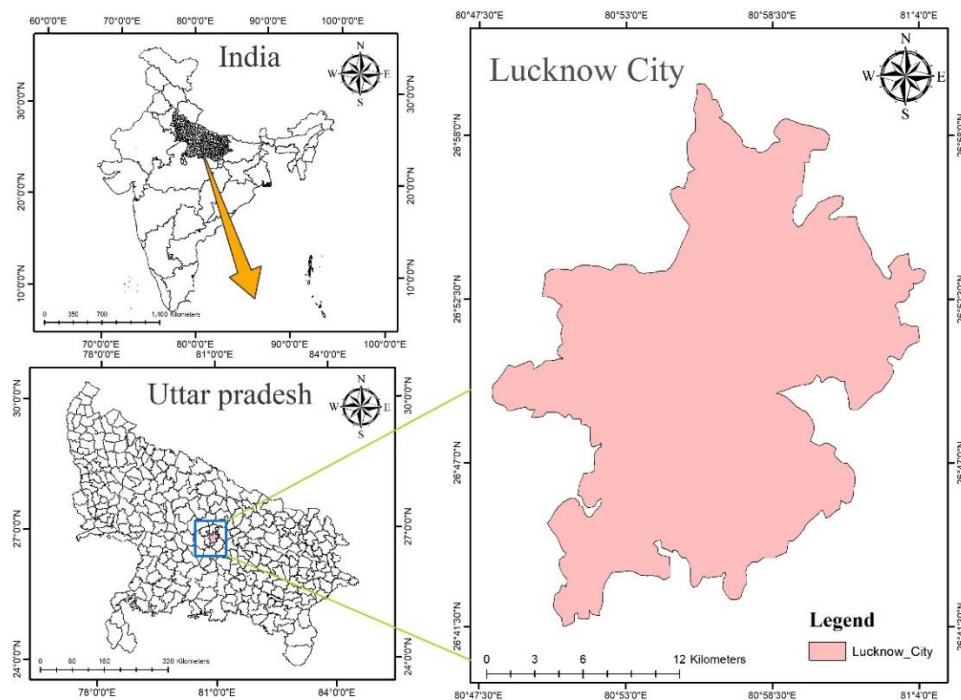


Fig. 1 Study Area Map of Lucknow City

2.2 Data Acquired

This study makes use of Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) data from the USGS Earth Explorer database, with a spatial resolution of 30 meters (Table 1). These remote sensing datasets are used to undertake a detailed investigation of urban sprawl dynamics in Lucknow City from 1992 to 2022. The data sets enable an assessment of land use changes and urban growth across a three-decade period.

S. no.	Satellite Imagery	Acquisition date	Sensor	Resolution (m)	Source
1	Landsat 5	13/11/1992	TM	30	USGS
2	Landsat 8	10/12/2022	OLI/TIRS	30	USGS

Table 1. Satellite Dataset used

2.3 Support Vector Machine (SVM) Classification

The Land Use and Land Cover (LULC) classification conducted for Lucknow City from 1992 to 2022 utilized the advanced Support Vector Machine (SVM) classifier within the ArcGIS Software 10.7.1 environment. This comprehensive analysis segmented the urban landscape into five distinct classes, namely Water Bodies, Vegetation, Built-up Areas, Barren Land, and Agricultural Land. The SVM classifier proved to be a robust choice for this task, as it excels in handling complex and high-dimensional datasets, making it particularly suitable for the diverse LULC characteristics of an evolving city like Lucknow.

The Waterbodies class included both natural and man-made water features within the city borders, such as rivers, lakes, ponds, and reservoirs. Parks, forests, green spaces, and other natural vegetation were all covered with vegetation. Built-up Residential, commercial, and industrial zones were incorporated, depicting structures and

human development. Barren Land referred to areas that were devoid of vegetation or construction and generally included rocky terrain or wastelands. The Agricultural Land class included cultivable regions that represented the city's agricultural zones.

The SVM classifier efficiently demarcated these LULC classes from 1992 to 2022, using its capacity to handle both spectral and spatial data. The alteration of Lucknow city, Uttar Pradesh environment over three decades was tracked by analyzing multi-temporal satellite images, finding trends in urbanization, land use patterns, and the expansion of built-up regions. This analysis lays a solid platform for urban planners, politicians, and scholars to better understand the dynamics of urban expansion, environmental changes, and the consequences for Lucknow's sustainable city growth.

3. Results and Discussions

3.1 LU/LC Analysis

The results of the land use land cover (LULC) analysis for Lucknow City from 1992 to 2022 reveal significant changes in the urban landscape. In 1992, the dominant land cover class was barren land, accounting for a substantial 37.57% of the total area. Built-up areas and vegetation covered 23.27% and 34.95%, respectively, while agricultural land and water bodies represented 2.76% and 1.43% of the area, respectively. Over the three decades, notable transformations occurred in the urban fabric of Lucknow City. By 2022, built-up areas had expanded significantly, becoming the predominant land cover class, occupying 50.77% of the total area. This substantial increase suggests rapid urbanization and infrastructure development. Conversely, barren land and agricultural land saw reductions in their extents, with barren land decreasing to 11.70% and agricultural land declining to 13.42%. These shifts are indicative of land conversion for urban development and associated changes in land use practices.

The decline in vegetation from 34.95% in 1992 to 22.72% in 2022 raises concerns about potential environmental impacts, including reduced green spaces and vegetation health. The decrease in water bodies from 1.43% to 1.36% also warrants attention, highlighting the need for sustainable water resource management in the face of urban expansion. The results demonstrate a significant shift in land use land cover patterns in Lucknow City over the past three decades, with a notable increase in built-up areas at the expense of barren and agricultural land. These changes have important implications for urban planning, environmental conservation, and sustainable development, calling for informed policies and strategies to manage urban growth while preserving the Lucknow city ecological balance.

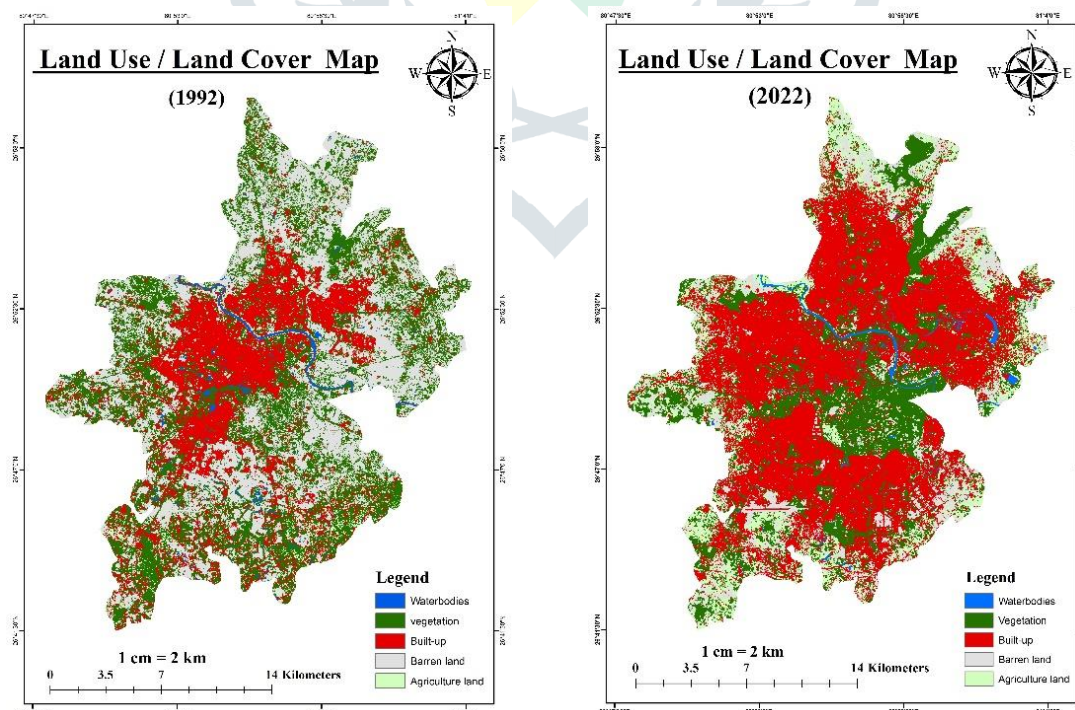


Fig. 2 The classified maps of Lucknow city for the study period 1992 and 2022

LULC classes	1992		2022	
	Area(Sq.km)	Area(%)	Area (Sq.km)	Area(%)
Agriculture Land	12.05	2.76	58.592	13.423
Barren Land	164.01	37.57	51.070	11.699
Built-Up	101.57	23.27	221.633	50.773
Vegetation	152.54	34.95	99.183	22.721
Waterbodies	6.23	1.43	5.941	1.361
Total	436.4	100.0	436.4	100.0

Table 2. Land use/ Land cover classes of the study area

LULC	1992-2022		% change
	Area(%)	Area(%)	
Agriculture Land	2.76	13.423	10.662
Barren Land	37.57	11.699	-25.873
Built-Up	23.27	50.773	27.505
Vegetation	34.95	22.721	-12.224
Waterbodies	1.43	1.361	-0.066

Table 3. Change in the LULC for the Periods 1992-2022

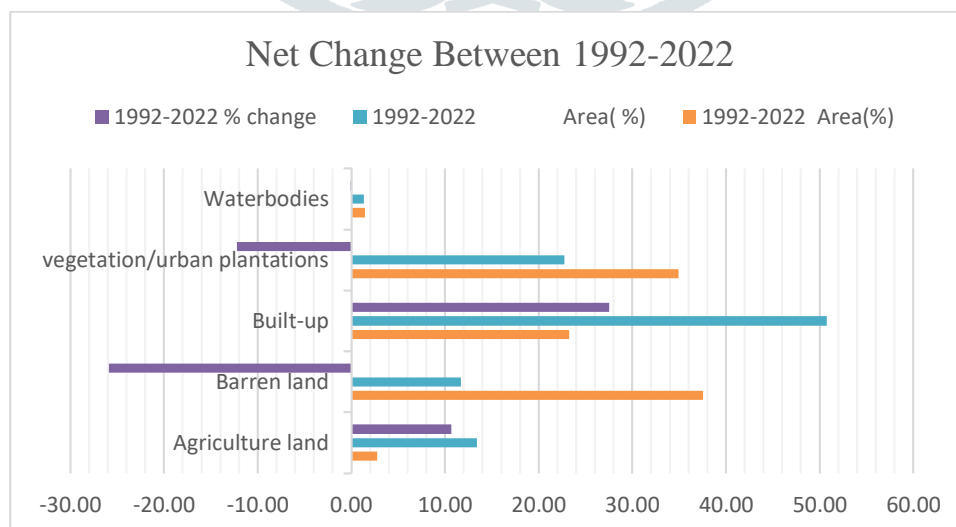


Fig. 3 Net Change from 1992 to 2022

3.2 Accuracy Assessment Analysis of LULC Classification

The accuracy evaluation study of Lucknow City land use land cover (LULC) change detection from 1992 to 2022, done using ArcGIS software 10.7.1 and a confusion matrix is shown below (Table 4-5). The total accuracy of the LULC classification was determined to be 87.4 % in 1992, demonstrating a high degree of accuracy in properly identifying distinct land cover groups. The Kappa Coefficient, which evaluates the agreement between observed and predicted accuracy, was estimated to be 0.8183. This Kappa score indicates strong agreement above and above what would be predicted by chance, further verifying the classification's correctness. Similarly, in 2022, the total accuracy increased to 89.2 %, demonstrating a little greater degree of categorization accuracy than in 1992. The 2022 Kappa Coefficient was found to be 0.840, indicating a significant level of agreement between observed and predicted accuracy, much greater than in 1992.

Table 4. Confusion Matrix of LU/LC Classification 1992

Confusion Matrix	Vegetation	Built-up	Waterbodies	Barren	Agriculture	Total	Users
1992				land	land		Accuracy
Vegetation	65.000	0.000	0.000	1.000	0.000	66.000	0.985
Built-up	1.000	33.000	0.000	8.000	0.000	42.000	0.786
Waterbodies	1.000	0.000	7.000	2.000	0.000	10.000	0.700
Barren land	6.000	0.000	0.000	66.00	1.000	73.000	0.904
Agriculture land	3.000	0.000	1.000	1.000	3.000	8.000	0.375
Total	76.000	33.000	8.000	78.00	4.000	199.00	0.000
Producer Accuracy	0.855	1.000	0.875	0.846	0.750	0.000	0.874
	Overall Accuracy= 87.4 %			Kappa Coefficient = 0.8183			

Table 5. Confusion Matrix of LU/LC Classification 2022

Confusion Matrix	Vegetation	Built-up	Waterbodies	Barren	Agriculture	Total	Users
2022				land	land		Accuracy
Vegetation	34.000	0.000	0.000	0.000	0.000	34.000	1.000
Built-up	0.000	75.000	0.000	0.000	0.000	75.000	1.000
Waterbodies	2.000	2.000	6.000	0.000	0.000	10.000	0.600
Barren land	1.000	2.000	0.000	15.000	0.000	18.000	0.833
Agriculture land	4.000	2.000	0.000	4.000	11.000	21.000	0.524
Total	41.000	81.000	6.000	19.000	11.000	158.000	0.000
Producer Accuracy	0.829	0.926	1.000	0.789	1.000	0.000	0.892
	Overall Accuracy= 89.2 %			Kappa Coefficient = 0.840			

3.3 Urban Sprawl Dynamics

The analysis of urban sprawl dynamics in Lucknow City from 1992 to 2022, based on the provided data, reveals a substantial and consistent increase in urban expansion over this three-decade period. In 1992, urbanized areas accounted for 23.27% of the total land area. By 2004, this percentage had risen to 27.82%, signifying a noticeable expansion in urban development within just 12 years. The most significant transformation occurred between 2004 and 2013 when the urbanized area jumped to 42.29%, indicating rapid urban sprawl during this period. By 2022, urban sprawl had further intensified, with urbanized areas covering a substantial 50.77% of the city's total land area.

This remarkable increase underscores the extensive urbanization and urban sprawl that Lucknow City has experienced over the years, highlighting the need for effective urban planning and sustainable development strategies to manage the associated challenges and ensure the city's long-term resilience (Figure 4).

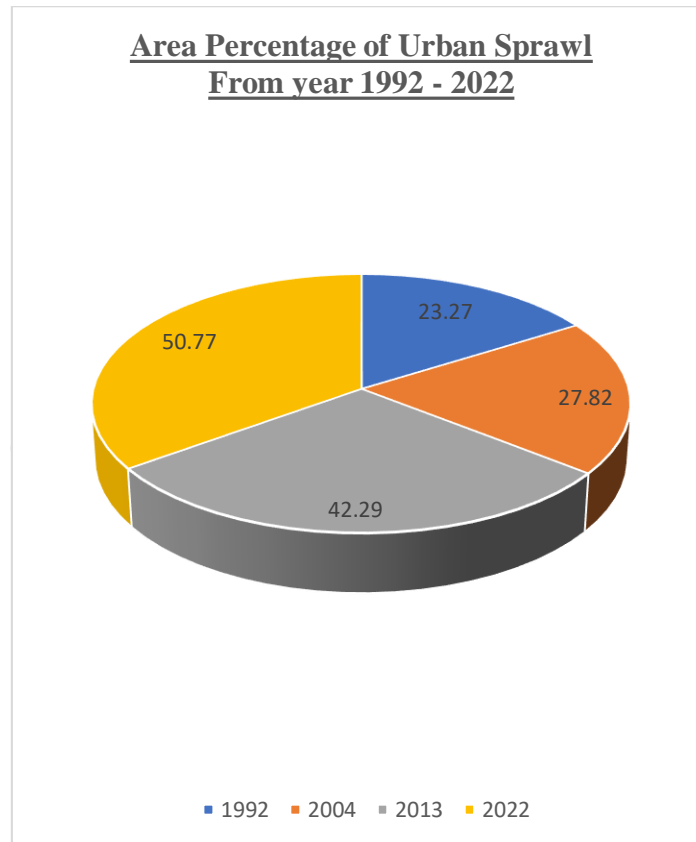


Fig. 4 Percentage Distribution of Urban Sprawl from 1992-2022

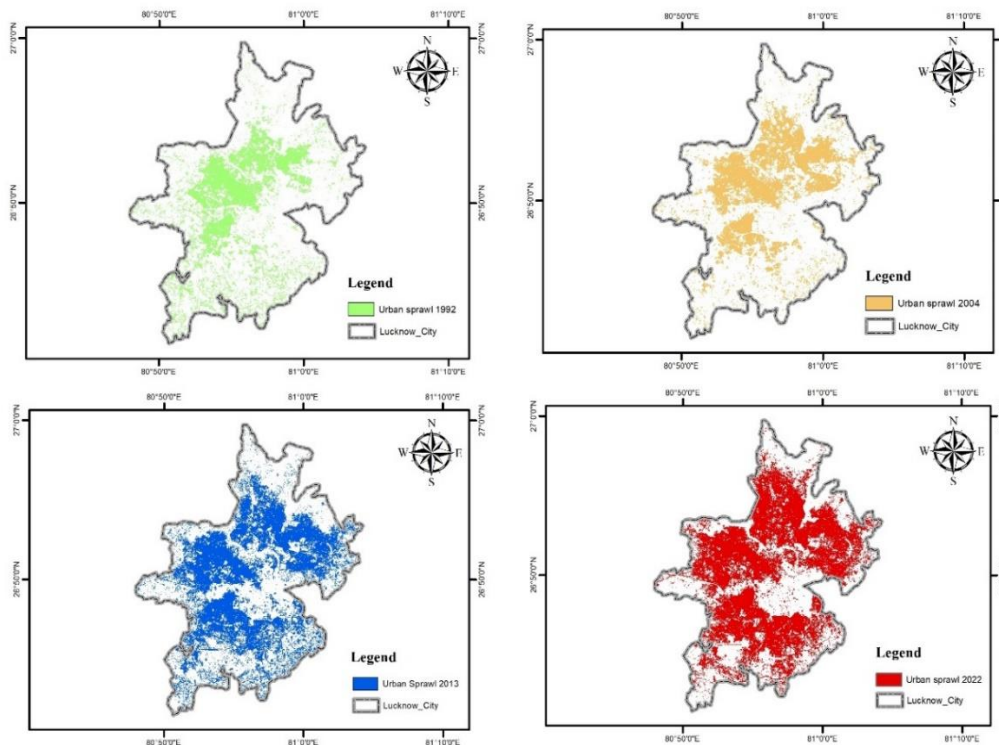


Fig. 5 Change detection of urban sprawl from 1992-2022

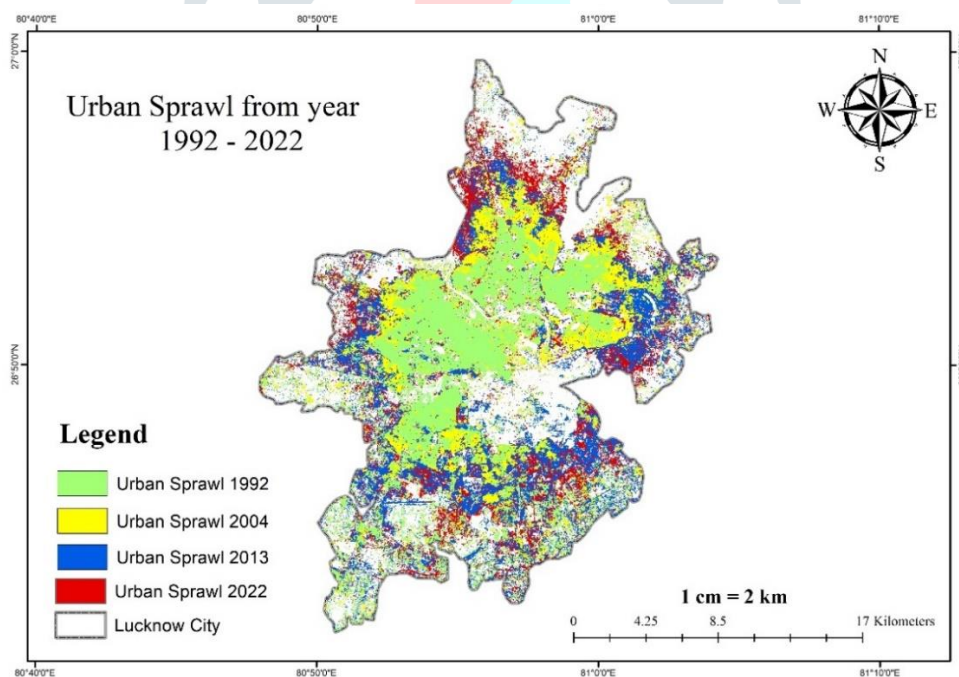


Fig. 6 Transformations during 1992-2022

4. Conclusions

In conclusion, the comprehensive analysis of Lucknow City's land use land cover (LULC) evolution from 1992 to 2022 paints a vivid picture of the city's urban transformation. The dominance of barren land in 1992, constituting 37.57% of the area, has significantly shifted over the years. Built-up areas have risen to prominence, covering 50.77% of the city's land by 2022, reflecting rapid urbanization and infrastructure development. This transition has not been without consequences. The decline in vegetation from 34.95% in 1992 to 22.72% in 2022 raises

environmental concerns, as it signifies reduced green spaces and potential stress on the city's ecology. Similarly, the decrease in water bodies from 1.43% to 1.36% underscores the importance of sustainable water resource management amidst urban expansion.

The accuracy assessment of the LULC classification further validates the reliability of our findings. The high overall accuracy of 87.4% in 1992 and 89.2% in 2022, coupled with Kappa Coefficients of 0.8183 and 0.840, respectively, demonstrates the robustness of our classification and change detection methods. Moreover, the analysis of urban sprawl dynamics emphasizes the city's remarkable growth over three decades. The progression from 23.27% urbanization in 1992 to 50.77 % in 2022 is indicative of an expanding urban footprint. This evolution necessitates careful urban planning and sustainable development strategies to address the challenges posed by rapid urbanization while preserving the city's ecological balance. The findings underscore the critical importance of informed policies and strategies for managing urban growth, environmental conservation, and sustainable development in Lucknow City as it continues to evolve in the coming years.

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