*Original Research Article*

**Spatiotemporal Analysis of Land Use and Land Cover Changes in Bengaluru Metropolitan Region (1990–2023) using GIS and Remote Sensing**

**ABSTRACT**

*Bengaluru Metropolitan Region (BMR) has undergone significant land use and land cover (LULC) transformations from 1990 to 2023 due to rapid urbanization and economic expansion. This study employs remote sensing and GIS techniques to analyze these spatiotemporal changes using multi-date satellite imagery from Landsat-5 TM, Landsat-7 ETM+, IRS-P6 LISS-III, Landsat-8 OLI, and Sentinel-2A MSI. A supervised classification approach with post-classification accuracy assessment (Overall Accuracy: 85.7–92.1%; Kappa Coefficient: 0.82–0.89) was used to categorize the region into seven LULC classes: built-up area, cropland, vegetation, flooded vegetation, water bodies, bare ground, and rangeland. The results indicate an explosive expansion of built-up land, which grew from 28,009 hectares in 1990 to 202,521 hectares in 2023 a sevenfold increase, largely at the expense of cropland (-36.7%), vegetation (-24.3%), and wetlands (-99%). Water bodies, despite initial decline, increased to 17,913 hectares in 2023, reflecting restoration efforts.*

*The spatial analysis reveals that urban growth has been concentrated around Bengaluru city, expanding radially along major transportation corridors into peri-urban areas, particularly along Tumkur Road, Mysore Road, Old Madras Road, and Bellary Road. The near-total loss of flooded vegetation (from 290,756 hectares in 1990 to 1,423 hectares in 2023) underscores the severe ecological degradation caused by urban sprawl. Furthermore, Barren land declined from 212,109 hectares in 1990 to just 488 hectares in 2023, suggesting almost complete land utilization. The continued contraction of rangeland (from 151,118 hectares in 1990 to 162,033 hectares in 2023) highlights the transition of open spaces into urbanized land.*

*These LULC shifts have profound implications, including increased impervious surfaces, loss of green spaces, and heightened water stress, exacerbating urban heat island effects and flood risks. To address these challenges, the study advocates for polycentric urban development, stricter land use regulations, ecological conservation, and the integration of GIS-based land monitoring into metropolitan planning frameworks. The findings provide critical insights for policymakers, urban planners, and researchers, emphasizing the need for evidence-based planning to ensure climate resilience and sustainable urbanization in BMR.*

**Keywords:** Land Use Land Cover (LULC), Urbanization, Bengaluru Metropolitan Region (BMR), Remote Sensing, GIS, Sustainable Planning and Urban Sprawl.

**I. INTRODUCTION**

Urbanization is a major driver of land use and land cover (LULC) changes, fundamentally transforming landscapes, ecosystems, and urban sustainability worldwide. The United Nations (UN) projects that by 2050, approximately 68% of the global population will reside in urban areas, with developing countries experiencing the highest urbanization rates (UN DESA, 2018). In India, urbanization has intensified, with the urban population increasing from 27.8% in 2001 to 31.2% in 2011, and it is projected to reach 40% by 2036 (Census of India, 2011; World Bank, 2024). This rapid expansion necessitates a deeper understanding of LULC transitions, as unplanned urban growth often leads to loss of vegetation, wetland degradation, and increased impervious surfaces, exacerbating climate risks and urban livability concerns (Ramachandra & Aithal, 2016).

The Bengaluru Metropolitan Region (BMR) exemplifies the challenges of urban expansion and its impact on land systems. Covering 8,005 km², BMR includes Bangalore Urban, Bangalore Rural, and Ramanagara districts, with Bruhat Bengaluru Mahanagara Palike (BBMP) forming the core urban area (BMRDA, 2017). Over the last three decades, Bengaluru’s built-up area has expanded sevenfold, largely replacing croplands, vegetation, and wetlands (Ramachandra, Mondal, Setturu, & Aithal, 2023). Studies indicate that this urban sprawl has predominantly followed major transportation corridors such as Tumkur Road, Mysore Road, Old Madras Road, and Bellary Road, contributing to the loss of open spaces and natural water bodies (Sudhira, Ramachandra, & Jagadish, 2004). A particularly concerning trend is the near-total disappearance of flooded vegetation, which declined by 99% from 1990 to 2023, emphasizing the severe ecological consequences of unregulated urban growth (Hollyhead, Ramachandra, & Kumar, 2022).

Geospatial technologies such as Remote Sensing (RS) and Geographic Information Systems (GIS) provide powerful tools for analyzing spatiotemporal LULC dynamics. Recent advancements in machine learning classification methods, including Random Forest and Support Vector Machines (SVMs), have significantly improved LULC mapping accuracy (Li, Zhang, Xu, & Wang, 2020). In Bengaluru, previous studies using Landsat and Sentinel imagery have identified substantial land transitions, particularly in peri-urban regions (Dehingia, Das, Rahaman, Surendra, & Hanjagi, 2022). However, there remains a critical need for longitudinal studies incorporating high-resolution multi-temporal datasets to evaluate long-term urbanization trends and their planning implications.

This study employs a remote sensing and GIS-based approach to assess LULC changes in BMR from 1990 to 2023. It specifically aims to (1) classify LULC patterns using multi-date satellite imagery, (2) quantify land transformations over time, (3) examine spatial trends of urban expansion, and (4) provide planning insights for sustainable land management. A supervised classification approach was applied using the Maximum Likelihood Algorithm (MLA), and classification accuracy was assessed through Overall Accuracy (85.7–92.1%) and Kappa Coefficient (0.82–0.89). The findings highlight rapid urban expansion, the disappearance of flooded vegetation, increasing land saturation, and partial restoration of water bodies. The study underscores the urgent need for polycentric urban planning, stricter land-use regulations, and GIS-based monitoring frameworks to ensure climate resilience and sustainable development in BMR.

This paper is structured as follows: Section II presents a review of relevant LULC literature; Section III details the study methodology, including data acquisition, classification techniques, and accuracy assessment; Section IV describes the Growth Dynamics of BMR, Section V discusses the results and discussions, focusing on spatial urban growth trends and environmental implications; and Section VI gives conclusion for balancing urbanization with sustainable land management. The study’s findings contribute to the growing discourse on evidence-based urban planning, offering actionable insights for policymakers, urban planners, and researchers.

**II. LITERATURE REVIEW**

Land use and land cover (LULC) changes have been widely studied as indicators of urban expansion and environmental transformation. Globally, rapid urbanization has resulted in significant LULC modifications, particularly in developing regions such as Asia and Africa. The United Nations Department of Economic and Social Affairs (UN DESA, 2018) reported that urban areas are expected to house nearly 68% of the world’s population by 2050, leading to increased impervious surfaces, loss of vegetation, and fragmented water bodies. Studies conducted in metropolitan areas such as Nairobi, Kenya, and Bangkok, Thailand, indicate that urban growth often results in the conversion of natural landscapes into built-up areas, contributing to ecological degradation and increased land-use conflicts (Edwin, Adiel, & Cyprian, 2019; Li et al., 2020). Similar trends are observed in Indian metropolitan regions, where cities such as Delhi, Mumbai, and Bengaluru have experienced substantial LULC transformations over the past three decades due to infrastructure expansion, population growth, and economic development (Ramachandra, Mondal, Setturu, & Aithal, 2023).

Bengaluru, India’s fastest-growing metropolitan region, has undergone intensive LULC changes, primarily driven by IT sector-led urbanization and population influx. Studies by Sudhira, Ramachandra, and Jagadish (2004) highlight that Bengaluru’s urban expansion follows a radial growth pattern, with built-up areas extending outward along major transportation corridors such as Tumkur Road, Mysore Road, Old Madras Road, and Bellary Road. The Bengaluru Metropolitan Region Development Authority (BMRDA, 2017) reported that the city’s built-up area expanded sevenfold between 1990 and 2023, leading to a sharp decline in cropland, vegetation, and wetlands. Hollyhead et al. (2022) examined the environmental consequences of LULC changes in Bengaluru and found that more than 200 lakes had disappeared due to unchecked urbanization, resulting in significant disruptions to groundwater recharge and ecosystem stability. Similarly, Dehingia, Das, Rahaman, Surendra, and Hanjagi (2022) observed that vegetation cover in Bengaluru declined due to unregulated land-use transitions, impacting the region’s microclimate and increasing urban heat island effects.

The application of Geographic Information Systems (GIS) and remote sensing has significantly improved the accuracy of LULC assessments. Recent studies have demonstrated that high-resolution multi-temporal satellite imagery, when combined with machine learning techniques such as Random Forest and Support Vector Machines (SVMs), enhances the precision of LULC classification (Li et al., 2020). In Bengaluru, Ramachandra and Aithal (2016) employed supervised classification techniques using Landsat, Sentinel, and IRS imagery to track LULC changes, reporting a 99% decline in flooded vegetation between 1990 and 2023. Their study also indicated that bare ground in the metropolitan region had almost disappeared, decreasing from 212,109 hectares in 1990 to just 488 hectares in 2023. This reflects near-total land utilization, with most available spaces being converted into built-up areas or agricultural land.

The implications of LULC changes in Bengaluru extend to urban planning, land conservation, and sustainable development. NITI Aayog (2021) emphasized that polycentric urban development and stricter land-use regulations are essential for managing metropolitan expansion. Sundaresan (2019) argued that weak enforcement of zoning laws in Bengaluru has led to the unregulated conversion of wetlands and green spaces into urban areas, reinforcing the need for GIS-based spatial monitoring and policy interventions. Additionally, the Smart Cities Mission (2015) and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT, 2021) have advocated for real-time land-use monitoring to track and manage LULC dynamics at five-year intervals, ensuring more effective urban governance.

In summary, the literature indicates that Bengaluru’s LULC changes align with broader global urbanization patterns, with built-up areas expanding at the expense of natural ecosystems. GIS and remote sensing techniques provide valuable tools for monitoring and analyzing these changes, offering insights that can inform sustainable urban planning. The findings from this study build upon existing research by employing high-resolution multi-temporal imagery, accuracy assessments, and spatial analysis to provide a refined understanding of Bengaluru’s LULC dynamics. This contributes to evidence-based policymaking aimed at mitigating the adverse effects of uncontrolled urban expansion and ensuring more resilient metropolitan development.

**III. METHODOLOGY**

This study employs a remote sensing and GIS-based approach to analyze land use and land cover (LULC) changes in the Bengaluru Metropolitan Region (BMR) from 1990 to 2023. The methodology consists of four key components: (1) Data Acquisition, (2) Image classification, (3) Accuracy Assessment, (4) Change Detection, and Spatial Analysis, structured to meet the study’s objectives. These objectives include (a) preparing LULC maps for BMR at five time points (1990, 2000, 2010, 2020, and 2023), (b) quantifying LULC changes over time, particularly urban expansion and loss of agricultural or vegetated areas, (c) analyzing spatial patterns of urban growth, and (d) deriving planning insights relevant to sustainable urbanization.

**3.1 Study Area and Spatial Extent**

BMR, located in the southeastern part of Karnataka, India, spans 800,500 hectares (8,005 km²), making it one of India’s largest metropolitan regions (BMRDA, 2017). Geographically, it is positioned between 12°14'16” to 13°30'26” north latitude and 77°2'51” to 77°57'45” east longitude. The region includes Bangalore Urban, Bangalore Rural, and Ramanagara districts, with Bruhat Bengaluru Mahanagara Palike (BBMP) as the urban core.

**3.2 Data Acquisition**

Multi-temporal satellite imagery was obtained from the United States Geological Survey (USGS) Earth Explorer and the Indian Space Research Organisation’s (ISRO) Resourcesat. The dataset selection ensured temporal consistency in resolution and minimal cloud cover. The study relied on data acquired during dry season months to reduce atmospheric interference and ensure uniformity in land classification. Ancillary datasets, including topographic maps from the Survey of India for geo-referencing, OpenStreetMap and Diva-GIS data for road network verification, and census records for population analysis, were also incorporated. Table-1 provides the details of Input Data for LULC Classification.

**Table 1: Details of Input Data for LULC Classification**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Sensor Used** | **Resolution** | **Acquisition Date** | **Cloud Cover (%)** |
| 1990 | Landsat-5 TM | 30m | Jan–Feb 1990 | <10% |
| 2000 | Landsat-7 ETM+ | 30m | Jan–Feb 2000 | <5% |
| 2010 | IRS-P6 LISS-III | 23.5m | Jan–Feb 2010 | <10% |
| 2020 | Landsat-8 OLI | 30m | Jan–Feb 2020 | <5% |
| 2023 | Sentinel-2A MSI | 10m | Jan–Feb 2023 | <5% |

(Source: Author Based on Imagery Data)

**3.3 Image Classification and LULC Categories**

A supervised classification approach was applied using the Maximum Likelihood Algorithm (MLA) in ArcGIS (Version 10.9) and Google Earth Engine. Training samples were selected based on high-resolution reference imagery and field validation data to enhance classification accuracy.

This study categorized the landscape into seven LULC types to ensure consistency with the land classification presented in the figures.

1. **Water Bodies** – Lakes, reservoirs, and other surface water features.
2. **Vegetation** – Dense and sparse tree cover, plantations, and forests.
3. **Flooded Vegetation** – Seasonally flooded agricultural land, marshlands, and wetlands.
4. **Cropland** – Agricultural fields, orchards, and horticultural zones.
5. **Built-up Area** – Residential, commercial, and industrial urban spaces.
6. **Barren Land** – Open barren lands, exposed soil, and non-vegetated areas.
7. **Rangeland** – Grasslands, pastures, and open shrublands.

Post-classification **accuracy assessment** was conducted to validate the classification results.

**3.4 Accuracy Assessment**

To ensure classification reliability, an accuracy assessment was performed using reference data from Google Earth historical imagery and ground-truth data collected from field surveys and ancillary datasets. The following metrics were computed:

* **Overall Accuracy (OA)** – Measures the percentage of correctly classified pixels.
* **Kappa Coefficient (K)** – Measures the statistical agreement between classification results and reference data.

The accuracy assessment results are summarized in Table-2 below:

**Table 2: Accuracy Assessment Metrics for LULC Classification**

|  |  |  |
| --- | --- | --- |
| **Year** | **Overall Accuracy (%)** | **Kappa Coefficient** |
| 1990 | 85.7 | 0.82 |
| 2000 | 88.2 | 0.85 |
| 2010 | 86.9 | 0.83 |
| 2020 | 91.3 | 0.88 |
| 2023 | 92.1 | 0.89 |

(Source: Author based on accuracy assessment)

The high overall accuracy and Kappa values (>0.80) confirm reliable classification results.

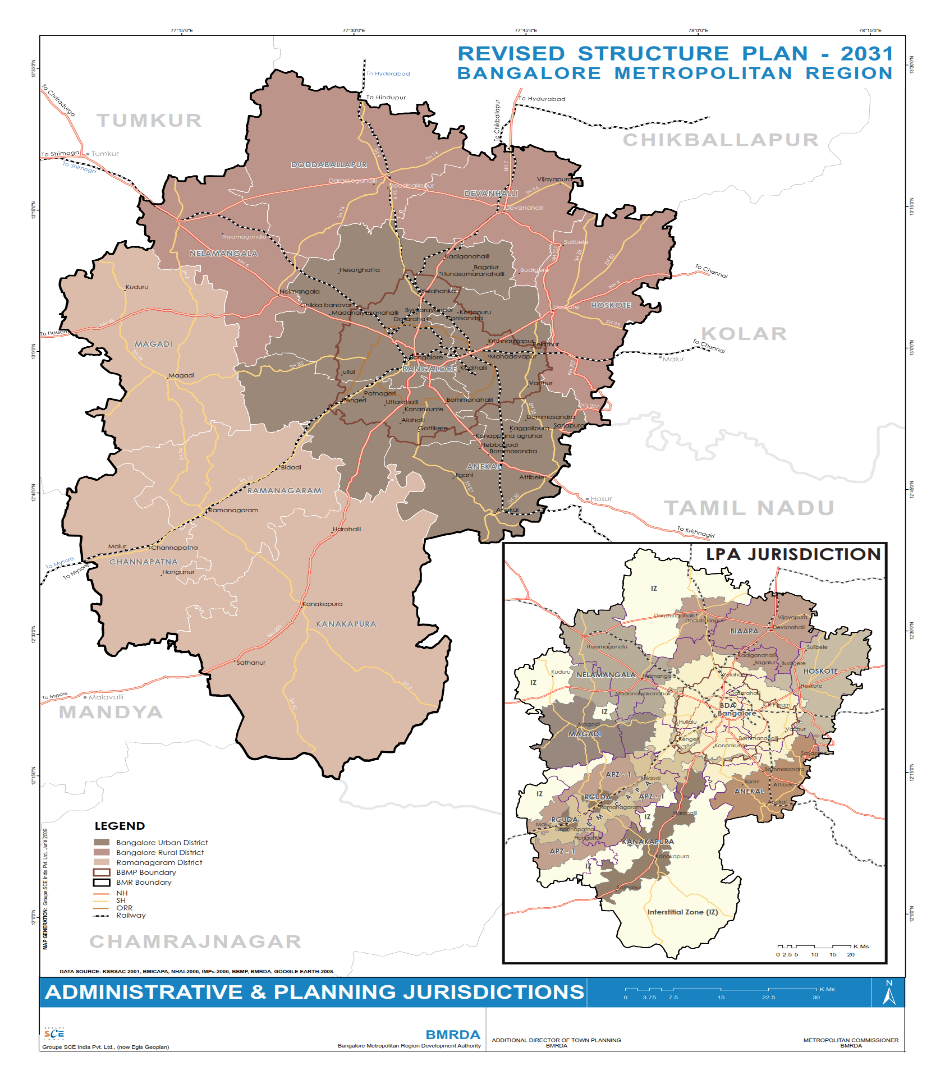
**3.5 LULC Change Detection and Analysis**

A change detection analysis was performed using the post-classification comparison (PCC) method, where classified LULC maps were compared across different time periods (1990, 2000, 2010, 2020, and 2023). Transition matrices were generated to quantify shifts in land use patterns, particularly urban expansion, vegetation loss, and wetland degradation. Additionally, the study incorporated administrative boundaries (taluks and planning zones) to evaluate the regional implications of LULC changes on planning frameworks and infrastructure development.

**IV. GROWTH DYNAMICS OF BENGALURU METROPOLITAN REGION (BMR)**

**4.1 Location and Regional Setting**

The Bengaluru Metropolitan Region (BMR), a statutory planning area in Karnataka, India, spans 800,500 hectares (8,005 km²), making it one of India’s largest metropolitan regions (BMRDA, 2017). It lies between 12°14'16” to 13°30'26” north latitude and 77°2'51” to 77°57'45” east longitude and comprises Bangalore Urban, Bangalore Rural, and Ramanagara districts, with Bruhat Bengaluru Mahanagara Palike (BBMP) as the urban core. While BBMP covers 800 km², the remaining area includes towns such as Yelahanka, Hosakote, Ramanagara, and Kanakapura, along with rural settlements. The region features undulating terrain (~900 m elevation), no major rivers, and a network of man-made lakes historically used for irrigation and water supply (Figure 1)



**Figure 1: Location and Administrative Map of BMR**

(Source: BMR Revised Structure Plan, 2016)

**4.2 Demographic Trends**

BMR has witnessed rapid population growth, primarily driven by Bengaluru’s economic expansion. The population was approximately 6.5 million in 1991 and rose to 8.42 million in 2001, with the urban core (BBMP) housing nearly 6 million residents (Census and BMRDA, 2017). As per Census 2011, BMR’s population reached 11.66 million, reflecting a 38% decadal increase. Bangalore Urban District alone accounted for 9.59 million people in 2011, making up 20% of Karnataka’s total population while occupying less than 5% of its area.

Urbanization has been highly concentrated in BBMP, which housed 77% of BMR’s population by 2011, growing from 48% in 1991 to 73% in 2001. This demographic trend indicates a strong regional imbalance, where Bengaluru city continues to dominate population and economic activities while surrounding areas lag in development.

**4.3 Migration and Urban Expansion**

Bengaluru’s rise as India’s IT and biotechnology hub since the 1990s has attracted migrants from across the country. The city’s population grew by 47% in the 1990s and 35% in the 2000s, significantly higher than national urbanization rates (BMRDA, 2017). Migration has transformed once semi-rural areas into urban townships; for instance, Electronics City and Whitefield formerly agricultural areas are now key IT corridors. Census data indicates a young workforce, high literacy rates (>85%), and a service-industry-driven economy. The expansion of Bengaluru’s employment base has led to peri-urbanization, with villages in BMR experiencing conversion into residential, commercial, and industrial hubs. However, rural areas are shrinking in population share due to decreasing agricultural viability and rising land values.

**4.4 Economic Structure and Regional Disparities**

Bengaluru city is the economic nucleus of BMR, hosting major IT clusters, research institutions, and multinational corporations. The tech industry in the southeastern (Whitefield, Marathahalli) and northern (Hebbal, Devanahalli) corridors has fueled high per capita income growth. However, economic benefits have been unevenly distributed. Peripheral regions remain largely agrarian, with sericulture, horticulture, and small-scale industries dominating (e.g., Ramanagara’s silk market, Kanakapura’s granite quarries). The infrastructure divide is stark: while Bengaluru has an extensive (but congested) road network, peripheral areas lack reliable public transport, consistent water supply, and quality education and healthcare facilities. The BMR Structure Plan 2031 acknowledges this core-periphery disparity and warns of over-centralization risks (BMRDA, 2017).

**4.5 Land Use and Urban Growth Patterns**

Historically, BMR was predominantly agricultural, with built-up areas confined to Bengaluru’s core. In 2001, only 80000 Ha (800 km²) was urban/built-up, while rural land covered over 700000 Ha (7,000 km²) (BMRDA, 2017). However, rapid urban expansion has reshaped the landscape. By 2020, extensive farmland in Bengaluru Rural and Ramanagara had urbanized, particularly along major highways (Tumkur Road NH4, Mysore Road NH275, Old Madras Road NH75, and Bellary Road NH7). The BMR Structure Plan outlines planned growth corridors and new townships to manage expansion, while green belts are designated to contain sprawl, though enforcement remains weak

**4.6 Environmental and Planning Challenges**

BMR’s environmental assets include forested areas like Bannerghatta National Park and interconnected lake systems. However, Bengaluru has lost over 80% of its lakes since the 1960s, with severe implications for groundwater recharge, flooding, and ecosystem stability (Ramachandra et al., 2016). Encroachments and pollution have drastically reduced the number of healthy lakes, threatening BMR’s water security. Governance remains fragmented; BMR falls under the BMRDA, but planning responsibilities are shared across multiple agencies (BBMP, BDA, BMRDA, urban local bodies), often leading to uncoordinated development.

BMR is undergoing intense urban transformation, largely shaped by Bengaluru’s economic pull. The concentration of population and economic activities in the core has resulted in land use changes, rural-to-urban transitions, and environmental concerns. The imbalance between Bengaluru’s growth and the underdevelopment of surrounding regions poses significant planning challenges. This study captures these trends through LULC analysis, highlighting how land use dynamics have evolved in response to demographic and economic shifts. The findings offer insights for future urban planning, emphasizing the need for balanced regional growth, environmental sustainability, and improved metropolitan governance.

**V. RESULTS AND DISCUSSIONS**

**5.1 Introduction to Spatiotemporal Analysis of Land Use and Land Cover (LULC)**

The spatiotemporal analysis of Land Use and Land Cover (LULC) changes in Bengaluru Metropolitan Region (BMR) from 1990 to 2023, as presented in the Table 3 and Figures 2, 3 and 4, reflects the complex interplay of urbanization, environmental changes, and policy interventions over the past three decades. This assessment integrates all seven land-use classes: water, vegetation, flooded vegetation, crops, built-up area, bare ground, and rangeland and links them spatially to observed patterns in the LULC maps. The findings align with the objectives of analyzing LULC transformations, identifying urban expansion drivers, assessing their environmental and planning implications, and proposing policy recommendations.

**Table 3: Analysis of Land Use Land Cover Changes of BMR (1990-2023)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **ID** | **LULC Category/Year** | **1990** | **2000** | **2010** | **2020** | **2023** |
| 1 | **Water Bodies** | 2269 | 9119 | 5232 | 9034 | 17913 |
| 2 | **Vegetation Cover** | 63977 | 121720 | 95698 | 49988 | 79505 |
| 3 | **Flooded Vegetation** | 290756 | 71969 | 4057 | 295 | 1423 |
| 4 | **Crop Land** | 53284 | 399351 | 88600 | 322700 | 337640 |
| 5 | **Built-up Area** | 28009 | 65868 | 87424 | 177277 | 202521 |
| 6 | **Barren Land** | 212109 | 27951 | 211566 | 719 | 488 |
| 7 | **Range Land** | 151118 | 105544 | 308947 | 241510 | 162033 |
|  | **Total Area in Ha** | **801522** | **801522** | **801522** | **801522** | **801522** |
| **Note: All Values Represented in Hectares (Ha) (Source: Author using GIS Data)** | | | | | | |

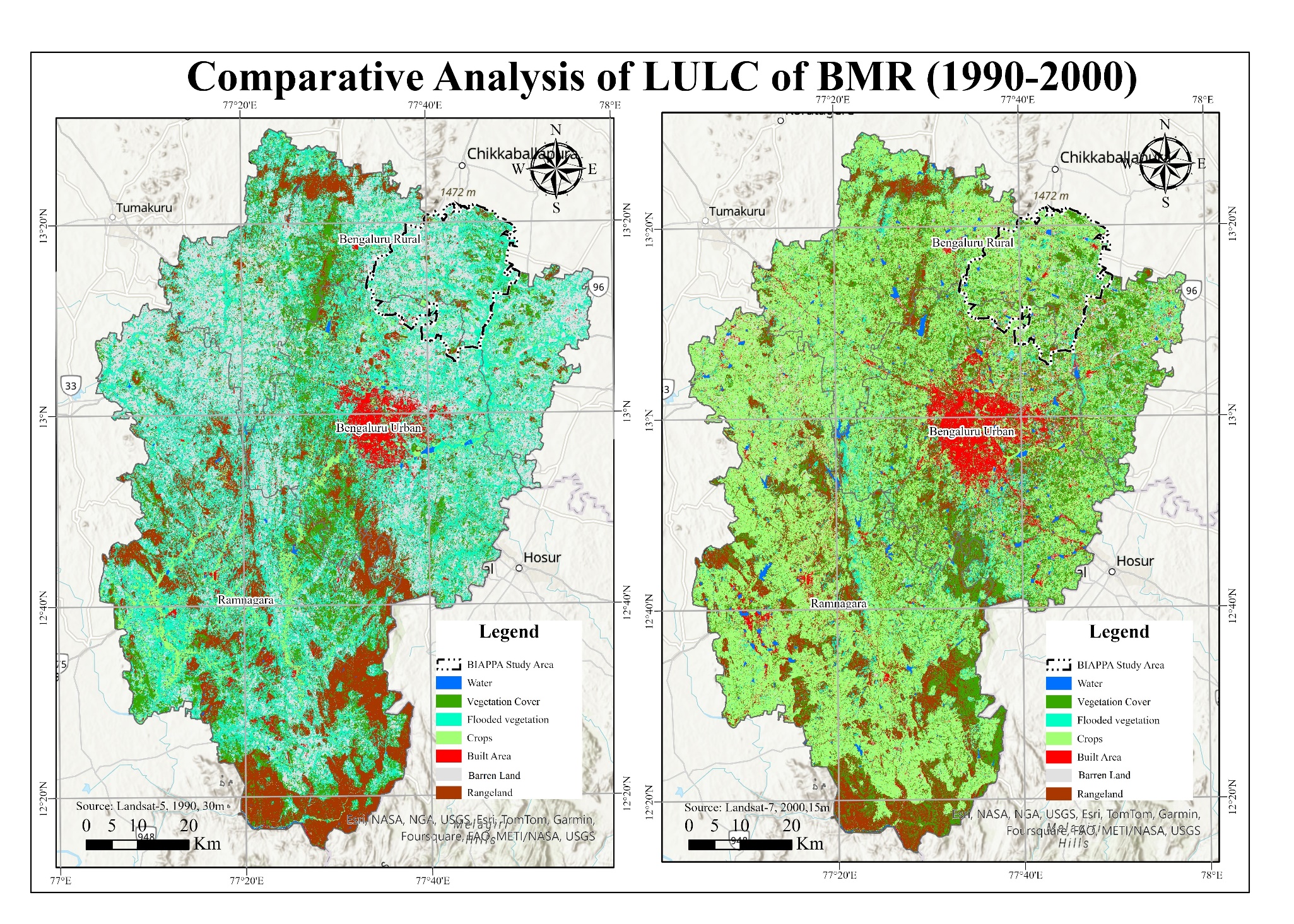
**5.2 Comparative Analysis of LULC from 1990 to 2000: Early Urban Expansion and Agricultural Intensification**

The 1990-2000 period, illustrated in Figure 2, marks the early phase of urban expansion, particularly in Bengaluru Urban and its surrounding periphery. The built-up area increased significantly from 28,009 Ha in 1990 to 65,868 Ha in 2000, expanding outward from the core city along major corridors leading to Whitefield, Electronic City, and Yelahanka. This early urbanization was concentrated along major roads, indicating a shift towards peri-urban development.

Simultaneously, the vegetation cover nearly doubled from 63,977 Ha to 121,720 Ha, indicating possible afforestation efforts or classification improvements. However, this increase was accompanied by a sharp decline in flooded vegetation, which dropped drastically from 290,756 Ha in 1990 to 71,969 Ha in 2000. This loss corresponds with the ongoing encroachment on wetlands, especially in the northern and southern parts of BMR, leading to the gradual degradation of Bengaluru’s natural hydrological systems.

Agricultural land underwent a substantial shift, as cropland expanded from 53,284 Ha to 399,351 Ha, reflecting intensive agricultural practices. This expansion was more pronounced in the northern and southwestern parts of BMR. Meanwhile, Barren land decreased sharply from 212,109 Ha in 1990 to 27,951 Ha in 2000, indicating increasing land utilization for either agriculture or construction purposes. Rangeland declined from 151,118 Ha to 105,544 Ha, signifying early-stage land conversion. Water bodies showed a slight increase from 2,269 Ha to 9,119 Ha, which could be linked to water retention or rejuvenation projects in certain parts of the region.

Overall, the 1990-2000 period marks a phase where the built-up area grew rapidly, agricultural land expanded, and wetlands were significantly reduced, as illustrated in Figure 2.

**Figure 2: Comparative Analysis of LULC of BMR (1990-2000)**

(Source: Author using GIS)

**5.3 Comparative Analysis of LULC from 2010 to 2020: Peak Urbanization & Rapid Landscape Change**

The 2010-2020 period, as depicted in Figure 3, represents the most aggressive phase of urban expansion in BMR, with the built-up area doubling from 87,424 Ha in 2010 to 177,277 Ha in 2020. This increase reflects extensive real estate and infrastructure development, which extended urbanized zones beyond Bengaluru’s core into satellite towns such as Hoskote, Bidadi, and Doddaballapur. During this time, vegetation cover declined significantly from 95,698 Ha in 2010 to 49,988 Ha in 2020, signaling widespread land conversion for urban uses. This reduction was evident in the loss of green spaces in peri-urban and rural areas, reinforcing the challenges of unplanned urban expansion.

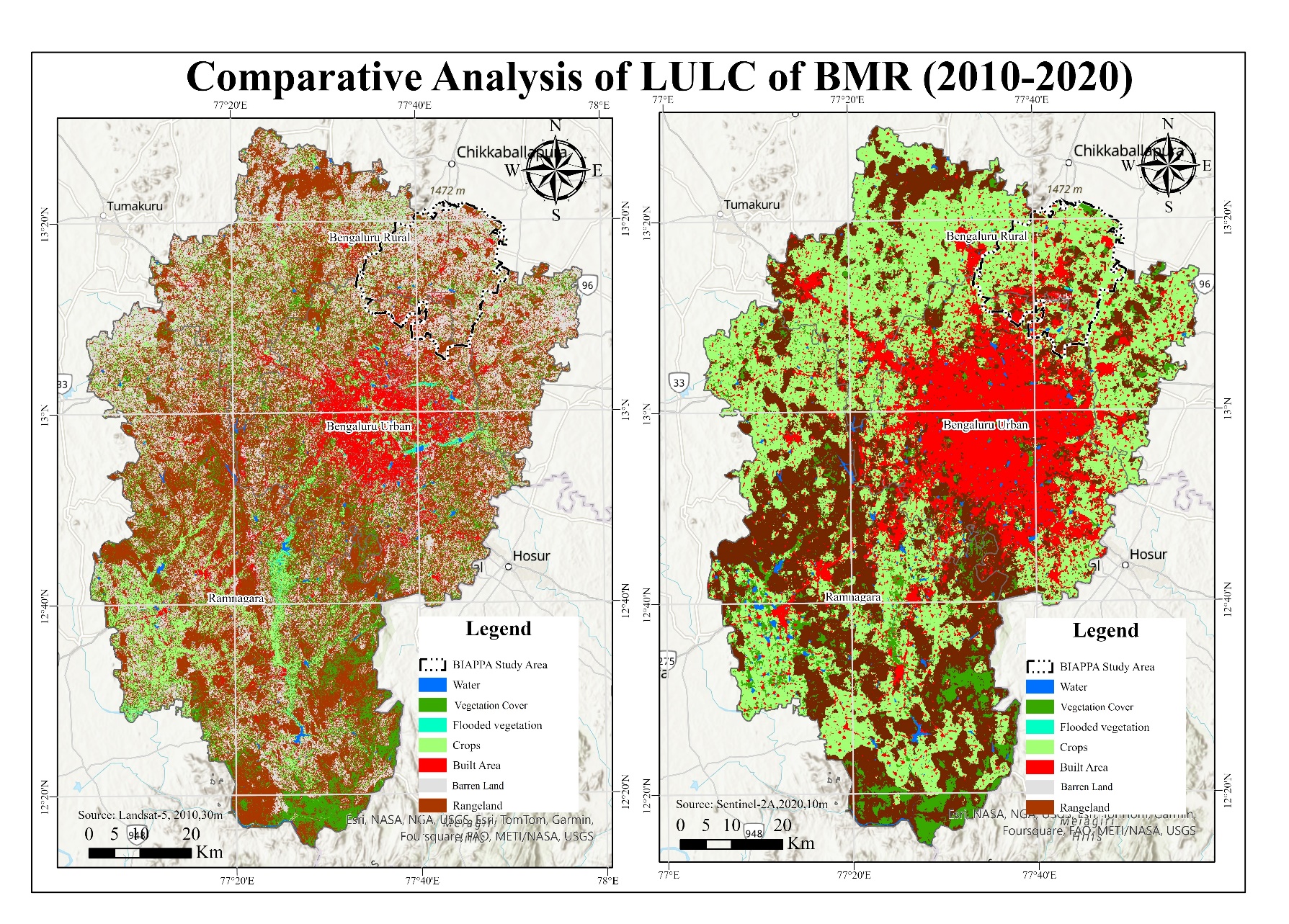
Wetlands and water retention areas also suffered, as flooded vegetation decreased from 4,057 Ha in 2010 to only 295 Ha in 2020. The near-complete disappearance of these ecosystems corresponds with widespread lake encroachments and urban drainage issues. Cropland saw fluctuations during this period, initially declining but recovering to 322,700 Ha by 2020. This change indicates the persistence of agriculture in peri-urban regions despite increasing land pressures. Barren land was nearly eliminated, dropping from 211,566 Ha in 2010 to only 719 Ha in 2020, suggesting that almost all available land had been converted to other uses.

Similarly, rangeland declined from 308,947 Ha in 2010 to 241,510 Ha in 2020, reinforcing the notion that land previously designated for pasture and open use was increasingly being urbanized. Water bodies showed an increase from 5,232 Ha in 2010 to 9,034 Ha in 2020, possibly due to lake restoration projects. The 2010-2020 period highlights the peak of Bengaluru’s urban expansion, during which land-use conversion was at its most intense, leading to major environmental concerns, as illustrated in Figure 3.

**5.4 Analysis of LULC in 2023: Intensification of Urban Dominance & Sustainability Challenges**

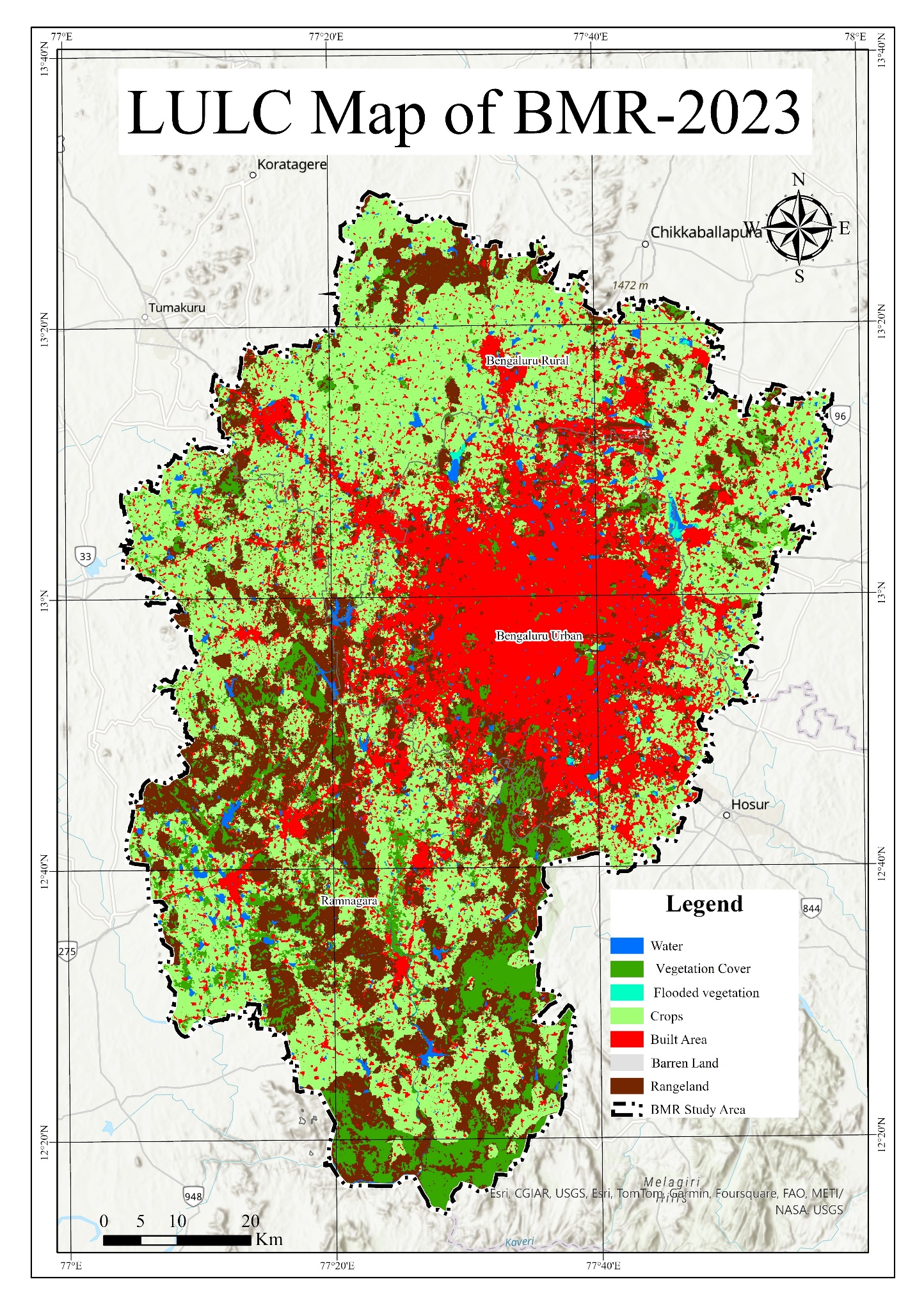
The 2023 LULC scenario, depicted in Figure 4, underscores the continuing dominance of urban land use in BMR. The built-up area reached 202,521 Ha, demonstrating that urban sprawl is now the primary feature of Bengaluru’s landscape. The spread of urbanization has expanded significantly into areas that were previously agricultural or rural. Despite this, vegetation cover has shown a slight recovery to 79,505 Ha, suggesting conservation efforts or afforestation projects in certain peri-urban areas.

However, the fragmentation of these spaces reduces their ecological benefits. The flooded vegetation category recorded a marginal increase to 1,423 Ha, indicating isolated wetland preservation efforts, although the overall wetland ecosystem remains critically endangered. Cropland remains significant at 337,640 Ha, but its spatial distribution suggests that it is under increasing pressure from urban encroachment. Similarly, rangeland continues to shrink, reducing to 162,033 Ha, reinforcing the trend of decreasing open spaces. The Barren land category is almost eliminated, with only 488 Ha remaining, meaning that nearly every available parcel of land in BMR is now developed or actively utilized.

Encouragingly, water bodies have increased to 17,913 Ha, likely due to ongoing lake rejuvenation efforts, particularly in regions that had suffered significant encroachments. However, concerns remain regarding the long-term sustainability of these water bodies amid ongoing land-use pressures. The 2023 scenario, as illustrated in Figure 4, highlights the continued urban dominance in BMR, with limited spaces left for ecological preservation and agricultural resilience.

**Figure 3: Comparative Analysis of LULC of BMR (2010-2020)**

(Source: Author using GIS)

**Figure 4: LULC Map of BMR-2023**

(Source: Author using GIS)

**5.5 Implications of LULC Changes**

The spatiotemporal LULC transformations in Bengaluru Metropolitan Region (BMR) from 1990 to 2023 have profound implications for urban sustainability, ecological balance, and planning governance. The sevenfold expansion of built-up areas, primarily replacing cropland (-36.7%), vegetation (-24.3%), and wetlands (-99%), has significantly altered the region’s land composition (Ramachandra et al., 2023). The near elimination of flooded vegetation and reduction of barren land indicate near-total land saturation, leading to increased impervious surfaces, altered hydrological cycles, and heightened flood risks (Hollyhead et al., 2022).

These shifts have exacerbated water stress due to encroachments on lakes and wetlands, crucial for groundwater recharge (Dehingia et al., 2022). Despite partial restoration efforts, unregulated urban sprawl has compromised ecological stability (BMRDA, 2017). The fragmentation of peri-urban agricultural zones raises concerns over food security and land speculation, mirroring trends observed in rapidly growing cities across Asia and Africa (Edwin, Adiel, & Cyprian, 2019; Li et al., 2020).

To mitigate these impacts, integrating GIS-based monitoring frameworks into metropolitan planning is critical (NITI Aayog, 2021). A polycentric urban development strategy should be prioritized, promoting planned satellite towns to alleviate pressure on Bengaluru’s core (Sudhira et al., 2004). Strengthening land-use regulations and enforcing wetland conservation laws are essential to counter unregulated expansion (Sundaresan, 2019). Sustainable urbanization in BMR requires balanced land use, ecological conservation, and adaptive policy interventions, ensuring climate resilience and long-term livability (Ramachandra & Aithal, 2016).

**VI. CONCLUSION**

This study examines the spatiotemporal changes in Land Use and Land Cover (LULC) in Bengaluru Metropolitan Region (BMR) from 1990 to 2023 using remote sensing and GIS techniques. The findings reveal a sevenfold expansion of built-up areas from 28,009 hectares in 1990 to 202,521 hectares in 2023, primarily replacing cropland (-36.7%), vegetation (-24.3%), and wetlands (-99%). The conversion of open spaces and agricultural land into urbanized zones has been most intense along major corridors, including Tumkur Road, Mysore Road, Old Madras Road, and Bellary Road.

The study identifies three critical LULC transformations: (1) rapid urban expansion, which has drastically altered the spatial composition of BMR; (2) loss of flooded vegetation and wetlands, reflecting severe ecological degradation; and (3) increasing water body restoration efforts, as evidenced by the rise in water bodies from 2,269 hectares in 1990 to 17,913 hectares in 2023. The near-complete disappearance of Barren land (from 212,109 hectares in 1990 to just 488 hectares in 2023) suggests that almost all available land has been utilized, leaving little scope for further unplanned expansion.

These LULC shifts have significant implications for urban planning, particularly concerning land conservation, climate resilience, and sustainable growth strategies. The encroachment on wetlands and shrinking green spaces necessitate stricter land-use regulations and spatial monitoring using GIS-based planning tools. To mitigate uncontrolled urban sprawl, the study recommends a polycentric urban development model that promotes balanced growth across BMR’s peri-urban areas. By employing a supervised classification approach and post-classification accuracy assessment (Overall Accuracy: 85.7–92.1%; Kappa Coefficient: 0.82–0.89), the study ensures high reliability of LULC change detection. The results contribute to evidence-based policymaking, enabling planners to monitor urban expansion trends effectively and design long-term land management strategies.

Future research should focus on predictive modeling of land-use changes for 2035 and beyond, incorporating socioeconomic factors and urban growth drivers to refine sustainable metropolitan planning strategies for BMR.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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