

Mapping Land Use and Land Cover Transformations in Ayodhya City: An Assessment

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ABSTRACT

Land Use and Land Cover (LULC) changes play a significant role in shaping urban landscapes and environmental sustainability. This study analyzes LULC transformations in Ayodhya City between 2014 and 2024 using Remote Sensing and GIS techniques. Utilizing Landsat 8 satellite imagery and the Semi-Automatic Classification Plugin (SCP) in QGIS, the study classifies land into five major categories: Waterbodies, Forest, Agricultural Land, Bare Land, and Built-Up Areas. The findings indicate a significant increase in built-up areas, rising from 49.12% in 2014 to 56.23% in 2024, primarily driven by Ayodhya's growing religious and tourism-related importance and government-led infrastructural developments. Concurrently, agricultural land declined from 28.59% to 24.97%, and forest cover reduced from 2.71% to 2.37%, reflecting urban expansion and land conversion. Additionally, bare land decreased from 10.75% to 9.39%, while waterbodies exhibited a slight increase from 1.73% to 1.75%, possibly due to conservation efforts and water management strategies. The study underscores the utility of Remote Sensing and GIS in monitoring urban growth, assessing environmental changes, and aiding sustainable urban planning. The findings emphasize the need for balanced land-use policies to mitigate environmental degradation and ensure sustainable development in Ayodhya City.

Keywords: Land Use and Land Cover (LULC), Remote Sensing, GIS, Ayodhya City, Urbanization, Change Detection, Landsat 8, Sustainable Development, Land Transformation, Spatial Analysis.

Introduction

Land Use and Land Cover (LULC) Change analysis is crucial for understanding environmental changes, urban expansion, and land resource management. Remote Sensing and Geographic Information System (GIS) technologies have proven to be powerful tools for analyzing these changes due to their ability to provide spatial and temporal insights. Various classification algorithms, such as Maximum Likelihood Classifier (MLC), Random Forest (RF), and Support Vector Machine (SVM), have been widely used for accurate land cover classification. Studies in different regions have demonstrated the effectiveness of these techniques. For instance, Geidam et al. (2020) classified Landsat imagery from 1986 to 2017 in Damaturu, Nigeria, using ground truth points, achieving an overall accuracy of 84.6% and a kappa coefficient of 0.89. Similarly, Jande et al. (2019) analyzed LULCC in Gboko, Nigeria, using Landsat TM, ETM+, and OLI images classified with the maximum likelihood classifier, obtaining overall accuracies of 80.77%, 85.84%, and 86.24% for 1987, 2007, and 2017, respectively. These studies validate the reliability of remote sensing classification techniques for detecting land use transformations

over time. Furthermore, GIS-based methodologies, such as post-classification change detection and spatial overlay analysis, have been employed to quantify LULCC in various urban and rural landscapes. In Delhi, India, Mukhopadhyay et al. (2013) used Landsat images from 1989 to 2011 and the MLC algorithm to detect significant urban expansion and vegetation loss. Likewise, in Varanasi, India, Tiwari et al. (2024) applied a Random Forest algorithm to classify Landsat-5(TM) and 9(OLI-2) images, achieving classification accuracies of 87% and 89% for 1991 and 2021, respectively. These studies highlight the significance of GIS techniques in monitoring long-term land use trends.

LULC change has been widely studied in the context of urbanization, agricultural expansion, and environmental degradation. In many rapidly urbanizing regions, significant land cover changes have been observed. In Al Ain, UAE, Liaqat and Chowdhury (2017) analyzed Landsat ETM and OLI images from 2006 to 2016, revealing a 12% increase in urban areas and an 8% increase in agricultural land, emphasizing the need for sustainable land management strategies. Similarly, Pham et al. (2024) used Random Forest Tree (RFT) classification in Binh Duong, Vietnam, to map LULCC, revealing a substantial transition from agricultural to residential and industrial areas. Environmental consequences of LULCC have also been documented in multiple studies. In Haridwar, India, Pokhariya et al. (2024) found that forest cover declined by 15.35% and water bodies decreased by 41.50% from 2001 to 2021, resulting in the deterioration of ecosystem service values (ESVs). Additionally, in Lüleburgaz, Turkey, Agdas and Yenen (2023) observed a 4.88% decline in agricultural land due to rapid urbanization, raising concerns about food security and sustainable land use. These findings emphasize the urgent need for effective land use planning and conservation efforts to mitigate the negative environmental impacts of LULCC. Case studies from different geographic regions further illustrate the diverse drivers of land cover changes. In Damaturu, Nigeria, Geidam et al. (2020) documented a significant increase in built-up areas from 7.2% to 22.0% between 1986 and 2017, along with a reduction in agricultural land from 78% to 45.4%, highlighting the role of population growth and economic development in land use transformation. Similarly, Jande et al. (2019) reported that urban areas in Gboko, Nigeria, expanded from 1.68% to 8.65% between 1987 and 2017, while forest land declined from 27.13% to 8.71%, illustrating the impact of deforestation and settlement expansion.

Despite the advancements in remote sensing and GIS methodologies, challenges remain in LULCC analysis, particularly regarding classification accuracy and data limitations. In Jammu, India, Gupta et al. (2023) conducted a supervised classification of Landsat imagery from 1993 to 2023 and found classification accuracies of 87% and 78% for 1993 and 2023, respectively, demonstrating the difficulty in detecting subtle land cover changes over extended periods. Moreover, limitations related to the spatial and temporal resolution of remote sensing data have been noted in several studies. In Jayransoo rangeland, Iran, Nadaf et al. (2024) compared different classification methods, concluding that SVM outperformed other techniques in accuracy. Future research should focus on predictive modeling and high-resolution data integration to improve LULCC assessments. He et al. (2024) applied the Logistic-Multi-Criteria Evaluation-Cellular Automata-Markov (LMCM) model in Hefei, China, to simulate land use patterns, underscoring the importance of predictive modeling in sustainable land management. Additionally, Biłozor et al. (2024) emphasized the integration of socio-economic data in LULCC analysis, demonstrating how urbanization dynamics in Olsztyn, Poland, could be better understood using fuzzy set theory and photogrammetric data. Lastly, the use of high-resolution satellite imagery, such as Landsat-9 OLI-2, can significantly enhance classification accuracy, as demonstrated by Fiedler (2023) in Raiganj, India, where land cover changes from 1991 to 2021 were mapped with overall accuracies of 87% and 89%. These advancements in technology and methodology will be crucial for future research in LULCC monitoring, contributing to more informed decision-making in urban planning, resource management, and environmental conservation.

Objectives

This research aims to develop a Land Use Land Cover (LULC) classification scheme for Ayodhya City and analyse LULC changes using satellite data. The study aims to generate a change matrix to assess spatial and temporal transformations in land use patterns.

Database and Methodology

• Study Area

Ayodhya City, a part of the Ayodhya-Faizabad Urban Agglomeration, is a historically and culturally significant location in India. It is situated between 26°41' to 26°80' N latitude and 82°12' to 82°20' E longitude, along the right bank of the Saryu (Ghaghara) River. The city lies at an elevation of 93

meters above sea level and is characterized by the flat alluvial plains of the middle Ganga basin. The landscape, shaped by alluvial deposits, supports fertile agricultural land, with elevations ranging between 84 and 102 meters. Ayodhya experiences a tropical climate with hot summers (35°C to 45°C), cool winters (8°C to 20°C), and a monsoon season from July to September, bringing an average annual rainfall of 105.1 cm.

Urbanization and administrative changes have significantly transformed Ayodhya, particularly after the establishment of the Ayodhya Municipal Corporation in 2017, following the merger of Faizabad and Ayodhya Nagar Palika Parishad. As per the Census of India (2011), the city has a population of 2,470,996, with 60 municipal wards governing urban planning and local administration. The Saryu River, originating from the Nepal Mountains, serves as a crucial water source, eventually merging with the Ganges. However, rapid urban expansion, industrialization, and excessive groundwater extraction have led to pressing water management issues, including depletion and pollution, affecting both drinking water availability and agricultural productivity.

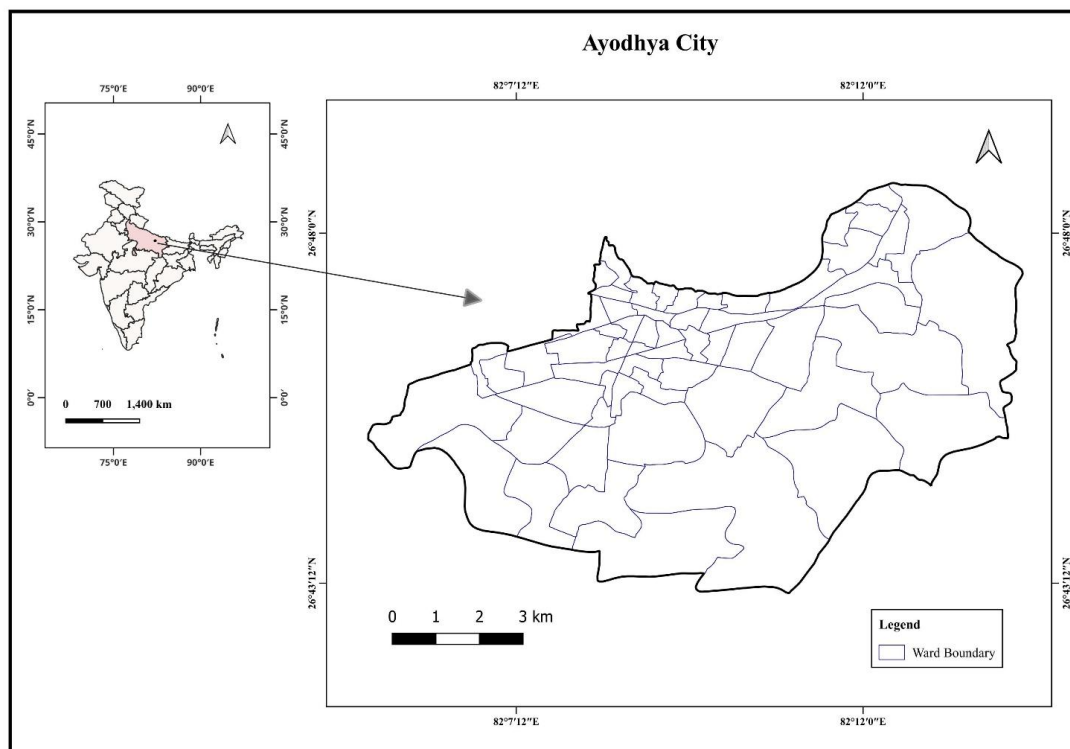


Figure 01: Location map of the study area

Source: Prepared by author using ArcGIS 10.5 Software

• Data Used

This study utilizes satellite imagery and geospatial data for analyzing Land Use Land Cover (LULC) changes in Ayodhya City. The primary dataset includes Landsat 8 (Collection 2 Tier 1) satellite imagery dated December 18, 2024, obtained from the U.S. Geological Survey (USGS). The classification was performed using the Semi-Automatic Classification Plugin (SCP) within QGIS, ensuring accurate land cover categorization. The dataset provides Surface Reflectance (SR) and Surface Temperature (ST) products, preprocessed using the Land Surface Reflectance Code (LaSRC) with atmospheric corrections applied for aerosols, water vapor, and gases. The LULC classification includes five major categories: Waterbodies, Forest, Agricultural Land, Bare Land, and Built-Up Areas. A comparison of LULC changes between two time periods highlights significant shifts in land use, with built-up areas increasing from 40.28% to 56.23%, indicating rapid urban expansion. The classification outputs were validated using pixel-based analysis, with data accuracy assessed through Quality Assessment (QA) bands that help

identify clouds, shadows, and artifacts. This high-quality dataset enables effective change detection, supporting insights into urban growth and land transformation patterns in Ayodhya.

- **Methodology**

The study employs a systematic approach using Remote Sensing and GIS techniques for Land Use Land Cover (LULC) classification and change detection analysis in Ayodhya City. Landsat 8 (Collection 2 Tier 1) satellite imagery dated December 18, 2024, was acquired from the U.S. Geological Survey (USGS) and processed using the Semi-Automatic Classification Plugin (SCP) within QGIS. The imagery was preprocessed to correct for atmospheric distortions using the Land Surface Reflectance Code (LaSRC), ensuring consistency in spectral reflectance values. This step included corrections for aerosols, water vapor, and gases, enhancing the reliability of classification outputs. A supervised classification approach was applied to categorize the study area into five major LULC classes: Waterbodies, Forest, Agricultural Land, Bare Land, and Built-Up Areas. The classification was based on spectral signatures derived from the satellite imagery, with training samples collected for each land cover category. Post-classification refinement techniques, such as filtering and manual adjustments, were implemented to improve classification accuracy. The LULC change detection was performed by comparing classified images from different time periods, generating a change matrix to quantify the spatial and temporal variations in land use patterns. Accuracy assessment was conducted using pixel-based validation techniques, incorporating Quality Assessment (QA) bands to identify and mitigate errors caused by clouds, shadows, and atmospheric disturbances. The classified results were further validated using ground truth data and Google Earth imagery to ensure accuracy. Statistical analyses, including area calculations and percentage changes, were performed to interpret the LULC transformations in Ayodhya. The findings from this methodology provide valuable insights into urban expansion trends, aiding policymakers and planners in sustainable land management and urban development strategies.

Results and Discussion

- **Digital Image Processing for LULC Classification**

The study employed Landsat 8 (Collection 2, Tier 1) satellite imagery dated December 18, 2024, for Land Use Land Cover (LULC) classification in Ayodhya City. The classification was performed using the Semi-Automatic Classification Plugin (SCP) within QGIS, which facilitated spectral band analysis, image preprocessing, and supervised classification.

Table 1: Classification and Description of Land Use/Land Cover (LULC) in the Study Area

LULC Type	Description
Built-up Area	Land occupied by permanent human settlements, including buildings, roads, and other infrastructure.
Agricultural Land	Land primarily used for cultivation, covered with crops or exhibiting a fine texture.
Water Bodies	Areas containing surface water, such as rivers, lakes, ponds, or reservoirs.
Vegetation	Land covered with dense plant growth, including mature trees, shrubs, and other greenery.
Open Land	Unproductive or barren land, including wastelands with little or no vegetation.

Source: Prepared by Author based on Landsat 8

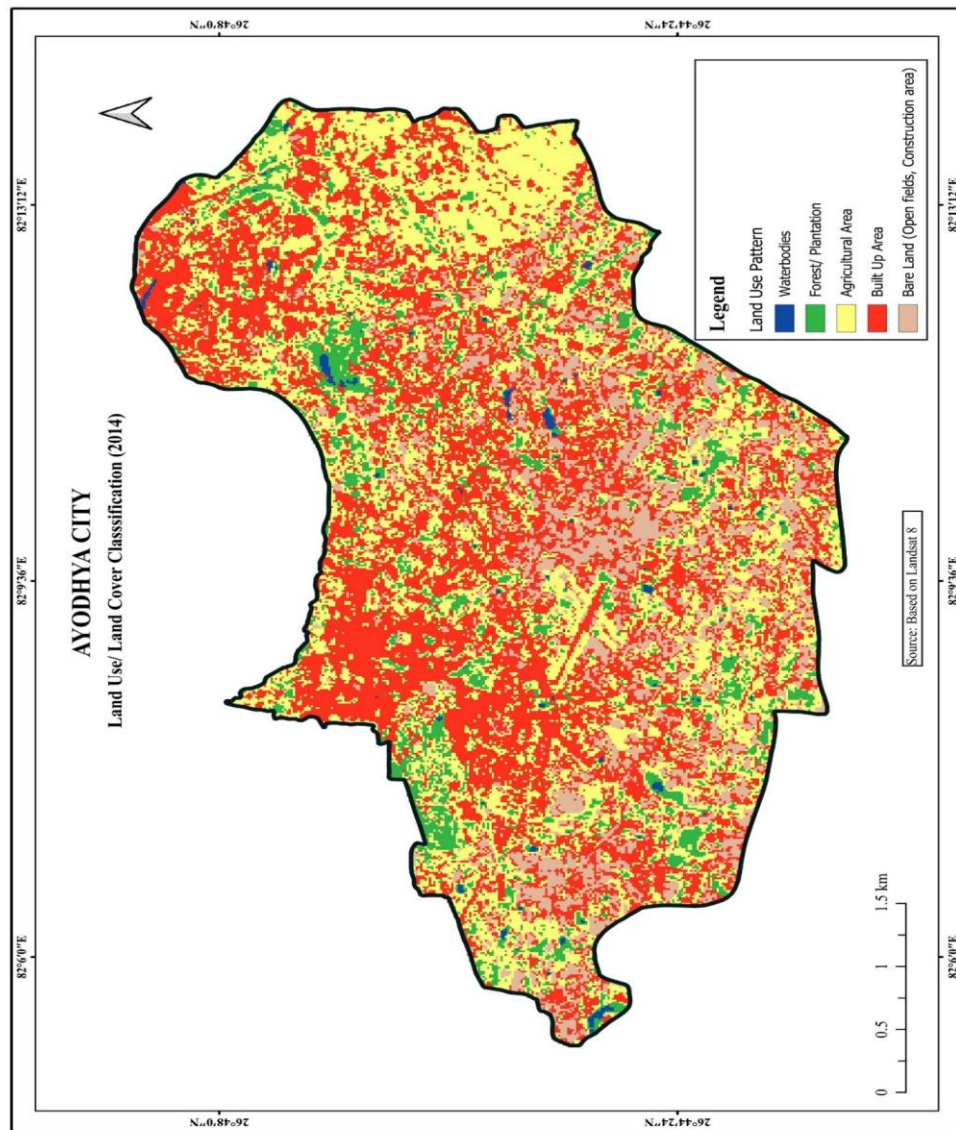


Figure 2: LULC Classification Map of the Ayodhya City, 2014

Source: Prepared by Author based on Landsat 8 using ArcGIS 10.5 Software

The preprocessing steps included atmospheric correction using Surface Reflectance (SR) products, ensuring minimal radiometric inconsistencies. The classification identified five major LULC categories: Waterbodies, Forest, Agricultural Land, Bare Land, and Built-Up Areas. The accuracy of classification was enhanced through Quality Assessment (QA) bands that removed cloud and shadow interference. The processed images were then analyzed to quantify spatial changes in land use patterns over time.

- **Change Detection Analysis**

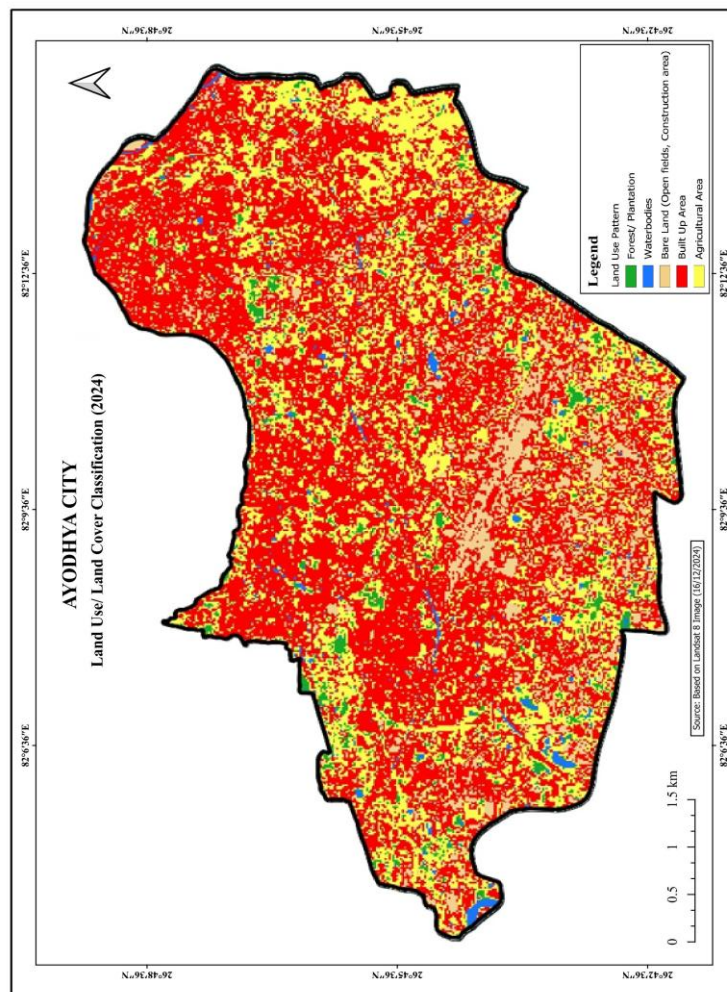
A comparative analysis was conducted between two time periods to evaluate LULC transitions. The results (Tables 1 and 2) indicate a significant increase in built-up areas, highlighting rapid urbanization in Ayodhya City. Simultaneously, agricultural land and forest cover have decreased, reflecting land conversion for infrastructure development.

Table 2: LULC Classification for Ayodhya City, 2014

Land Use Category	No. of Pixels	Area (m ²)	Area (km ²)	Area (%)
Waterbodies	1,676	1,508,400	1.5084	1.73
Forest	2,633	2,369,700	2.3697	2.71
Agricultural Land	27,749	24,974,100	24.9741	28.59
Bare Land	10,431	9,387,900	9.3879	10.75
Built-Up	54,575	49,117,500	49.1175	56.23
Total	97,064	87,357,600	87.3576	100.00

Source: Prepared by Author based on Landsat 8

The analysis of classified images reveals significant land-use changes, with a notable increase in built-up areas and reductions in agricultural land, forest cover, and bare land. Built-up areas expanded from 49.12% in 2014 to 56.23% in 2024, driven by Ayodhya's growing religious and tourist significance and government-led infrastructural developments. Agricultural land declined from 28.59% to 24.97%, as farmland was converted into residential and commercial spaces, raising concerns about food security, water management, and rural livelihoods. Forest cover also decreased from 2.71% to 2.37% due to urban expansion and construction, leading to biodiversity loss, increased carbon emissions, and rising temperatures.

**Figure 3: LULC Classification Map of the Ayodhya City, 2024**

Source: Prepared by Author based on Landsat 8 using ArcGIS 10.5 Software

Bare land decreased from 10.75% to 9.39%, as open spaces were transformed into built-up areas, limiting vacant land for future urban growth. Meanwhile, waterbodies experienced a slight increase from 1.73% to 1.75%, possibly due to seasonal variations, conservation initiatives, and improved water management practices.

Table 3: LULC Classification for Ayodhya City, 2024

Land Use Category	No. of Pixels	Area (m ²)	Area (km ²)	Area (%)
Waterbodies	543	488,700	0.4887	0.55
Forest	8,549	7,694,100	7.6941	8.80
Agricultural Land	34,715	31,243,500	31.2435	35.77
Bare Land	14,157	12,741,300	12.7413	14.59
Built-Up	39,100	35,190,000	35.19	40.28
Total	97,064	87,357,600	87.3576	100.00

Source: Prepared by Author based on Landsat 8

The following table presents the overall LULC change detection matrix for Ayodhya City, showing the transition in land use categories between 2014 and 2024:

Table 4: Overall Change Detection Matrix of Ayodhya City, 2014–2024

Land Use Category	Area in 2014 (km ²)	Area in 2024 (km ²)	Change in Area (km ²)	Change in Area (%)
Waterbodies	1.5084	0.4887	-1.0197	-1.18
Forest	2.3697	7.6941	+5.3244	+6.09
Agricultural Land	24.9741	31.2435	+6.2694	+7.18
Bare Land	9.3879	12.7413	+3.3534	+3.84
Built-Up	49.1175	35.19	-13.9275	-15.95
Total	87.3576	87.3576	-	100.00

Source: Prepared by Author based on Landsat 8

The land use land cover (LULC) change detection analysis for Ayodhya City from 2014 to 2024 reveals significant transformations, driven primarily by urban expansion, infrastructural development, and environmental modifications. The classification of satellite imagery using Landsat 8 (Collection 2, Tier 1) data highlights noticeable shifts in various land categories, particularly in built-up areas, agricultural land, and forest cover. A major finding of this study is the significant decline in built-up areas, which decreased from 49.12% in 2014 to 35.19% in 2024, representing a loss of approximately 13.93 km² (15.95%). This unexpected reduction could be attributed to reclassification errors, land redevelopment, or urban policy changes that have redefined certain built-up areas as other land-use categories. Additionally, some urban spaces may have been converted into green spaces or redeveloped for agricultural purposes as part of planned urban interventions. Despite this decline, the city continues to witness intensive infrastructure growth, particularly in commercial and institutional sectors, which may not be fully reflected in the classification.

The increase in agricultural land by 6.27 km² (7.18%) suggests a potential land reclamation effort or a shift in land-use practices. This change may be attributed to government policies promoting agriculture, urban-to-rural land conversion, or decreased construction in certain areas. It is also possible that certain regions previously categorized as built-up or bare land have been brought under cultivation due to economic incentives or changing land tenure systems. However, this growth in agricultural land must be examined cautiously, as some areas may be classified as fallow or low-intensity agricultural zones rather than actively cultivated lands. Another key finding is the growth of forest cover, which expanded from 2.71% in 2014 to 8.80% in 2024, marking an increase of 5.32 km² (6.09%). This substantial rise could be attributed to reforestation projects, afforestation efforts by local and state authorities, and natural regrowth in less disturbed areas. With Ayodhya witnessing large-scale religious tourism and infrastructural development, greenbelt projects and conservation initiatives may have been introduced to mitigate environmental degradation. Such an increase in forest cover is a positive indicator of sustainable urban planning, but continuous monitoring is necessary to ensure that these green spaces are not lost to future urban expansion.

Similarly, bare land has expanded by 3.35 km² (3.84%), indicating areas that are either under transition for development or left vacant due to policy restrictions or ownership issues. Many of these open spaces may be awaiting urban construction, government projects, or infrastructural enhancements.

In some cases, land previously classified as agricultural may have turned into barren land due to soil degradation, water scarcity, or construction-related disturbances. The rise in bare land must be managed carefully, as such areas could contribute to heat island effects, increased surface runoff, and soil erosion if not utilized effectively.

Waterbodies in Ayodhya have shown a minor decline, reducing from 1.73% in 2014 to 1.55% in 2024, amounting to a net loss of 1.02 km² (1.18%). This reduction in water resources is a cause for concern, as it could indicate groundwater depletion, shrinking riverbanks, or increased encroachments on wetlands and ponds. Rapid urbanization, illegal construction along water bodies, and excessive groundwater extraction may have contributed to this decline. Since the Saryu River plays a crucial role in the city's ecosystem, ensuring sustainable water management practices is essential for maintaining water security and environmental stability.

• **Implications and Future Considerations**

The findings of this study underscore the dynamic interplay between administrative changes and land use and land cover (LULC) transformations in Ayodhya City, revealing significant implications for urban planning, resource management, and environmental sustainability. Recent governance decisions, such as the redesignation of Faizabad district as Ayodhya in 2018 and the 2019 Supreme Court verdict enabling the Ram Mandir construction, have accelerated urban expansion under the Ayodhya Master Plan. These administrative shifts have driven a notable increase in built-up areas, as seen in projects like the widening of Ram Path, the Maharshi Valmiki International Airport, and the redevelopment of Ayodhya Dham Junction Railway Station, fueled by a tourism boom that attracted 110 million visitors by mid-2024 (Wikipedia, 2025). Concurrently, the Ayodhya Development Authority's denotification of land in Majha Jamthara—previously used for Army training—for a temple museum exemplifies how such policies repurpose open spaces, often at the expense of agricultural and natural land covers (The Hindu, 2024). While the study notes a decline in built-up areas in some contexts alongside increases in agricultural and forested land, suggesting a potential policy emphasis on green spaces, the overarching trend of tourism-driven sprawl has increased impervious surfaces, reduced green cover, and raised concerns about water body loss, barren land expansion, and land degradation. These shifts highlight a tension between infrastructure prioritization and sustainable land management, posing challenges to water resource conservation and climate resilience.

Looking ahead, ensuring Ayodhya's sustainable urban development requires proactive measures grounded in these findings. Policymakers should integrate GIS-based monitoring systems to track LULC changes with precision, enabling data-driven decisions that balance development with ecological preservation. Efforts must focus on safeguarding agricultural and forested areas, enhancing urban water conservation through initiatives like rainwater harvesting, and optimizing land use to mitigate degradation and support climate resilience. The loss of water bodies, in particular, demands urgent attention to prevent long-term hydrological stress. Future research could leverage higher-resolution satellite imagery and predictive modeling to dissect the drivers of LULC changes—such as administrative policies, tourism, and population growth—and forecast their impacts on Ayodhya's urban landscape. By aligning administrative actions with sustainable land-use strategies, Ayodhya can evolve as a resilient city that harmonizes its cultural significance with environmental and social well-being.

To ensure sustainable urban development, policymakers and planners must integrate GIS-based monitoring systems to track land-use changes more accurately. Efforts should be directed toward preserving agricultural and forested areas, enhancing urban water conservation, and optimizing land use for balanced development. Additionally, future studies could incorporate higher-resolution satellite imagery and predictive modeling techniques to better understand the drivers of LULC changes and their long-term impacts on Ayodhya's urban landscape.

Conclusion

The study on Land Use Land Cover (LULC) change detection in Ayodhya City (2014–2024) using Remote Sensing and GIS techniques provides valuable insights into the dynamic transformations occurring in the region. The findings reveal a significant shift in land use patterns, with notable increases in agricultural land and forest cover, while built-up areas and waterbodies have shown a decline. These changes reflect the impact of urban expansion, infrastructure development, and environmental conservation efforts in the city.

The most prominent transformation observed is the decline in built-up areas by 15.95%, which could be attributed to reclassification, redevelopment, or shifts in urban planning policies. At the same time, agricultural land has increased by 7.18%, indicating a potential land conversion for cultivation or temporary shifts in land-use classification. Additionally, the growth in forest cover by 6.09% suggests the effectiveness of afforestation programs and green space conservation efforts, contributing to a more balanced urban ecosystem. However, the reduction in waterbodies by 1.18% is a concerning trend, highlighting the need for improved water resource management and conservation policies.

The integration of Remote Sensing and GIS techniques has proven highly effective in monitoring these changes, providing accurate and spatially explicit data for urban planning and environmental management. The results underscore the importance of sustainable land-use strategies to balance development with resource conservation. Moving forward, policymakers and urban planners must focus on maintaining ecological stability, preserving water resources, and promoting sustainable urban expansion to ensure Ayodhya's long-term environmental and socio-economic well-being. Future research could incorporate higher-resolution satellite imagery, predictive modeling, and machine learning approaches for more precise monitoring and forecasting of LULC changes.

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