

# Assessment of Land Use Land Cover Change and NDVI-Based Vegetation Dynamics Using Google Earth Engine in Ballia District, Uttar Pradesh, India

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## Abstract

Land Use Land Cover (LULC) change and vegetation dynamics are critical indicators of environmental transformation and human environment interactions. Rapid agricultural expansion and urbanization have significantly altered natural landscapes, particularly in developing regions. Therefore, understanding these changes is essential for sustainable land management and ecological conservation. The present study aims to assess the Spatio-temporal changes in LULC and vegetation dynamics in Ballia district between 2017 and 2024. This study utilized the Dynamic World dataset for LULC classification and Landsat 8 Collection 2 Level-2 imagery for NDVI analysis, processed using the Google Earth Engine platform. A mode based classification approach was employed to generate LULC maps, while NDVI was calculated to evaluate vegetation health. Change detection techniques were applied to identify spatial transformations in land use and vegetation patterns. The results revealed a significant increase in agricultural land and built-up areas, accompanied by a substantial decline in vegetation cover, barren land, and water bodies. Additionally, NDVI analysis indicated a slight improvement in maximum vegetation health. However, the overall green area decreased during the study period. Spatial analysis further highlighted heterogeneous patterns of change, with major transformations occurring near riverbanks and expanding settlements. The study demonstrates that increasing anthropogenic activities are driving significant landscape changes in the region, leading to ecological imbalance. These findings emphasize the need for sustainable land use planning and effective environmental management strategies to ensure long-term ecological stability.

**Keywords:** Land Use/Land Cover (LULC), NDVI, Spatio-temporal analysis, Remote sensing, Google Earth Engine, Vegetation dynamics, Change detection, Ballia district, Landsat 8, Dynamic World dataset

## 1. Introduction

Land Use and Land Cover (LULC) represent one of the most critical components of environmental studies, as they reflect the interaction between human activities and natural

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ecosystems. LULC changes are widely recognized as key drivers of environmental transformation, influencing climate regulation, biodiversity, hydrological processes, and ecosystem services (Lambin et al., 2003; Foley et al., 2005). With the advancement of remote sensing and geospatial technologies, it has become possible to monitor these changes with greater accuracy and temporal consistency. Consequently, LULC analysis has emerged as an essential tool for understanding landscape dynamics and supporting sustainable land management.

At the global level, LULC change has become a major environmental concern due to rapid population growth, urbanization, and agricultural expansion. Studies have shown that nearly half of the Earth's land surface has been altered by human activities, primarily for agriculture and settlement purposes (Ellis & Ramankutty, 2008). Urban expansion, in particular, has accelerated significantly over the past few decades, leading to increased pressure on natural resources and ecosystems (Seto et al., 2012). Moreover, these changes are closely linked with global environmental issues such as climate change, land degradation, and loss of biodiversity (Turner et al., 2007; Foley et al., 2011). Therefore, understanding LULC dynamics is crucial for addressing global sustainability challenges. In addition to LULC, vegetation dynamics play a vital role in assessing ecosystem health and environmental change. The Normalized Difference Vegetation Index (NDVI), first introduced by Tucker (1979), has been widely used as a reliable indicator of vegetation condition and productivity. NDVI-based studies have demonstrated its effectiveness in detecting changes in vegetation cover, monitoring drought conditions, and assessing ecological responses to environmental stress (Pettorelli et al., 2005; Jiang et al., 2006). Thus, integrating LULC analysis with NDVI provides a comprehensive understanding of both land transformation and vegetation health.

LULC changes have been particularly significant due to rapid population growth and increasing demand for land resources. India has experienced extensive agricultural expansion and urbanization, leading to the conversion of forests, wetlands, and other natural landscapes (Roy et al., 2015). Urban areas in India are projected to expand substantially, further intensifying land use pressure (Sudhira et al., 2004). Moreover, studies have reported considerable changes in vegetation patterns across different regions, influenced by both climatic variability and human activities (Ghosh et al., 2019). These transformations highlight the urgent need for region-specific studies to assess land use dynamics and their environmental implications. In the state of Uttar Pradesh, LULC changes are particularly pronounced due to high population density and intensive agricultural practices. The state is characterized by fertile alluvial plains, which support extensive farming activities but also make the region vulnerable to land degradation and environmental stress. Previous studies have indicated a gradual decline in natural vegetation and an increase in built-up areas across several districts of Uttar Pradesh (Singh et al., 2017). Furthermore, the presence of major river systems such as the Ganga and Ghaghara significantly influences land use patterns through processes such as flooding and sediment deposition.

Existing studies have explored LULC and NDVI-based vegetation changes across different regions. For instance, (Lambin et al. 2003) and (Turner et al. 2007) emphasized the importance of land change science in understanding global environmental processes. (Foley et al. 2005)

highlighted the ecological consequences of agricultural expansion, while (Seto et al. 2012) focused on urban growth and its environmental impacts. Similarly, (Pettorelli et al. 2005) demonstrated the application of NDVI in ecological monitoring. In the Indian context, Roy et al. (2015) developed national-level LULC datasets, while Ghosh et al. (2019) examined vegetation trends using satellite data. These studies collectively underscore the importance of integrating remote sensing techniques for environmental monitoring.

However, despite the availability of global and national-level studies, there remains a significant research gap at the district level, particularly in regions like Ballia. Most existing studies either focus on large-scale analysis or lack integration between LULC and vegetation dynamics. Additionally, the use of high-resolution datasets such as Dynamic World and cloud-based platforms like Google Earth Engine has not been extensively applied in this region. Therefore, there is a need for a comprehensive study that combines LULC classification, change detection, and NDVI analysis to provide a detailed understanding of land surface dynamics. In this context, the present study aims to analyze the Spatio-temporal changes in LULC and vegetation dynamics in Ballia district between 2017 and 2024 using satellite-based datasets and cloud computing techniques. The specific objectives of the study are (i) to assess LULC patterns and their changes over time, (ii) to evaluate vegetation health using NDVI, and (iii) to identify spatial patterns of environmental change. The outcomes of this study are expected to contribute to sustainable land management planning and provide valuable insights for policymakers and researchers.

## **2. Data sources and methodology**

This study utilized cloud-based geospatial analysis techniques to assess Land Use/Land Cover (LULC) dynamics and vegetation changes in the Ballia district. The analysis was carried out using Google Earth Engine (GEE) as the primary platform for data processing, while ArcMap was employed for map visualization, layout preparation, and final cartographic outputs. The integration of these tools enabled efficient handling of large geospatial datasets and ensured accurate spatial analysis.

### **2.1.Data Source**

This study utilized multi-source satellite datasets to derive LULC classification and vegetation indices. For LULC analysis, the Dynamic World dataset (GOOGLE/DYNAMICWORLD/V1) was employed, which provides near real-time global land cover predictions at 10 m spatial resolution. The dataset includes nine distinct land cover classes such as water, trees, grass, flooded vegetation, crops, shrubland, built-up areas, bare land, and snow/ice. Furthermore, this study employed Landsat 8 Collection 2 Level-2 (LANDSAT/LC08/C02/T1\_L2) imagery to analyze vegetation dynamics using the Normalized Difference Vegetation Index (NDVI). Landsat data was selected due to its long-term availability, moderate spatial resolution (30 m), and suitability for temporal analysis. The study period included the years 2017 and 2024, allowing for a comparative assessment of environmental changes over time.

### **2.2.Data Analysis**

In order to ensure data quality and reliability, preprocessing steps were applied to the Landsat

imagery. Cloud and cloud shadow masking were performed using the QA\_PIXEL band, where bitwise operations were employed to remove contaminated pixels. Additionally, radiometric scaling factors were applied to convert raw digital numbers into surface reflectance values, which is essential for accurate spectral analysis. Subsequently, the processed images were clipped to the study area boundary (Ballia district), thereby ensuring that all further analysis was spatially constrained to the region of interest. Median compositing was then performed to reduce noise and generate representative annual images.

This study utilized the Dynamic World dataset to generate LULC maps for the years 2017 and 2024. The classification was derived using a mode reduction approach, which assigns the most frequently occurring land cover class to each pixel over the selected time period. Furthermore, a value transformation technique was applied using an expression function to shift class values from 0–8 to 1–9, thereby eliminating zero values and improving interpretability. The classified images were visualized using a predefined Color palette corresponding to each land cover class. In addition, a change detection map was generated by comparing the LULC maps of 2017 and 2024 using a pixel-wise inequality function, which highlights areas where land cover transitions have occurred.

To quantify LULC changes, this study employed a pixel-area-based approach. Each classified image was combined with pixel area information and processed using a grouped reducer to calculate the total area under each land cover class. The results were expressed in hectares, allowing for a detailed comparison of class-wise changes between 2017 and 2024.

This study employed the Normalized Difference Vegetation Index (NDVI) to assess vegetation health and density. NDVI was calculated using the standard formula,

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where the Near-Infrared (NIR) and red bands correspond to Landsat 8 bands SR\_B5 and SR\_B4, respectively. The NDVI values range from -1 to +1, where higher values indicate healthier vegetation. Annual NDVI maps for 2017 and 2024 were generated using median composites. A threshold value of 0.1 was applied to distinguish vegetated areas from non-vegetated surfaces. This threshold-based classification enabled the estimation of total green area for each year.

To evaluate temporal vegetation changes, this study employed a pixel-wise subtraction method, where the NDVI of 2017 was subtracted from that of 2024. The resulting difference map highlights areas of vegetation gain and loss. Positive values indicate an increase in vegetation, while negative values represent a decline. Furthermore, the average NDVI change for the entire study area was calculated using a mean reducer, providing a quantitative measure of overall vegetation trends. A color-coded visualization scheme was applied, where blue represents vegetation gain, red indicates loss, and white denotes no significant change.

Finally, all processed datasets, including LULC maps, NDVI maps, and change detection outputs, were exported from Google Earth Engine in GeoTIFF format for further use. ArcMap was subsequently employed for advanced visualization.

### 2.3. Study Area

This study was conducted in Ballia district, which is located in the eastern part of the state of Uttar Pradesh, India. The district lies along the fertile plains of the Middle Ganga River basin and is bounded by the Ghaghara River and the Ganga River, making it highly influenced by fluvial processes. Geographically, Ballia is characterized by low-lying alluvial terrain, which supports extensive agricultural activities. The region experiences a subtropical climate with hot summers, a monsoon season, and mild winters, all of which significantly influence land use patterns and vegetation dynamics.

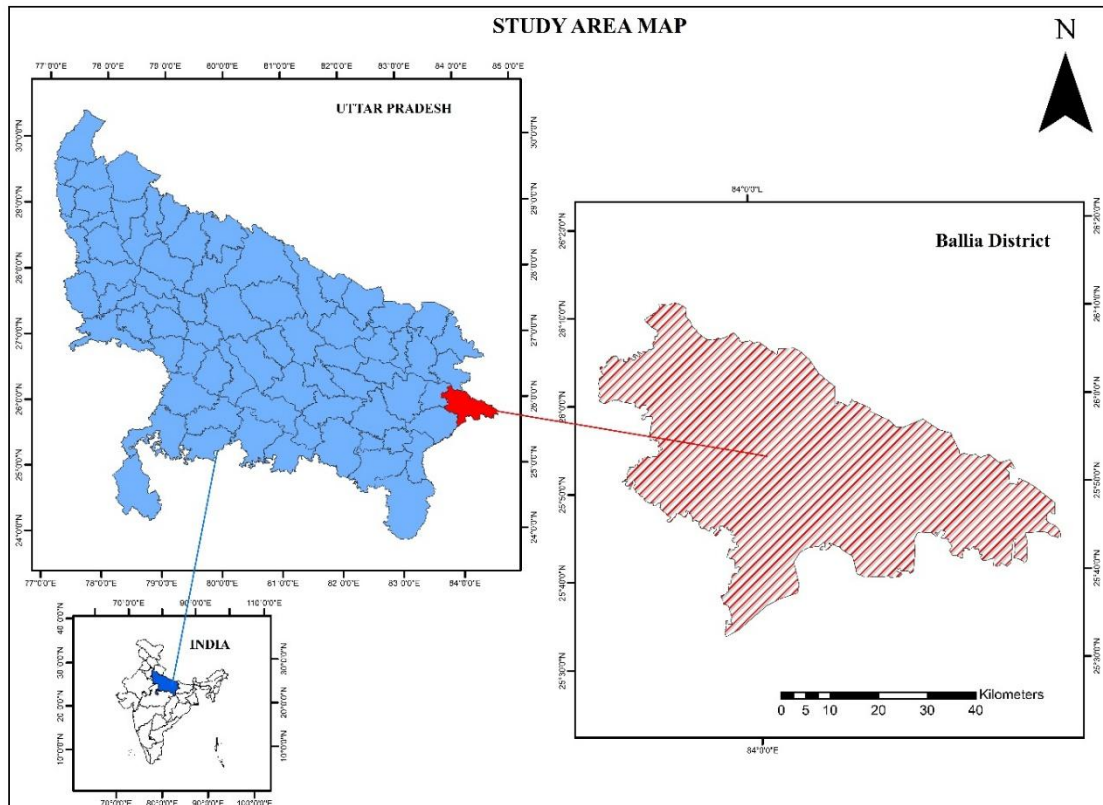


Figure: 1 Study area map of Ballia district, Uttar Pradesh, India

Furthermore, the economy of Ballia district is predominantly agrarian, with a large proportion of the population dependent on agriculture and allied activities. The presence of fertile soils and availability of water resources contribute to intensive cropping practices in the region. However, the district is also prone to seasonal flooding due to its proximity to major rivers, which often leads to changes in land cover and vegetation conditions. Therefore, this study area was selected to analyze Spatio-temporal variations in land use/land cover and vegetation health, as it provides a dynamic landscape influenced by both natural and anthropogenic factors.

### 3. Result

The Spatio-temporal analysis of Ballia district reveals significant transformations in land surface characteristics between 2017 and 2024. The results of this study are systematically categorized into two major components, namely Land Use/Land Cover (LULC) changes and

NDVI-based vegetation dynamics, in order to provide a comprehensive understanding of environmental change within the study area.

### 3.1.Land Use and Land Cover

The spatial distribution of LULC classes for the years 2017 and 2024 is presented in Figure 1(A) and Figure 2(B), respectively. A detailed quantitative assessment, as shown in Table 1, indicates a substantial expansion in both agricultural land and built-up areas over the study period. Agricultural land, which represents the dominant land use class in the district, increased significantly from 186,840.71 hectares in 2017 to 205,670.65 hectares in 2024, thereby recording a net gain of 18,829.94 hectares. Similarly, the built-up area exhibited a noticeable increase of 2,683.63 hectares, rising from 47,989.10 hectares to 50,672.73 hectares, reflecting ongoing urbanization and infrastructural development.

Table: 1 Land Use/Land Cover (LULC) category-wise area distribution and change analysis for Ballia district between 2017 and 2024 (area in hectares), based on Dynamic World dataset

Land Use Category	2017 (ha)	2024 (ha)	Change
Water	13618.81	13026.64	↓ -592.17
Vegetation	21766.04	7018.73	↓ -14747.31
Agriculture	186840.71	205670.65	↑ +18829.94
Built-up	47989.10	50672.73	↑ +2683.63
Barren Land	28836.78	22663.81	↓ -6172.97
Others	0.19	0.06	~

In contrast, other land cover categories experienced a considerable decline. Vegetation cover showed a sharp reduction, decreasing from 21,766.04 hectares in 2017 to 7,018.73 hectares in 2024, resulting in a substantial net loss of 14,747.31 hectares. Moreover, barren land decreased by 6,172.97 hectares, while water bodies recorded a slight decline of 592.17 hectares over the same period. Furthermore, Figure 2(C) illustrates the spatial extent of land use transitions, where change areas are highlighted in red. These changes are predominantly concentrated along riverbanks and in peri-urban zones, indicating the combined influence of fluvial processes and expanding human activities.

### 3.2.Vegetation Health and NDVI Dynamics

The Normalized Difference Vegetation Index (NDVI) maps, depicted in Figure 3(A) and Figure 3(B), illustrate the spatial and temporal variations in vegetation health across the district. As indicated in Table 2, the maximum NDVI value increased slightly from 0.74 in 2017 to 0.78 in 2024, suggesting localized improvements in peak vegetation conditions. Similarly, the minimum NDVI value showed a marginal increase from -0.25 to -0.22, indicating slight changes in non-vegetated or sparse vegetation areas.

Table: 2 Temporal variation in NDVI-based vegetation characteristics of Ballia district for the years 2017 and 2024, showing total green area (km<sup>2</sup>) and changes in maximum and minimum NDVI values

Parameter	2017	2024	Net Change
Total Green Area (km <sup>2</sup> )	2,889.49	2,871.38	-18.11
NDVI Max Value	0.74	0.78	+0.04
NDVI Min Value	-0.25	-0.22	+0.03

However, despite the observed increase in peak NDVI values, the overall vegetation extent exhibited a declining trend. As presented in Table 2, the total green area decreased from 2,889.49 km<sup>2</sup> in 2017 to 2,871.38 km<sup>2</sup> in 2024, resulting in a net loss of 18.11 km<sup>2</sup> of vegetative cover. This indicates that while certain areas may have experienced improved vegetation density, the overall spatial extent of vegetation has reduced. Furthermore, the spatial distribution of vegetation change is illustrated in Figure 3(C), where the NDVI change map highlights areas of gain (blue) and loss (red/orange). The observed pattern is highly heterogeneous, with distinct clusters of vegetation degradation evident across the district. These patterns suggest that vegetation dynamics are influenced by localized factors, including land use conversion, agricultural intensification, and urban expansion.

#### 4. Discussion

The findings of this study indicate that Ballia district has undergone substantial land surface transformations between 2017 and 2024, characterized by the expansion of agricultural and built-up areas alongside a notable decline in vegetation cover and overall green area. Such patterns of land transformation are widely reported in rapidly developing regions, where increasing population pressure and economic activities drive land conversion (Lambin et al., 2003).

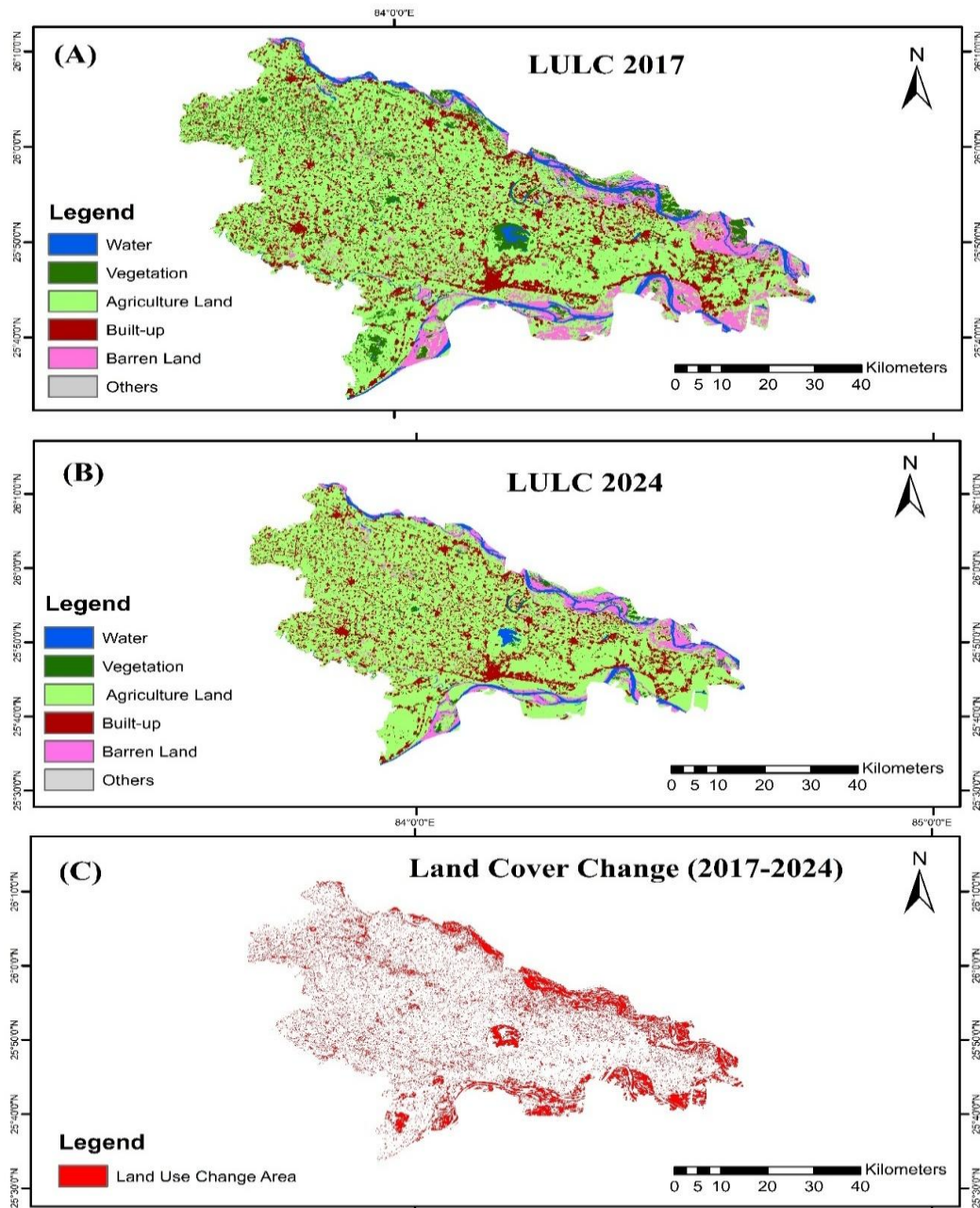


Figure 2 Spatio-temporal distribution of Land Use/Land Cover (LULC) in Ballia District: (A) LULC 2017, (B) LULC 2024, and (C) Identified land cover change areas during 2017–2024

Furthermore, the observed combination of localized vegetation improvement and overall decline reflects the complex interaction between land use intensification and ecological processes. The implication of these findings is that unchecked land transformation may lead to long-term ecological imbalance and reduced environmental resilience.

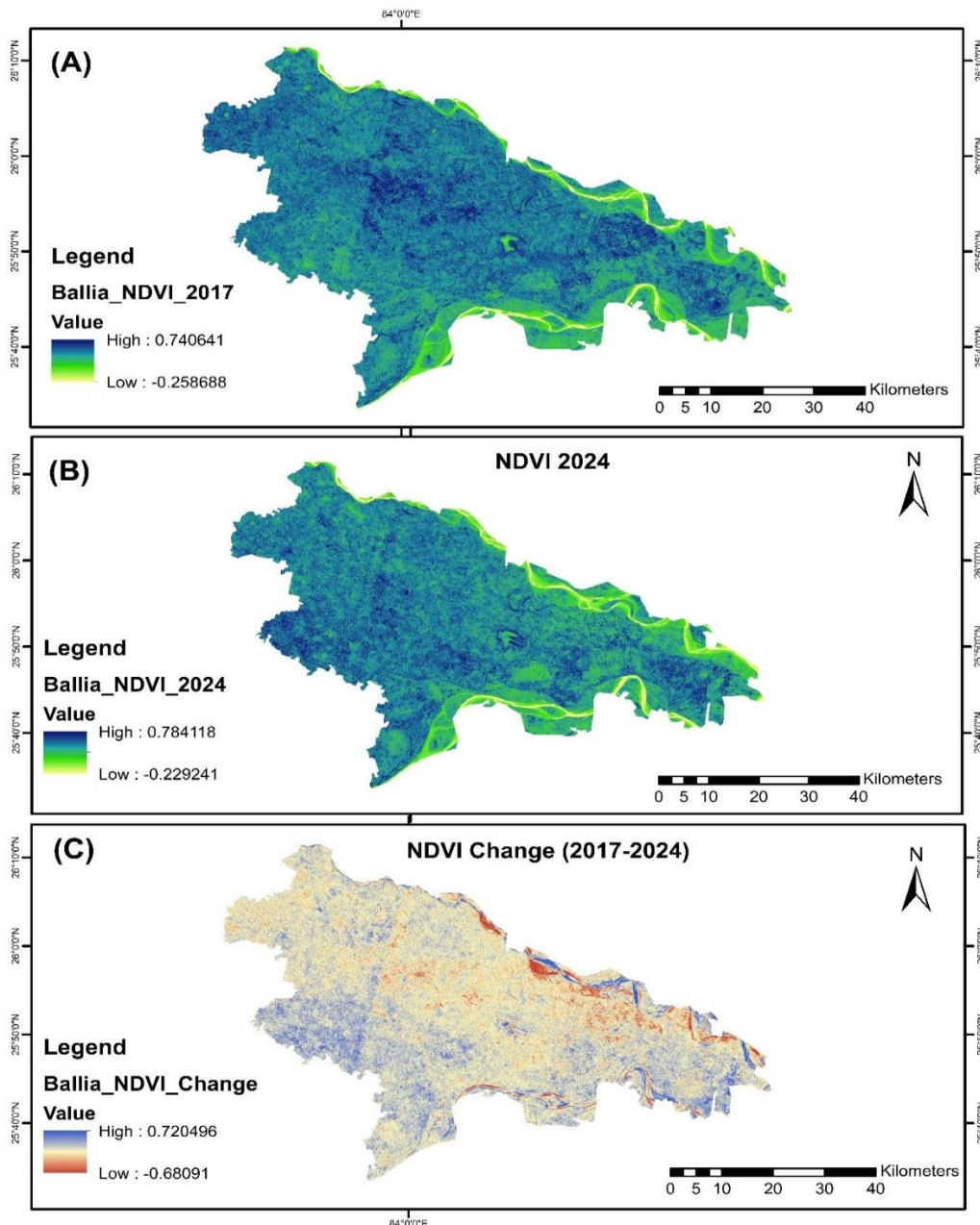


Figure 3 Vegetation Dynamics and NDVI variation in Ballia District: (A) NDVI 2017, (B) NDVI 2024, and (C) Spatial map of NDVI change between 2017 and 2024

Furthermore, the spatial heterogeneity observed in both LULC and NDVI changes suggests that environmental transformations are unevenly distributed across the district. This finding is consistent with land change science literature, which highlights that such processes are often spatially clustered and influenced by localized socio-economic and environmental factors (Turner et al., 2007). The clustered distribution of land conversion and vegetation loss observed in this study indicates that certain areas are more vulnerable, particularly regions near riverbanks and expanding settlements. The implication of this spatial variability is that uniform land management strategies may not be effective, thereby necessitating targeted and location-specific interventions for sustainable land use planning.

## 5. Conclusion

The results revealed a significant increase in agricultural land and built-up areas, accompanied by a decline in vegetation cover, barren land, and water bodies. These changes indicate the growing impact of anthropogenic activities on the regional landscape. Furthermore, NDVI analysis showed a slight improvement in vegetation health; however, the total green area decreased over time. This suggests that localized vegetation gains are insufficient to compensate for the overall loss of green cover. Overall, the findings highlight the need for sustainable land use planning to balance development and environmental conservation.

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