

Spatio-Temporal Dynamics of Urban Expansion and Ecological Vulnerability in Mysore, India

Running title: Urban expansion and ecological vulnerability in Mysore

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Abstract

Urban expansion is a major driver of environmental transformation in rapidly growing cities. This study evaluates the spatio-temporal dynamics of urban growth and associated ecological vulnerability in Mysore, India, between 2000 and 2024 using remote sensing and geospatial analysis. Multi-temporal Landsat imagery and Bhuvan datasets were used to generate land use/land cover maps through supervised classification, while vegetation condition was assessed using the Normalized Difference Vegetation Index (NDVI). Results reveal that built-up area increased from 10% in 2000 to 35% in 2024, accompanied by a decline in vegetation cover from 70% to 45%. NDVI values decreased from 0.65 to 0.45, indicating progressive vegetation degradation. Correlation analysis demonstrated a strong inverse relationship between urban expansion and ecological indicators. Regression-based projections suggest that built-up land may exceed 50% by 2040, with green space declining below recommended thresholds. The findings highlight intensifying thermal stress, degradation of urban ecosystems, and increasing ecological vulnerability. The study emphasizes the need for climate-sensitive urban planning, green infrastructure development, and geospatial monitoring to support sustainable urban growth in emerging Indian cities.

Keywords: Urban expansion; Ecological vulnerability; Remote sensing; GIS; NDVI; Land use/land cover; Urban heat island; Sustainable urban planning; Mysore, India

1. Introduction

Urbanization is widely recognized as one of the most significant anthropogenic processes reshaping natural landscapes and Earth system functions (Seto *et al.* 2012). Rapid conversion of vegetated and agricultural land into impervious urban surfaces alters surface energy balance, hydrological processes, carbon cycling, and biodiversity patterns, thereby increasing ecological vulnerability (Grimm *et al.* 2008; Foley *et al.* 2015). These impacts are particularly pronounced in

developing countries, where urban expansion often occurs at rates exceeding institutional and environmental management capacities.

Remote sensing and geographic information system (GIS) techniques have become essential tools for analyzing urban growth and its environmental consequences. Multi-temporal satellite imagery enables consistent assessment of land use/land cover (LULC) dynamics across extended time periods, allowing researchers to quantify spatial transformation and identify urban growth trajectories (Lu *et al.* 2014). Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) are extensively used to evaluate vegetation health and ecosystem condition, serving as reliable indicators of ecological stress within urban and peri-urban environments (Pettorelli *et al.* 2014; Xie *et al.* 2019).

India is currently undergoing rapid urban transition, with urban populations projected to increase substantially over the coming decades (UN-Habitat 2022). While metropolitan regions such as Delhi, Mumbai, and Bengaluru have received considerable research attention, mid-sized cities remain comparatively underexplored. These cities frequently exhibit dispersed urban growth, fragmented green spaces, and increasing pressure on natural resources, making them particularly susceptible to ecological degradation (Ramachandra *et al.* 2015; Taubenböck *et al.* 2020).

Mysore, a prominent mid-sized city in southern India, represents an important example of such urban transformation. Historically characterized by extensive green cover and interconnected lake systems, the city has experienced rapid land conversion driven by population growth, tourism development, and industrial expansion. Urban sprawl toward peripheral zones has intensified pressure on vegetation, water bodies, and local microclimatic conditions. Previous studies in the region have examined specific environmental components such as lake water quality and soil erosion independently (Yogesh 2016; Chandan and Harisha 2020); however, integrated assessments combining long-term land cover change, vegetation dynamics, and ecological vulnerability remain limited.

Recent urban sustainability research emphasizes the need for integrated and resilience-based analytical frameworks that combine spatial, ecological, and predictive approaches (Meerow *et al.* 2016; Elmquist *et al.* 2019). Such integrated assessments are essential for identifying cumulative environmental impacts and supporting evidence-based urban planning. In this context, the present study aims to evaluate the spatio-temporal dynamics of urban expansion and ecological vulnerability in Mysore from 2000 to 2024 using remote sensing, GIS, and statistical modeling approaches. The findings are expected to provide valuable insights for sustainable urban planning and climate-resilient development in rapidly growing mid-sized cities.

The primary objective of the present study was to evaluate the spatio-temporal dynamics of urban expansion and associated ecological vulnerability in Mysore, India, over a 24-year period (2000-2024) using integrated remote sensing and geospatial modeling techniques. Specifically, the study aimed to analyze land use and land cover (LULC) changes, assess vegetation dynamics through the Normalized Difference Vegetation Index (NDVI), and examine the relationship between urban growth and key environmental indicators such as vegetation loss, thermal stress, and ecosystem degradation. In addition, statistical correlation and regression-based modeling were employed to project future urban expansion trends and potential decline in green space availability, thereby providing scientific insights to support climate-sensitive urban planning and sustainable development strategies in rapidly growing mid-sized cities.

2. Materials and Methods

2.1 Study area

Mysore is located in southern Karnataka, India, between 12.25°-12.35° N latitude and 76.55°-76.70° E longitude. The city covers approximately 128 km² and lies on the Deccan Plateau at an average elevation of about 770 m above mean sea level. The climate of the region is classified as tropical savanna, characterized by moderate temperatures and an average annual rainfall of 780-850 mm.

The study area comprises a heterogeneous landscape including dense urban settlements, peri-urban agricultural land, forest fragments, and interconnected lake systems. Ecologically sensitive regions such as the Chamundi Hills and

surrounding green corridors significantly influence the city's environmental stability. Rapid population growth, infrastructure development, and tourism-driven expansion during the past two decades have resulted in substantial land transformation, making Mysore a suitable case for assessing urban expansion and ecological vulnerability.

2.2 Data sources

Multi-temporal satellite datasets were used to analyze land use and vegetation dynamics for the years 2000, 2010, and 2024. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery with a spatial resolution of 30 m was obtained from the United States Geological Survey (USGS) EarthExplorer platform (USGS 2023). To support classification accuracy and land cover validation, reference datasets were acquired from the Bhuvan Spatial Information Support for Decentralized Planning (SISDP) Phase I and Phase II portals developed by the Indian Space Research Organisation (ISRO 2022). Ancillary spatial data, including administrative boundaries and transportation networks, were collected from publicly available governmental sources. All datasets were projected to the Universal Transverse Mercator (UTM) coordinate system using the WGS-84 datum to ensure spatial consistency.

2.3 Image preprocessing

Prior to analysis, satellite images underwent standard preprocessing procedures to minimize radiometric and atmospheric distortions. Atmospheric correction was applied to reduce scattering effects, while cloud-affected pixels were masked using quality assessment bands. Individual scenes were mosaicked and clipped to the study area boundary. Geometric correction and co-registration were performed to ensure spatial alignment between temporal datasets, which is essential for accurate change detection analysis (Jensen 2016; Lu *et al.* 2014). All satellite images were selected from dry-season periods to minimize the influence of seasonal vegetation variability.

2.4 Land use/land cover classification

Land use and land cover (LULC) mapping was conducted using a supervised classification approach based on the Maximum Likelihood Algorithm. This classifier was selected due to its statistical robustness and widespread application in urban land cover studies (Foody 2002). Training samples were generated for four dominant land cover classes: vegetation, built-up area, water bodies, and open or barren land. Post-classification refinement was carried out using visual interpretation and neighborhood filtering to reduce classification noise. LULC change detection was performed through post-classification comparison, allowing quantification of land conversion patterns across different time periods (Congalton and Green 2019).

2.5 Vegetation assessment using NDVI

Vegetation condition and spatial greenness patterns were evaluated using the Normalized Difference Vegetation Index (NDVI), which is widely applied for assessing vegetation health and ecological condition (Pettorelli *et al.* 2014). NDVI was computed using the standard formula:

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$$

where NIR represents the near-infrared band and Red denotes the red band of Landsat imagery.

NDVI values range from -1 to $+1$, with higher positive values indicating dense vegetation cover. NDVI maps were generated for all study years to examine spatial and temporal variations in vegetation condition associated with urban expansion (Xie *et al.* 2019).

2.6 Accuracy assessment

Classification accuracy was assessed using reference land cover data obtained from Bhuvan datasets and high-resolution Google Earth imagery. Confusion matrices were generated to calculate overall classification accuracy and the Kappa

coefficient. An overall accuracy greater than 85% was considered acceptable for reliable interpretation of spatial patterns (Congalton and Green 2019).

2.7 Environmental indicators and statistical analysis

Ecological vulnerability was evaluated by integrating multiple environmental indicators, including vegetation loss, water quality trends, soil erosion susceptibility, and urban heat stress. Secondary datasets related to water quality indices and soil erosion rates were obtained from published regional studies (Yogesh 2016; Chandan and Harisha 2020).

Pearson correlation analysis was applied to quantify relationships between urban expansion and ecological indicators. Linear regression modeling was used to project future urban growth and green space decline based on historical land cover trends. Statistical analyses were conducted using SPSS and Microsoft Excel, while spatial analyses were performed using ArcGIS 10.8 (ESRI, USA) and ERDAS Imagine (Hexagon Geospatial, USA).

2.8 Methodological framework

A structured analytical workflow was adopted, including data acquisition, preprocessing, LULC classification, NDVI computation, accuracy assessment, statistical modeling, and interpretation. This integrated framework enabled consistent assessment of urban expansion and ecological vulnerability across temporal scales.

3. Results and Discussion

3.1 Spatio-temporal land use and land cover dynamics

The land use and land cover (LULC) classification results reveal substantial spatial transformation in Mysore between 2000 and 2024 (Fig. 1). A pronounced conversion of vegetated and agricultural land into built-up areas was observed, reflecting rapid urban expansion during the study period (Fig. 2).

Vegetation cover declined from approximately 70% of the total area in 2000 to 60% in 2010 and further to 45% by 2024 (Fig. 3 and 4). In contrast, built-up land increased markedly from 10% in 2000 to nearly 35% in 2024. Water bodies exhibited a moderate decline from 20% to 15%, indicating increasing anthropogenic pressure on urban aquatic systems.

These patterns demonstrate a shift from compact urban development toward dispersed peri-urban growth, particularly along transportation corridors and industrial zones. Similar trends have been documented in other Indian cities experiencing rapid socio-economic transformation (Ramachandra *et al.* 2015; Taubenböck *et al.* 2020).

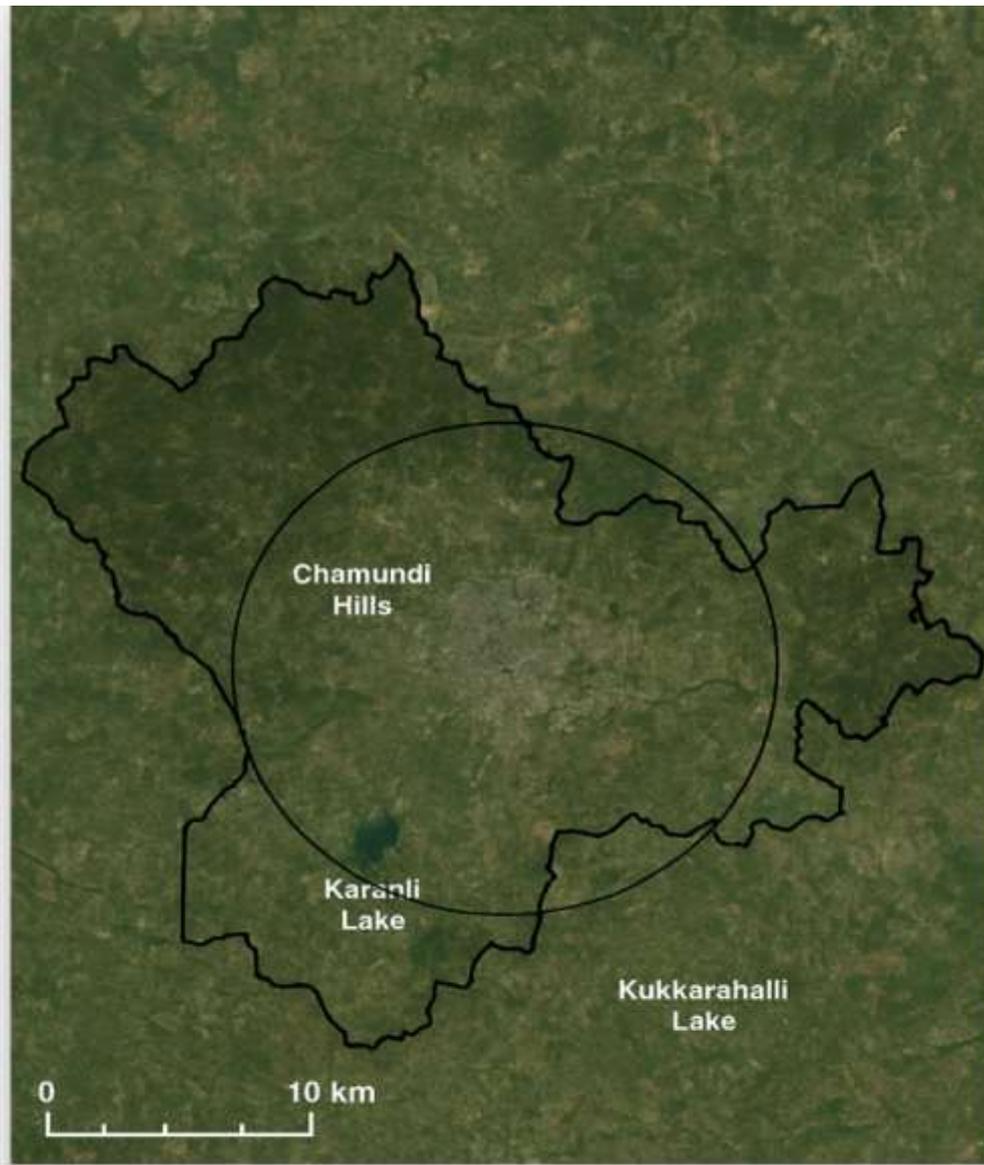


Figure 1. Location map of Mysore city, Karnataka, India, showing the geographical extent of the study area and major administrative boundaries.

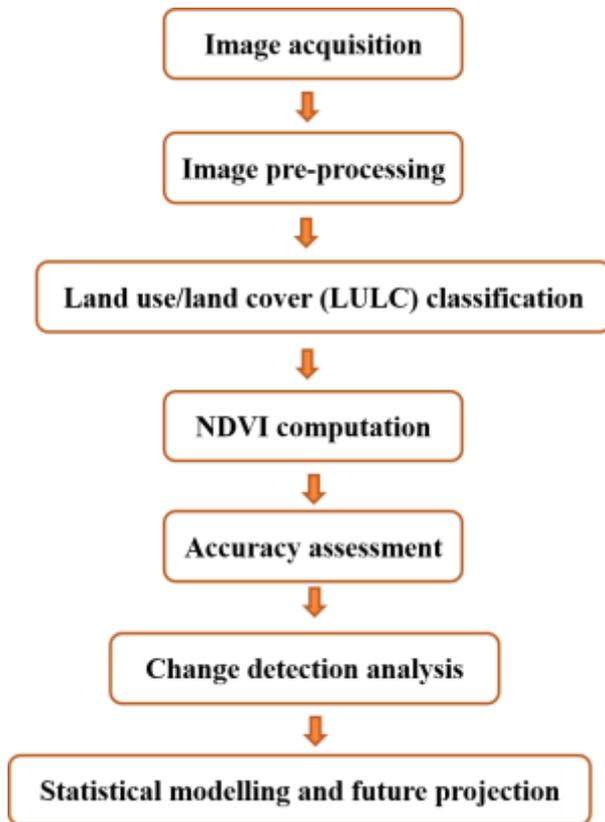


Figure 2. Methodological workflow adopted for satellite data processing, land use classification, vegetation assessment, and urban growth modelling.

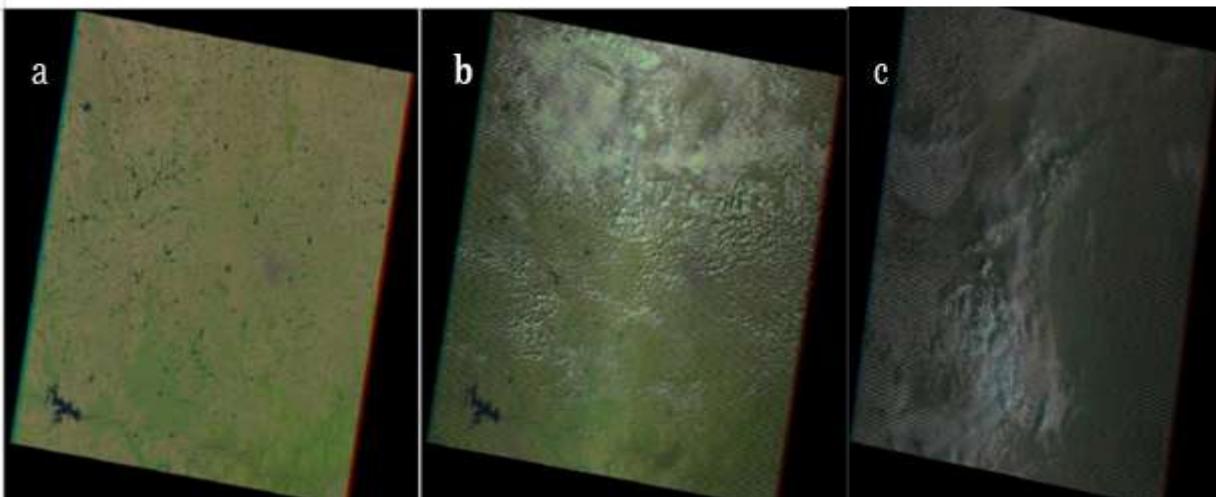


Figure 3. Land use and land cover (LULC) maps of Mysore city for the years (a) 2000, (b) 2010, and (c) 2024, showing spatial expansion of built-up areas and reduction of vegetated land.

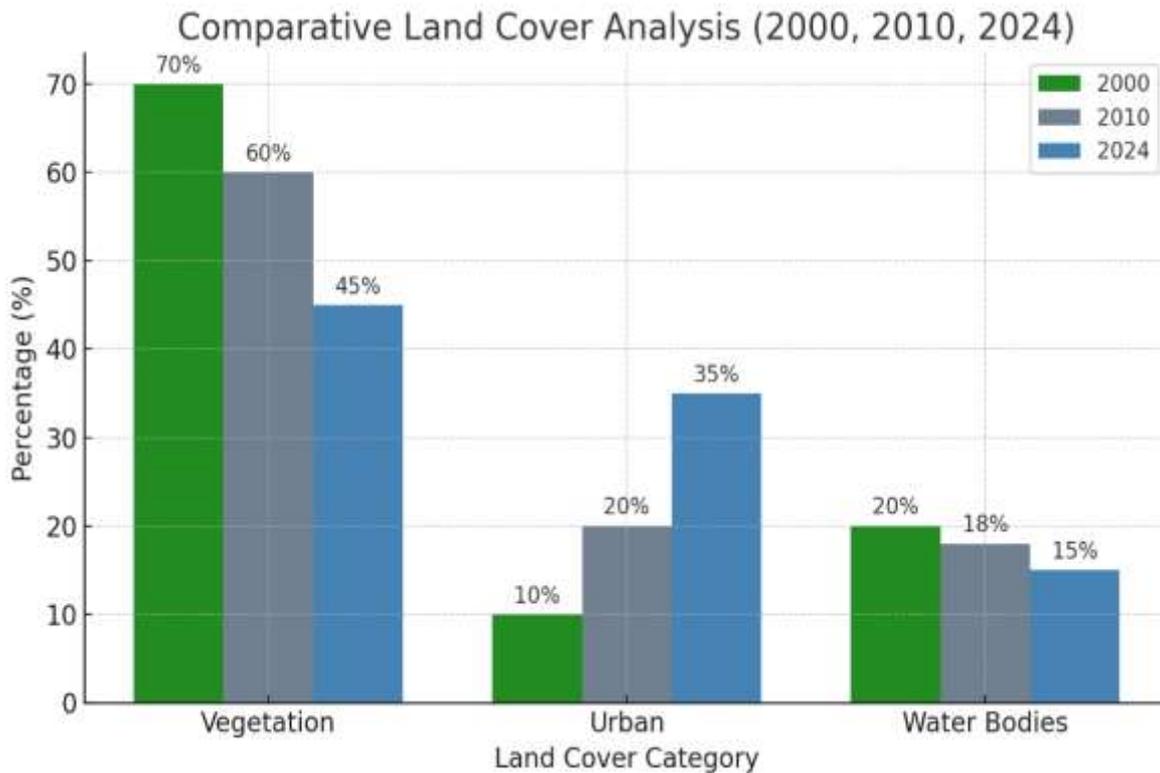


Figure 4. Temporal changes in land use and land cover distribution in Mysore city from 2000 to 2024, highlighting the progressive increase in built-up area and decline in vegetation cover.

The reduction in vegetated surfaces has significant implications for ecosystem services such as carbon sequestration, groundwater recharge, and microclimate regulation, thereby reducing overall urban ecological resilience (Grimm *et al.* 2008; Elmqvist *et al.* 2019).

3.2 Vegetation dynamics based on NDVI analysis

NDVI analysis revealed a continuous decline in vegetation health across the study period. In 2000, NDVI values predominantly ranged between 0.55 and 0.65, indicating dense vegetation cover. By 2010, values declined to approximately 0.45-0.55, while in 2024, extensive portions of the urban core exhibited NDVI values below 0.45, representing sparse or degraded vegetation (Fig. 5)

Spatial distribution analysis showed that higher NDVI values persisted mainly in southern and western peripheral zones, whereas central and northern urban regions experienced severe greenness loss. This spatial contrast closely corresponds with patterns of urban expansion and increased impervious surface coverage.

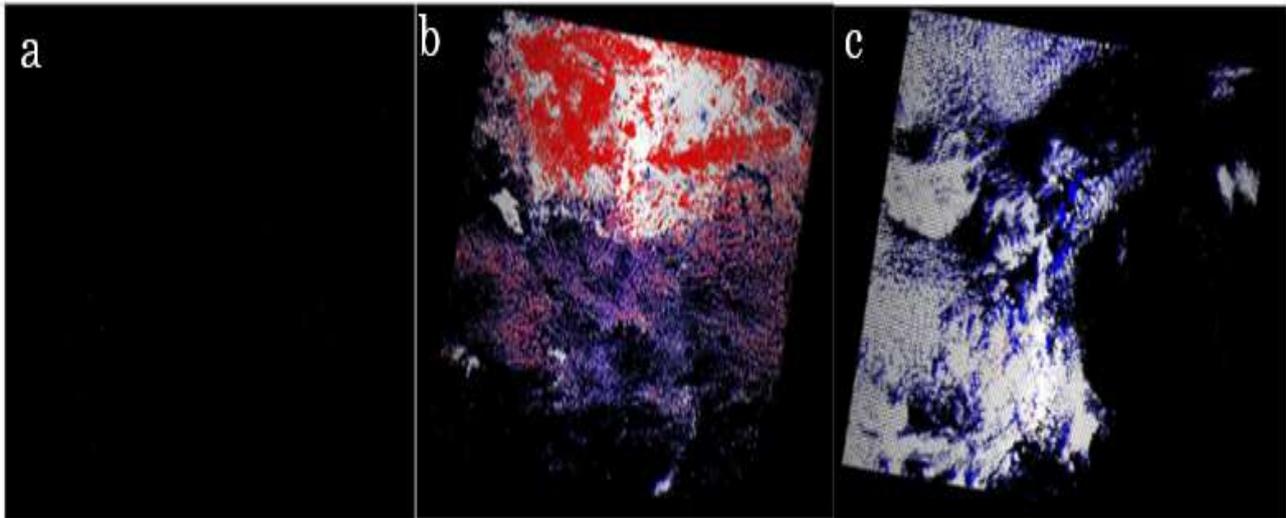


Figure 5. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in Mysore city for the years (a) 2000, (b) 2010, and (c) 2024, indicating gradual degradation of urban vegetation.

The observed decline in NDVI is consistent with findings reported in other rapidly urbanizing regions, where vegetation loss contributes to altered surface energy balance and reduced evapotranspiration (Pettorelli *et al.* 2014; Xie *et al.* 2019).

3.3 Urban expansion and thermal stress

Land cover transformation significantly influenced local climatic conditions in Mysore. Secondary climate datasets indicate an increase in average surface temperature of approximately 2.9 °C between 2000 and 2024. Intensification of the urban heat island (UHI) effect was particularly evident in densely built central zones.

Temperature differences of up to 2.5 °C were observed between the urban core and peripheral vegetated areas. The replacement of vegetation with impervious materials alters surface albedo and heat storage capacity, thereby amplifying thermal stress (Zhou *et al.* 2017). These results emphasize that urban expansion acts as a dominant driver of microclimatic modification, compounding the impacts of regional climate variability.

3.4 Environmental indicators and ecological vulnerability

Multiple environmental indicators collectively demonstrate increasing ecological vulnerability within the Mysore urban system. Water quality assessments of major urban lakes revealed declining Water Quality Index (WQI) values, primarily due to nutrient enrichment and untreated wastewater discharge, consistent with earlier regional studies (Chandan and Harisha 2020).

Soil erosion susceptibility increased notably in peri-urban zones undergoing land conversion. Reported USLE-based estimates indicate an increase in erosion rates from approximately 4.0 to 6.5 t ha⁻¹ yr⁻¹, attributed to vegetation removal and increased surface runoff (Yogesh 2016). The combined degradation of vegetation, aquatic ecosystems, and soil stability reflects a weakening of the city's natural buffering capacity against environmental disturbances.

3.5 Correlation between urban growth and ecological indicators

Correlation analysis revealed strong relationships between urban expansion and environmental degradation. Built-up area exhibited a strong negative correlation with vegetation cover and biodiversity proxies ($r = -0.99$), while a strong positive correlation was observed between urban growth and pollution indicators ($r = +0.94$) (Fig. 6)

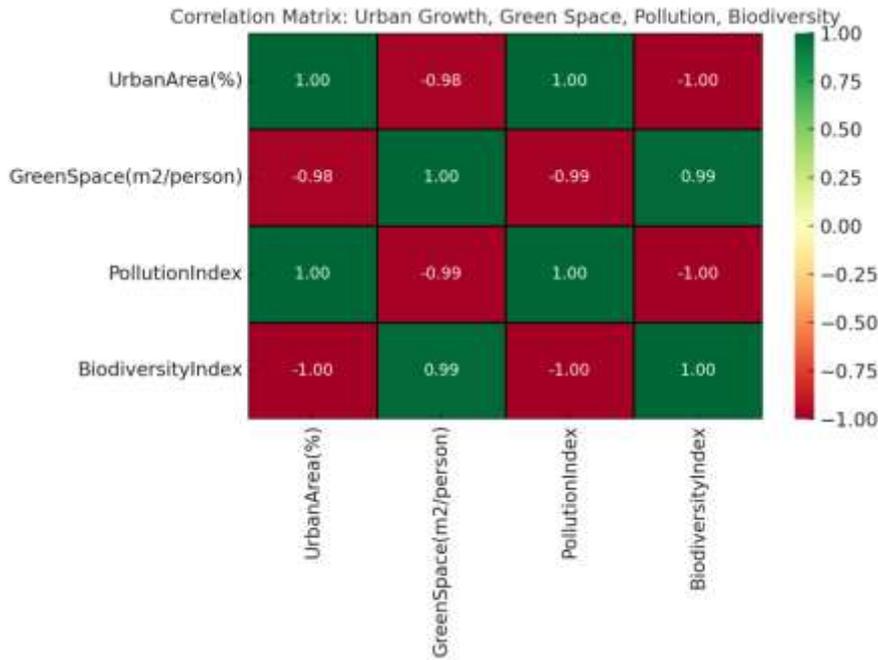


Figure 6. Correlation heatmap showing relationships between built-up area, vegetation cover, pollution index, and biodiversity indicators, illustrating the ecological impacts of urban expansion.

These results confirm that rapid urbanization remains a principal driver of ecological stress, consistent with global observations reported in urban ecological studies (Seto *et al.* 2012; Foley *et al.* 2015).

3.6 Regression-based future projections

Linear regression modeling was applied to predict future urban growth trends. Projections indicate that built-up land may reach approximately 42% by 2030 and nearly 50% by 2040 if current expansion patterns persist. Correspondingly, green space per capita is projected to decline to nearly 10 m² by 2040, significantly below the World Health Organization recommended minimum of 30 m² (Fig. 7)

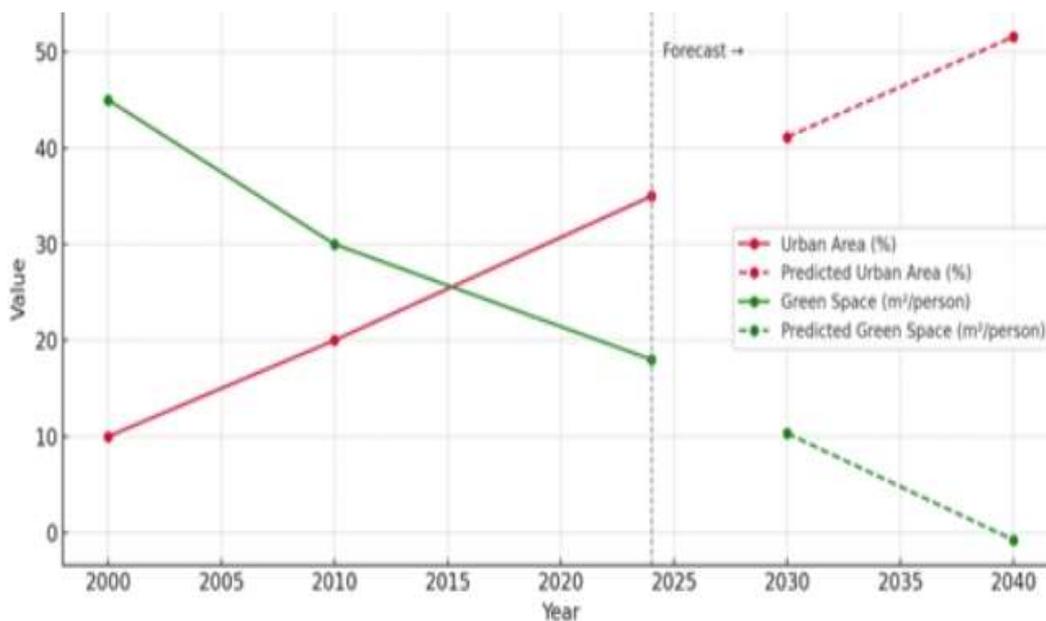


Figure 7. Regression-based projection of future urban expansion and decline in green space availability in Mysore city under current development trends.

These projections highlight the urgency of integrating ecological thresholds into urban development policies to prevent irreversible environmental degradation.

3.7 Discussion

The results demonstrate that Mysore's urbanization trajectory closely parallels patterns observed in other mid-sized cities across India and the Global South. Fragmentation of green spaces, degradation of water bodies, and intensification of thermal stress collectively undermine urban ecological resilience.

Urban sustainability research emphasizes the importance of maintaining ecological connectivity and multifunctional green infrastructure to enhance resilience (Meerow *et al.* 2016; Kabisch *et al.* 2017). The spatial patterns identified in this study indicate significant opportunities for restoration through lake buffer protection, urban green corridors, and climate-sensitive planning frameworks.

4. Conclusion

This study provides a comprehensive spatio-temporal assessment of urban expansion and ecological vulnerability in Mysore, India, over a 24-year period (2000-2024) using integrated remote sensing and geospatial modeling approaches. The findings reveal a substantial transformation of the urban landscape, characterized by rapid expansion of built-up areas and a pronounced decline in vegetation cover and water bodies. NDVI-based analysis confirmed progressive degradation of urban green spaces, particularly within the city core, indicating increasing ecological stress.

Statistical analyses demonstrated strong inverse relationships between urban growth and key ecological indicators, while regression-based projections suggest that continued expansion may significantly reduce green space availability by 2040. Such trends highlight the growing vulnerability of mid-sized cities to environmental degradation in the absence of effective spatial planning and ecological safeguards. The integrated analytical framework adopted in this study offers valuable insights into cumulative urban impacts and can support data-driven decision-making for sustainable urban development.

5. Policy Implications

The results emphasize the urgent need for climate-sensitive urban planning strategies in rapidly growing cities. Protection of urban lakes, enforcement of buffer zones, restoration of green corridors, and promotion of urban forestry initiatives can significantly enhance ecological resilience. Incorporating geospatial monitoring tools into municipal planning processes would enable continuous assessment of land transformation and early identification of vulnerable zones. Aligning city-level development strategies with national climate adaptation policies and the Sustainable Development Goals (SDG 11 and SDG 13) is essential for ensuring environmentally sustainable urban growth (Elmqvist *et al.* 2019; UN-Habitat 2022).

6. Limitations and future scope

Although the study provides a detailed assessment of urban expansion and ecological vulnerability, certain limitations should be acknowledged. The analysis relied primarily on medium-resolution satellite imagery, which may not capture fine-scale urban features. Additionally, some environmental indicators were derived from secondary datasets. Future research could integrate high-resolution Sentinel-2 imagery, machine-learning-based classification methods, and field-based ecological surveys to improve spatial accuracy. Incorporating socio-economic variables and scenario-based urban growth models would further enhance predictive capabilities and policy relevance.

Competing interests

The authors declare that they have no competing interests.

Acknowledgements

The authors acknowledge the United States Geological Survey (USGS) and the Indian Space Research Organisation (ISRO) for providing free access to satellite datasets used in this research. The authors also thank the developers of ArcGIS and ERDAS Imagine software for analytical support.

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