International Journal of Science and Social Science Research

ISSN: 2583-7877 Peer Reviewed & Refereed Journal

Page No: 155-166 DOI: https://doi.org/10.63671/ijsssr.v4i1.602

Volume: 4 | Issue: 1
April-June 2026

Trend Analysis of Land Use and Land Cover (LULC) along the Ganga River Corridor (2 Km Buffer) of Prayagraj City during 1985- 2025

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Abstract—This study focuses on the analysis of Land Use and Land Cover (LULC) changes in Prayagraj over the period 1985–2025 using a 2 km buffer zone approach along the ganga river corridor. LULC assessment plays an important role in understanding patterns of urban growth, environmental change, and regional development planning. The study classifies the area into four major categories: water bodies, agricultural land, built-up land, and sandy areas. A comparative analysis across different decades shows significant changes in land utilization patterns. The built-up area expanded considerably from 76.22 km² in 1985 to 387.26 km² in 2025, indicating rapid urbanization and increasing population pressure. In contrast, agricultural land experienced a continuous decline over the study period from 1231.73 to 902.14. Water bodies also showed a slight decrease, shrinking from 55.13 km² to 51.01 km², whereas sandy areas increased from 151.07 km² to 173.74 km². These transformations reflect growing human intervention around the river corridor and emphasize the importance of sustainable urban development and effective riverfront management practices in the region.

Keywords: Land Use Land Cover (LULC), Environmental Change, Urbanization, Remote Sensing, GIS, Prayagraj, Multi-buffer Analysis, River Corridor.

I. INTRODUCTION

Land Use and Land Cover (LULC) analysis is widely used in geographical and environmental studies to understand changes occurring on the Earth's surface over time. It helps in identifying how natural landscapes and human activities are transforming different regions (Gaur et al., 2020). Land cover mainly represents the physical features found on the land surface, such as forests, vegetation, rivers, barren land, and built-up areas (Regasa et al., 2021). On the other hand, land use explains how people utilize the land for various purposes like agriculture, housing, transportation, and industrial activities (Shah et al., 2017; Kumar et al., 2018). Although both terms are closely related, land cover focuses more on natural and physical conditions, while land use reflects human activities and socio-economic needs.

In recent decades, rapid growth in population, urban expansion, and infrastructure development have brought major changes in land patterns across many regions of the world (Gupta et al., 2024). Agricultural activities have also intensified to meet increasing human demands, resulting in continuous modification of natural landscapes (Dadashpoor et al., 2029). These changes have created several environmental challenges, including loss of biodiversity, degradation of soil quality, reduction in water resources, and changes in local climate conditions (Sharma et al., 2022; Mir et al., 2025). Because of these reasons, LULC studies have become important for understanding environmental transformations, examining the relationship between humans and nature, and supporting proper land management and sustainable planning.

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II. STUDY AREA

The study focuses on Prayagraj city, which is located in the northern Indian state of Uttar Pradesh. The city is widely recognized for the Triveni Sangam, the meeting point of the Ganga and Yamuna rivers along with the legendary Saraswati river. Prayagraj functions as the district headquarters of Prayagraj district and holds significant cultural and historical importance. Geographically, it is situated between 81°43′20″ E and 81°53′30″ E longitudes and 25°23′00″ N and 25°32′00″ N latitudes. As reported by the Municipal Corporation (2024), the city covers an area of approximately 365 square kilometres. The average elevation of the study area is around 98 metres above mean sea level.

III. OBJECTIVE

The main objective of this study is to examine the changes in Land Use and Land Cover (LULC) within the Ganga river corridor of Prayagraj city during the years 1985, 1995, 2005, 2015, and 2025. By analysing these five time periods, the research attempts to understand the pattern of landscape transformation that has taken place over the last four decades. The study also seeks to provide useful insights for land use planning, environmental management, and sustainable utilization of natural resources in the region.

IV. METHODOLOGICAL FRAMEWORK OF LULC IN THE STUDY

To examine Land Use and Land Cover (LULC) changes during the period 1985–2025, the study applies a geospatial approach integrating Remote Sensing and Geographic Information System (GIS) techniques. The methodology includes data collection, image pre-processing, classification, accuracy assessment, change detection, and spatial analysis. Multi-temporal satellite imagery was collected at decadal intervals for the years 1985, 1995, 2005, 2015, and 2025 (Figure 4.1). The satellite datasets were obtained from two open-access sources: the USGS Earth Explorer and the Copernicus Open Access Hub.

Different satellite sensors were selected according to data availability for each period. Landsat 5 Thematic Mapper (TM) imagery was used for 1985 and 1995, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for 2005, Landsat 8 Operational Land Imager (OLI) for 2015, and Sentinel-2 Multispectral Instrument (MSI) for 2025. The spatial resolution of the datasets ranges between 10 and 30 metres, which is appropriate for regional-scale LULC analysis.

To maintain consistency in classification and reduce the influence of seasonal variations, the satellite images were selected mainly from the dry season with minimal cloud cover. This helped in improving comparability among all study years. Land use and land cover classification was carried out using a supervised classification method based on the Maximum Likelihood Classifier (MLC). The MLC is a statistical classification technique that assigns image pixels to the class with the highest probability based on spectral characteristics of the training samples.

V. TREND ANALYSIS OF LULC IN PRAYAGRAJ FROM 1985 TO 2025

The analysis of Land Use and Land Cover (LULC) changes from 1985 to 2025 shows noticeable transformations in the landscape of Prayagraj over the last four decades. Using multi-temporal satellite imagery and supervised classification techniques, four major LULC categories were identified for five different years—1985, 1995, 2005, 2015, and 2025. These categories include Waterbody, Agricultural Land, Built-up Land, and Sandy Area.

The results indicate considerable variation in the spatial distribution of these land cover classes during the study period. Among all categories, the most prominent changes were observed in built-up land, agricultural land, and sandy areas, reflecting increasing urban expansion and changing land use patterns in the region. Detailed information regarding the extent and variation of each category is presented in Table 1 and illustrated in (Figure 6).

Table: 1. LULC categories wise area in km2 and percentage (%) from 1985 to 2025

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LULC Category	1985 Area (km²)	1985 Area (%)	1995 Area (km²)	1995 Area (%)	2005 Area (km²)	2005 Area (%)	2015 Area (km²)	2015 Area (%)	2025 Area (km²)	2025 Area (%)
Waterbody	55.13	3.64	34.74	2.29	35.44	2.3	52.07	3.4	51.01	3.37
Agricultural	1231.73	81.35	1213.66	80.15	1102.31	72.8	958.12	63.3	902.14	59.58
Built-up land	76.22	5.03	90.11	5.95	198.79	13.1	331.18	21.9	387.26	25.58
Sandy area	151.07	9.98	175.64	11.6	177.85	11.7	173.02	11.4	173.74	11.47

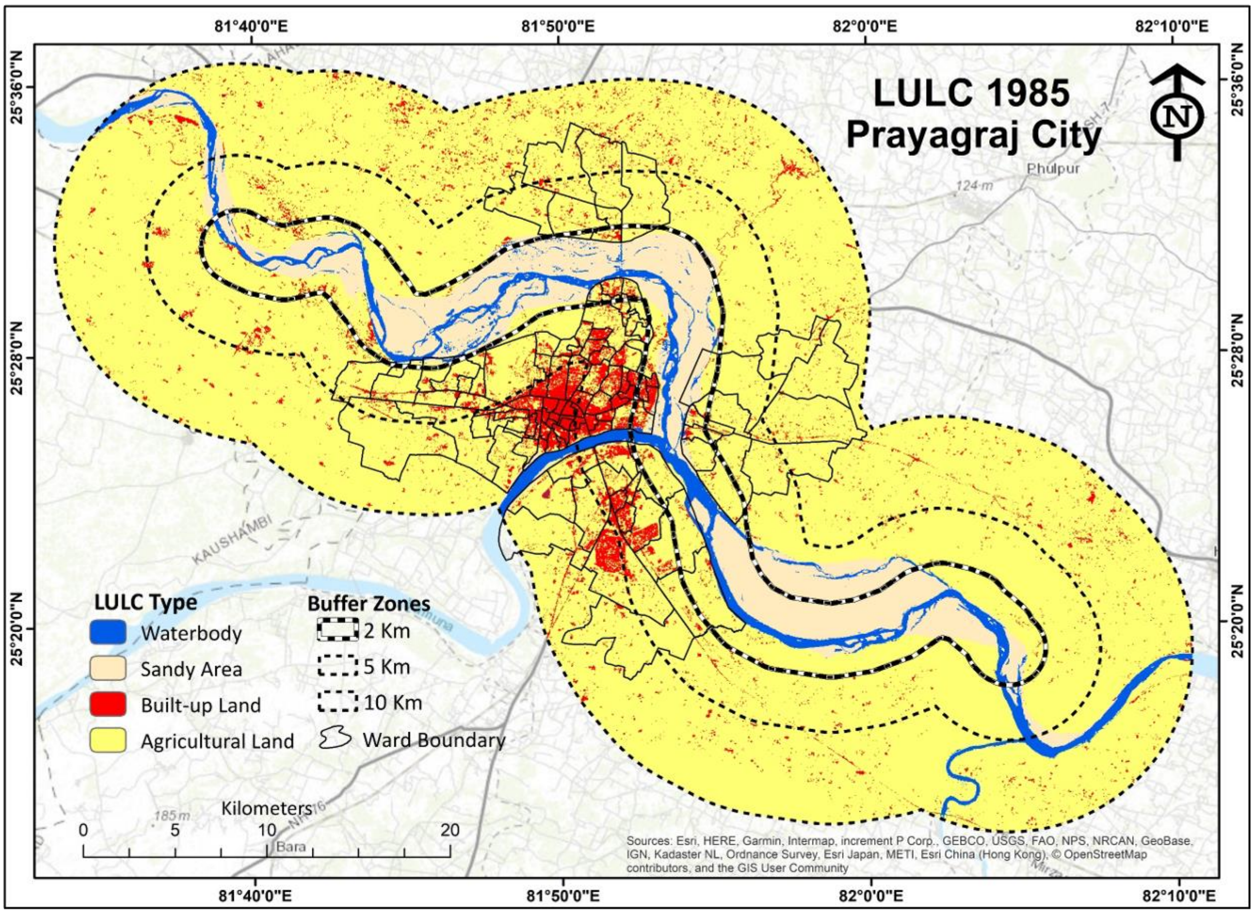

Figure 1: Showing the landuse/landcover distribution of Prayagraj for the year 1985 in multi buffers (2km, 5km and 10 km from the river).

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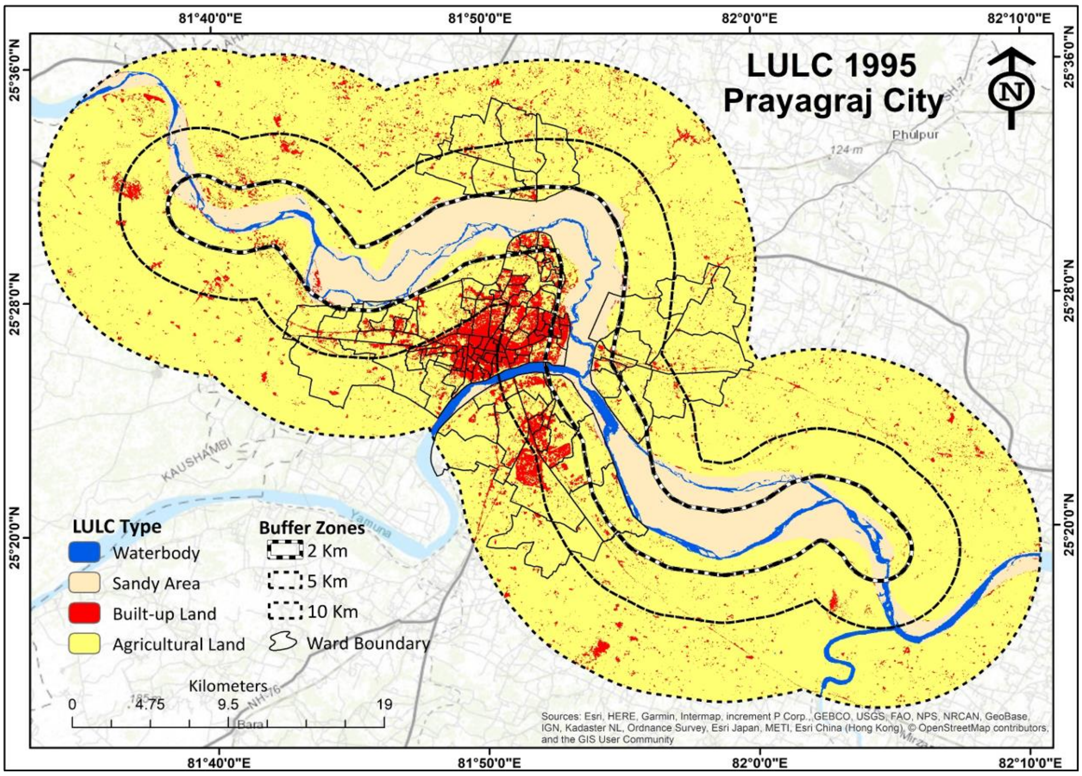

Figure 2. Showing the landuse/landcover distribution of Prayagraj in multi buffers (2km, 5km and 10 km from the river) for the year 1995.

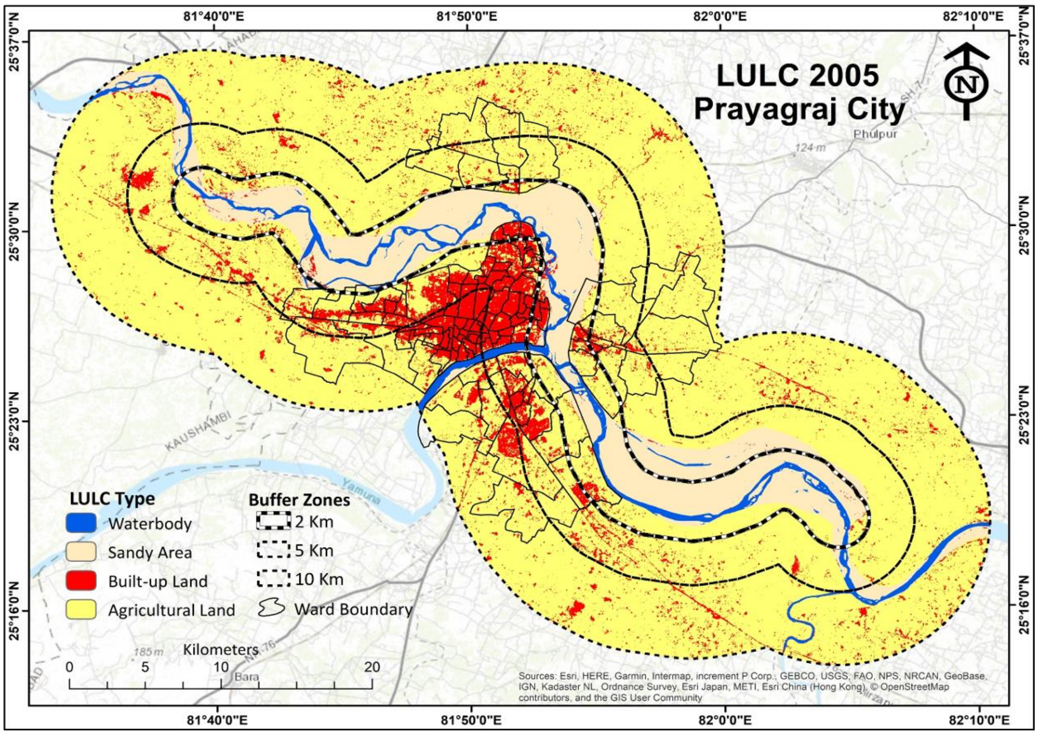

Figure 3. Showing the landuse/landcover distribution of Prayagraj in multi buffers (2km, 5km and 10 km from the river) for the year 2005.

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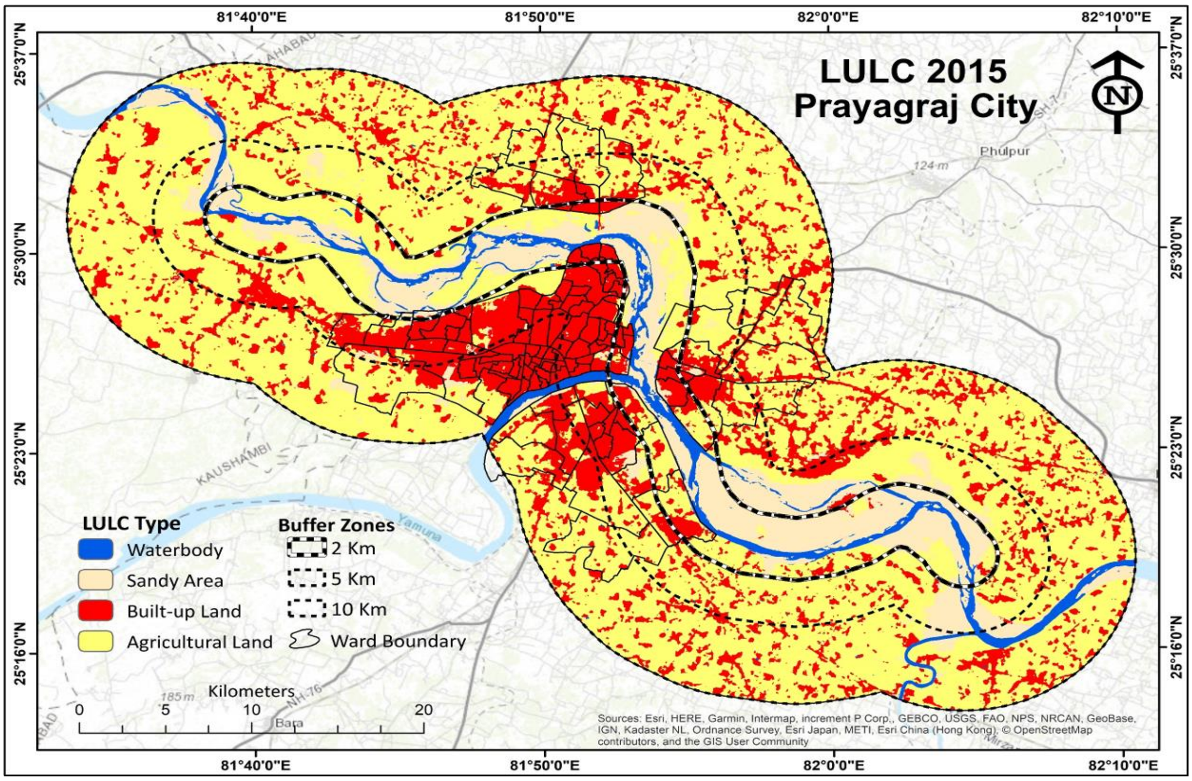

Figure 4. Showing the landuse/landcover distribution of Prayagraj in multi buffers (2km, 5km and 10 km from the river) for the year 2015.

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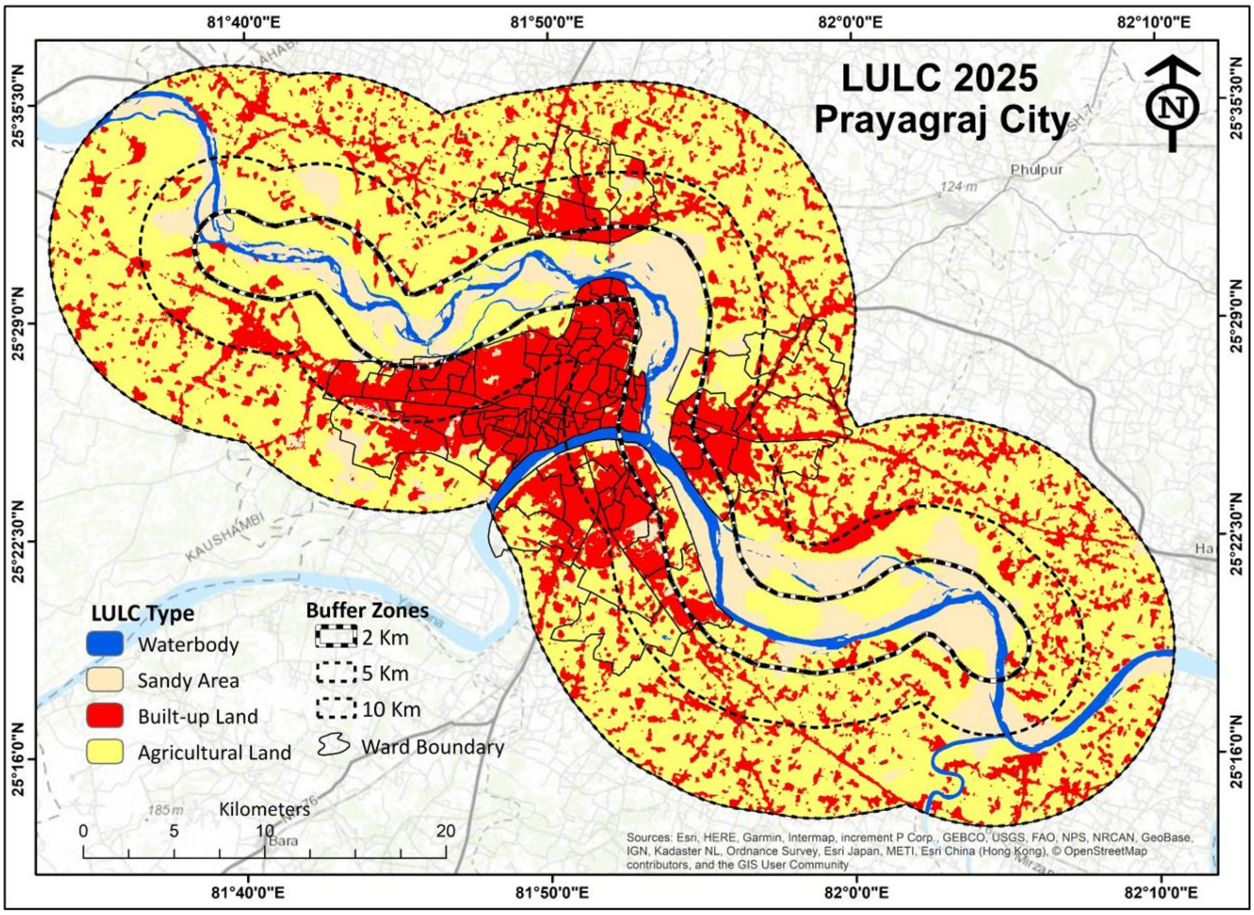

Figure 5. Showing the landuse/landcover distribution of Prayagraj in multi buffers (2km, 5km and 10 km from the river) for the year 2025.

V.I. TREND IN AGRICULTURAL LAND FROM 1985-2025

It was the most predominant land use category during the entire study period, with a consistent and progressive decreasing pattern across the five temporal periods. The maximum proportion of agricultural land (81.35%) has been recorded in 1985 for the total study area. The reduction was small in the first decade (1985-1995) when agricultural extent declined from 1,213.66 km2 (80.15%), indicating some relative stability and low conversion pressure during this time. This initial near-stationarity can be interpreted as an indication that the area was mainly agrarian before the arrival of major infrastructural investments and urbanization next 30 years marked a significant increase in the rate of land degradation in agriculture, though, in a continuous manner. The area under agriculture in 2005 was 1,102.31 km2 (72.80%) which has decreased by about 111.35 km2 in a decade, nearly six times more than lost during the previous decade. This pattern persisted in 2015, when agricultural area further declined to 958.12 km2 (63.28%), and again in 2025, when a record low was recorded at 902.14 km2 (59.58%) (Table 4.7 and Figure 4.12). The agricultural land category experienced the highest absolute decrease in size over the entire period of study, with a decrease of 329.59 km2 land area (Figure 4.13 & 4.14). Loss of agricultural land is mainly due to the lateral spread of the urban growth, which progressively occupied productive agricultural land, following population growth, increasing land demand, and infrastructure proliferation. The pattern of agriculture decline from this study is therefore not just a local land use problem but a wider structural shift that would have implications for regional food security, rural livelihoods and ecological services.

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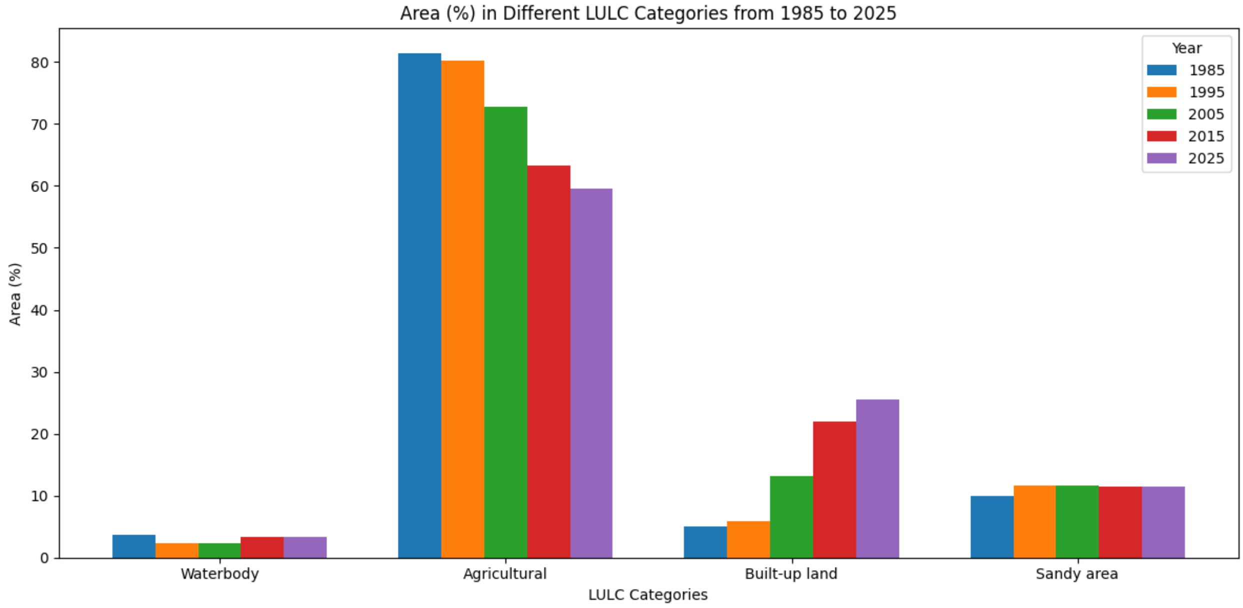

Figure 6. Showing the area (in %) under various landuse/landcover categories and its trend from 1985 to 2025.

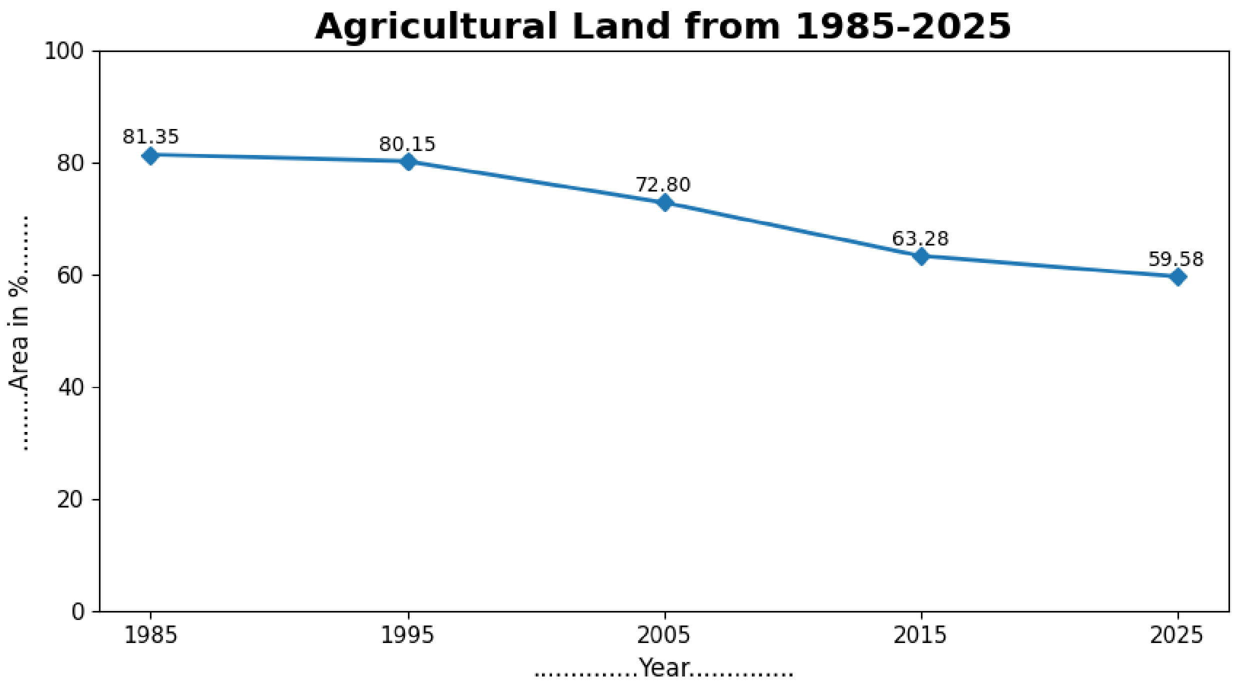

Figure 7. Showing the area (in %) under agricultural land category of LULC classification and its trend from 1985-2025

V.II. TREND IN BUILT-UP LAND FROM 1985-2025

The built-up land showed the most noticeable, uniform, and widespread increase for all LULC categories during the study period and acted as the most dominant force in shaping landscape change patterns in the study area. The area under built-up coverincreased by 13.89 km2 in the first decade (from 76.22 km2 in 1985 to 90.11 km2 in 1995), indicating a relatively slow rate of urbanization. During the next period, the rate of urban growth accelerated dramatically (Table 4.7 & Figure 4.15). The extent of built- up area has increased by more than two times to 198.79 km2 (13.13%) by 2005, rising by 108.68 km2 in ten years, which is almost eight times the growth over the previous decade (Figure 4.15). This period of quick expansion is probably

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a reflection of the interplay between the effects of economic liberalization, better road and transportinfrastructure, and greater housing demand through demographic transition.The upward trajectory continued steeply through 2015, when built-up areareached 331.18 km2 (21.87%), and further expanded to 387.26 sq. km (25.58%) by 2025 (Figure 4.15). The net increase over the 40-year period of study was 311.04 km2, an almost 5-fold increase in absolute area and proportion of the study area, and the most marked positive change in the study area. The spatial character of the built-up expansion is similar to the pattern of expansion that is evident in many of the peri-urban areas and rapidly growing secondary cities in India, where urban development pressures gradually penetrate into the agriculture and peri-urban landscapes around core urban centers (Dutta, 2012). This trend has been monotonic and accelerating, and appears to have no leveling off point or inflection point, indicating continued built-up expansion in the near future with potentially devastating impacts on the remaining agricultural land base and regional ecosystem functions.

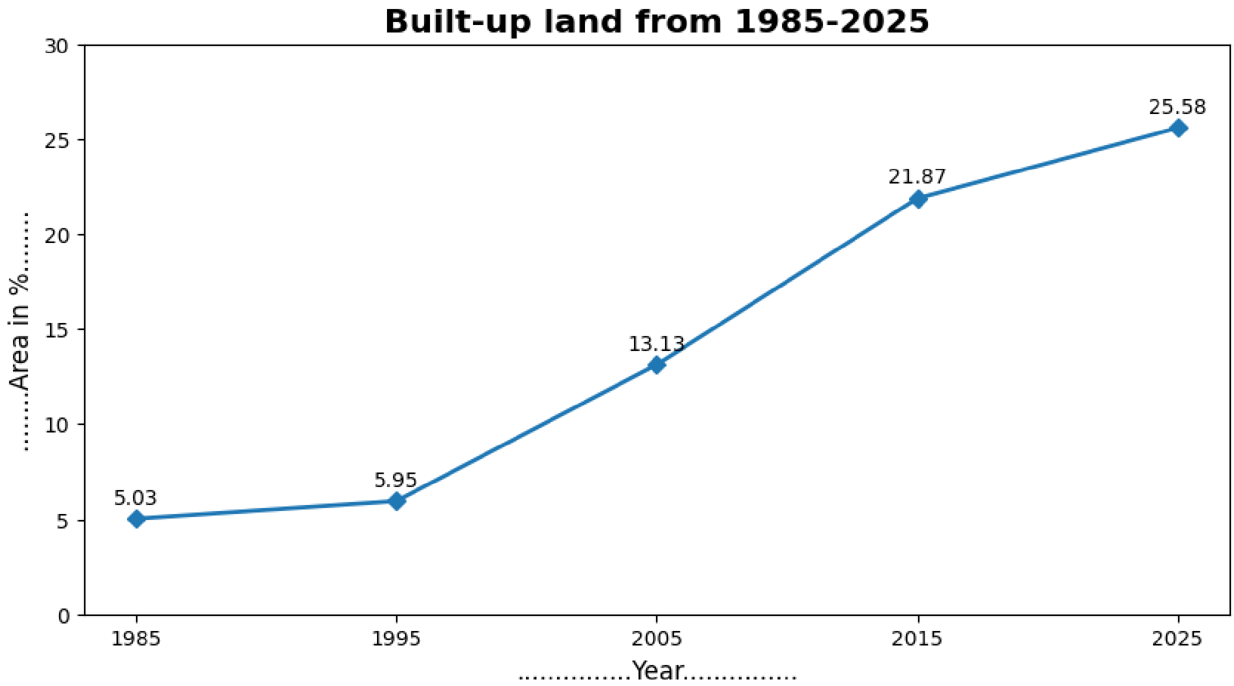

Figure 8. Showing the area (in %) under built-up category of LULC classification.

V.III. TREND IN WATERBODY CATEGORY FROM 1985-2025

The area under water bodies experienced uneven changes throughout the study period, showing both decline and fluctuation over time. These variations can be linked to factors such as changing climatic conditions, increasing human interference, excessive extraction of water resources, alterations in surrounding land use, and sediment deposition within river channels and wetlands. In 1985, water bodies covered nearly 55.13 km², representing about 3.64% of the total study area. This was the highest recorded extent during the entire period and indicated relatively balanced hydrological conditions in the region.

A noticeable reduction in waterbody coverage was observed during the following decade. By 1995, the total area had declined to 34.74 km², accounting for only 2.29% of the study area. This reflects a decrease of around 20.39 km² within ten years. The shrinking of water bodies may be attributed to rapid agricultural expansion, increased groundwater withdrawal, encroachment near riverbanks, and developmental activities around aquatic zones. In addition, silt accumulation and reduced natural recharge within the catchment area may also have contributed to the decline in surface water extent.

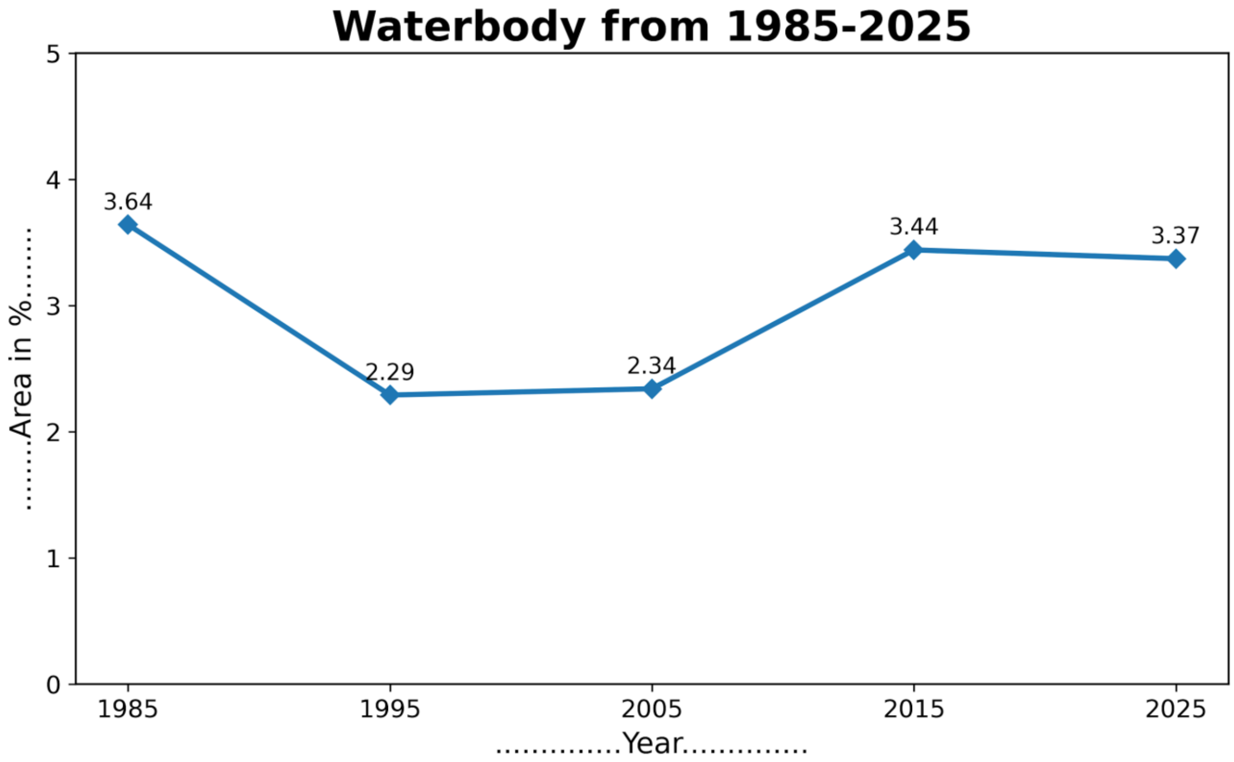

Figure 9. Showing the area (in %) under waterbody category of LULC classification and its trend from 1985-2025.

A slight improvement in waterbody coverage was recorded by 2005, when the total area increased marginally to 35.44 km², representing about 2.34% of the study area. However, the increase was relatively small and may have been influenced by yearly variations in rainfall and surface water conditions during the time of satellite image acquisition. A more noticeable recovery occurred during the period from 2005 to 2015, when the extent of water bodies expanded to 52.07 km² (3.44%). Although this value remained slightly lower than the 1985 level, it indicated a significant improvement in the hydrological condition of the area. This recovery may be associated with improved water management practices, implementation of rainwater harvesting measures, or favorable climatic conditions that supported greater surface water retention during this period.

After 2015, a minor decline was again observed. By 2025, the waterbody area had slightly reduced to 51.01 km², accounting for around 3.37% of the total study area. Overall, the net decrease in waterbody extent during the entire forty-year period was relatively small, amounting to about 4.12 km². Despite this limited overall decline, the strong fluctuations observed between decades are environmentally significant, as they reflect the sensitivity of the hydrological system to both human activities and climatic variations. With increasing urban expansion, rising water demand, and future climate-related stress, water bodies in the region may become more vulnerable, highlighting the need for continuous monitoring and sustainable conservation measures.

V.IV. TREND IN SANDY AREA CATEGORY FROM 1985-2025

The spatial and temporal assessment of sandy areas indicates that this land cover category remained comparatively stable throughout the study period, with only moderate changes observed between different decades. In 1985, sandy areas occupied about 151.07 km², accounting for nearly 9.98% of the total study area. During the following years, the extent of sandy surfaces gradually increased, reaching 175.64 km² (11.60%) in 1995 and further expanding to 177.85 km² (11.75%) in 2005, which represented the maximum recorded coverage during the entire study period.

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After 2005, a slight decline in sandy area was observed. The coverage decreased to 173.02 km² (11.43%) in 2015 and later remained almost stable at 173.74 km² (11.47%) in 2025. Overall, between 1985 and 2025, sandy areas showed a net increase of approximately 22.67 km², indicating a moderate expansion within the regional landscape. Compared to other LULC categories such as built-up land and agricultural land, sandy areas experienced relatively less transformation, suggesting lower sensitivity to rapid land use changes.

The increase in sandy surfaces during the period from 1985 to 2005 may be associated with both natural and human-induced factors. Processes such as river sediment deposition, wind erosion, deforestation, and the abandonment of marginal agricultural lands may have contributed to the exposure and spread of sandy surfaces. In riverine and alluvial environments, hydrological changes and sediment transport play a major role in the redistribution and accumulation of sandy deposits.

The period after 2005 reflects a comparatively stable condition, indicating the development of a balance between natural geomorphic processes and human activities. Sandy areas are generally less suitable for intensive agriculture and urban development because of their poor water retention capacity, high permeability, and vulnerability to erosion. As a result, large-scale conversion of these areas into other land-use categories remained limited throughout the study period.

From an environmental perspective, the persistence of sandy terrain highlights the influence of fluvial and depositional processes within the regional geomorphic system. These sandy surfaces also function as transitional ecological zones that are sensitive to hydrological variation, sediment movement, and land degradation processes. Therefore, sandy areas form an important component of the landscape structure and contribute significantly to the environmental and geomorphological characteristics of the study region.

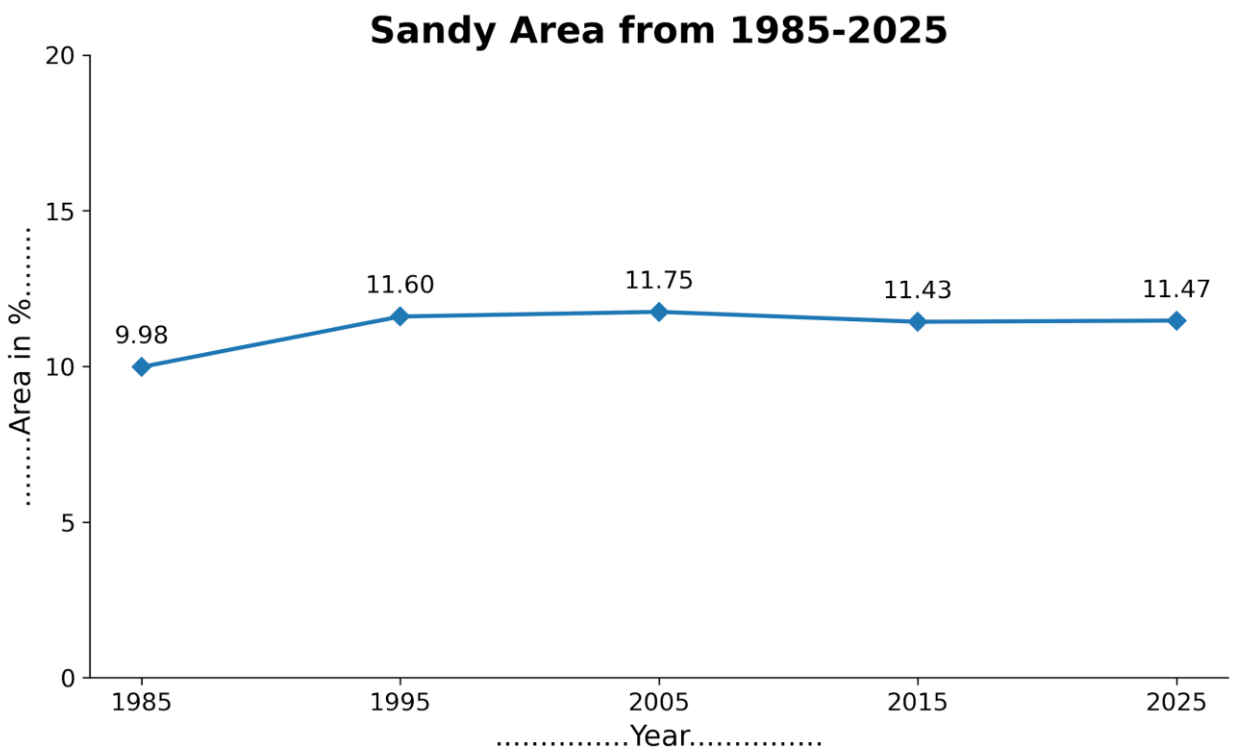

Figure 10. Showing the area (in %) under sand area category of LULC classification and its trend from 1985-2025.

V.V. EFFECT OF SPATIO-TEMPORAL CHANGES IN FLUVIAL MORPHOLOGY ON THE LANDSCAPE OF PRAYAGRAJ CITY

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The changing fluvial morphology of the Ganga River has played an important role in reshaping the landscape of Prayagraj city over the last four decades. Natural fluvial processes such as riverbank erosion, channel shifting, sediment deposition, floodplain alteration, and sandbar development have continuously modified the geomorphology of the river corridor. These changes have directly influenced patterns of land use, settlement growth, and urban expansion in the surrounding areas.

The LULC analysis carried out for the period 1985–2025 shows major changes in the regional landscape. Built-up land increased rapidly from 76.22 km² in 1985 to 387.26 km² in 2025, while agricultural land declined considerably from 1231.73 km² to 902.14 km² during the same period. This trend reflects increasing urbanization and expansion of settlements over environmentally sensitive floodplain regions. Changes in sandy areas and the disturbance of natural drainage systems further indicate growing human pressure on active riverine landscapes.

These geomorphic and land-use transformations have created several environmental concerns, including higher flood risk, instability along riverbanks, degradation of natural ecosystems, and loss of fertile alluvial land. Rapid development near river corridor has also disturbed natural hydrological processes, reduced groundwater recharge potential, and negatively affected riparian ecology. The spatial growth of urban areas visible in recent LULC maps, particularly for 2015 and 2025, clearly demonstrates the conversion of natural floodplain surfaces into densely built-up zones. As a result, the changing fluvial morphology of the Ganga River has become a significant factor influencing the present-day urban structure, environmental conditions, and socio-economic development of Prayagraj city.

VI. CONCLUSION

The analysis of spatio-temporal changes in fluvial morphology and Land Use/Land Cover (LULC) patterns reveals that Prayagraj city has experienced substantial landscape transformation between 1985 and 2025. The combined influence of river dynamics and human activities has significantly altered the physical, ecological, and socio-economic environment of the region. The 2km buffer LULC analysis highlights rapid expansion of built-up areas, reduction in agricultural land, modification of floodplain surfaces, and variations in waterbody and sandy areas along the Ganga and Yamuna River corridors.

Increasing urban encroachment into ecologically fragile floodplain zones has intensified environmental problems such as flooding, drainage congestion, riverbank erosion, and ecological degradation. At the same time, natural fluvial processes including erosion, deposition, sedimentation, and channel migration continue to shape the river landscape of Prayagraj.

The study emphasizes the need for sustainable management of river corridors, floodplain areas, agricultural land, and urban growth in order to maintain environmental balance and minimize future risks. In this context, an integrated planning approach based on GIS and Remote Sensing techniques, floodplain zoning, ecological conservation, and controlled urban development is essential for sustainable and resilient urban growth. Such scientifically informed strategies can support balanced socio-economic development while preserving the dynamic riverine environment and ecological stability of Prayagraj city.

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