



ISSN : 2350-0743



## RESEARCH ARTICLE

### TRACKING URBAN GREEN COVER TRANSFORMATION IN HYDERABAD THROUGH NDVI-BASED SPATIO-TEMPORAL ANALYSIS (2000–2024)

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#### ARTICLE INFO

##### Article History

Received 14<sup>th</sup> November, 2025  
Received in revised form  
20<sup>th</sup> December, 2025  
Accepted 15<sup>th</sup> January, 2026  
Published online 27<sup>th</sup> February, 2026

##### Keywords:

Urban Vegetation, NDVI, Urbanisation, Remote Sensing, Climate Resilience.

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#### ABSTRACT

In Indian metropolitan cities rapid administration has significantly transformed the land surfaces and ecological conditions. There is a direct implication for the urban climate and environmental sustainability. Hyderabad which is one of the fastest growing cities in southern India has experienced extensive spatial expansion over the past two decades. This study will be examining the spatiotemporal dynamics of the urban vegetation in Hyderabad by using the normalised difference vegetation index NDVI. Which is an indicator of vegetation health and density. Three distinct periods multi temporal satellite data were analysed 2000-04, 2010-2014, 2020-2024 to capture long term vegetation trends which is associated with different phases of urban growth. The study results reveal that there is a progressive decline and fragmentation of vegetated areas. The change is particularly observed along the major urban expansion corridors in the West common north western and eastern parts of the city. The research also observed that the NDVI values persist in reservoir catchment defence lands and institutional real gas. But the spatial extent of the urban green cover has considerably reduced overtime. These vegetation changes indicate increasing ecological strengths and also reduce to capacity for the climate regulation within the urban environment. This study once a highlights the effectiveness of NDVI based remote sensing for long term monitoring of urban vegetation and emphasis users the need to integrate green infrastructure planning into Urban Development policies. It will enhance the climate residence and environmental sustainability in rapidly growing cities.

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Citation: Ms. Pratusha, Sr. Prof. B. Srinagesh, Sourav Pattanaya et al. 2026. "Tracking Urban Green Cover Transformation in Hyderabad Through NDVI-Based Spatio-Temporal Analysis (2000–2024)", *International Journal of Recent Advances in Multidisciplinary Research*, 13,(02), 12131-12138.

## INTRODUCTION

Urbanization in developing countries, particularly in Asia, has emerged as a major driver of environmental change. Since the mid-20th century, cities have experienced rapid spatial expansion, resulting in extensive land-use and land-cover transformations. While urban growth supports economic development and infrastructure expansion, it simultaneously exerts considerable pressure on natural ecosystems, especially urban vegetation (Seto *et al.*, 2012). The loss and fragmentation of green spaces have far-reaching implications for ecological balance, urban climate regulation, and long-term environmental sustainability. Urban vegetation provides essential ecosystem services that play a crucial role in maintaining ecological stability. Green spaces contribute to temperature regulation, mitigation of the urban heat island effect, improvement of air quality, enhancement of groundwater recharge, and conservation of urban biodiversity (Bowler *et al.*, 2010). However, rapid and often unplanned urban expansion has led to the conversion of vegetated land into impervious surfaces, disrupting surface energy balance and hydrological processes. Such transformations increase

environmental stress, reduce urban resilience, and intensify vulnerability to climate extremes (Grimm *et al.*, 2008). Remote sensing has emerged as an effective and reliable tool for monitoring vegetation dynamics across different spatial and temporal scales. Numerous studies demonstrate that declining NDVI values in rapidly urbanizing areas reflect the replacement of natural vegetation with built-up surfaces (Wang *et al.*, 2004; Li *et al.*, 2015). In the Indian context, several NCBI-indexed studies highlight significant vegetation loss in major metropolitan regions due to population growth, infrastructure development, and peri-urban expansion. However, many of these studies are limited to short time frames or broad regional scales, restricting the ability to capture long-term urban ecological change. Hyderabad, one of India's fastest-growing metropolitan cities, provides a compelling case for analyzing urban vegetation dynamics. Over the past two decades, the city has undergone rapid spatial and economic transformation driven by population growth, expansion of the information technology sector, industrial development, and large-scale infrastructure projects. These processes have significantly altered the urban landscape, raising concerns about declining green cover, ecological

imbalance, and environmental instability (Ramachandra *et al.*, 2014). Despite extensive urbanization, comprehensive long-term assessments of vegetation dynamics using consistent multi-temporal datasets remain limited. Understanding vegetation change across different phases of urban development is essential for identifying zones of ecological stress and informing sustainable urban planning strategies. A multi-decadal NDVI-based analysis enables the examination of both spatial and temporal variations in vegetation cover, providing insights into patterns of decline, persistence, and transformation. Against this background, the present study analyzes the spatio-temporal dynamics of vegetation cover in Hyderabad using NDVI data for 2000–2004, 2010–2014, and 2020–2024. The findings are expected to contribute to urban environmental research and support policy initiatives aimed at promoting sustainable and resilient urban development.

**Urbanization and vegetation dynamics:** Urbanization is a major driver of land use and land cover change in developing countries, where the expansion of built-up areas often occurs at the expense of natural and semi-natural vegetation. This process leads to habitat loss, landscape fragmentation, and ecological imbalance (Seto *et al.*, 2012). Urban growth alters surface characteristics, reduces green cover, and modifies local climatic conditions, increasing environmental stress in cities (Grimm *et al.*, 2008). In India, rapid population growth, infrastructure development, and economic restructuring have accelerated urban expansion, resulting in a significant decline in vegetation, particularly in core urban zones. This loss of vegetation adversely affects biodiversity, intensifies the urban heat island effect, and degrades overall environmental quality (Sudhira *et al.*, 2004).

**Role of urban vegetation in environmental sustainability:** Urban vegetation provides essential ecosystem services that support environmental sustainability in cities. Green spaces regulate microclimates by reducing surface and air temperatures through shading and evapotranspiration (Bowler *et al.*, 2010). Vegetation also improves air quality, enhances soil stability, supports urban biodiversity, and promotes human well-being (Tzoulas *et al.*, 2007). Cities with higher vegetation cover show greater resilience to climate extremes, while vegetation loss increases surface runoff, flood risk, and thermal discomfort (Gill *et al.*, 2007), highlighting the need to monitor vegetation change for sustainable urban planning and climate adaptation.

**NDVI as a tool for vegetation assessment:** The Normalized Difference Vegetation Index (NDVI) is widely used in remote sensing to assess vegetation health, density, and spatial distribution. Introduced by Tucker in 1979, it exploits the contrast between red and near-infrared reflectance to quantify photosynthetic activity. NDVI values close to +1 indicate dense vegetation, while values near zero or negative represent sparse vegetation or built-up surfaces. Owing to its simplicity and consistency across sensors such as Landsat, MODIS, and Sentinel, NDVI is particularly useful for long-term vegetation monitoring and urban green cover assessment (Pettorelli *et al.*, 2005; Weng *et al.*, 2004).

**Multi temporal NDVI analysis in Urban studies:** Multi-temporal NDVI analysis enables the detection of long-term trends and seasonal variations in vegetation cover. Time-series NDVI studies across rapidly urbanizing regions in Asia, Africa, and Latin America report consistent declines in urban cores and transitional zones of newly developed areas. In

India, NDVI-based analyses reveal significant vegetation degradation in metropolitan cities such as Delhi, Bengaluru, Mumbai, and Hyderabad due to unplanned urban growth. These studies emphasize that long-term NDVI datasets are essential for understanding the cumulative impacts of urbanization and for identifying spatial patterns of environmental stress not evident in short-term analyses.

**Research gap:** Hyderabad experiencing rapid economic growth and special expansion. Remote sensing and GIS have been used to study urban sprawl, land use change, and landscape fragmentation. Some studies also have incorporated NDVI to vegetation distribution and its relationship with land surface temperature highlighting the ecological consequence of urban growth. Most Hyderabad studies are short-term or focus on one urban zone. This limits their long-term vegetation dynamics capture. There is a lack of comprehensive multi decadal analysis that is comparing the vegetation change across different phases of Urban Development using consistent NDVI data set. This gap highlights the necessity for comprehensive spatio-temporal vegetation dynamics assessment over several time intervals. This study analyses long-term vegetation change in Hyderabad using multi-temporal NDVI data from 2000–2004, 2010–2014, and 2020–2024. The study examines special partners and temporal trains to better understand urban environmental change and support evidence-based urban planning and sustainable initiatives.

**Study area:** Hyderabad is the capital city of Telangana state. It is located in the South Central part of India in the Deccan plateau. Hyderabad is located with an average elevation of about 536 metres above mean sea level. Hyderabad is occupying a predominantly rocky terrain interspersed with low hill ranges plateaus and shallow valleys. Hyderabad has formed a major administrative economic and technological hub in southern India and has experienced a rapid urban growth over past few decades. Hyderabad falls under semi arid tropical climate. It is characterised by hot summers moderate monsoon rainfall and mild winters. The city receives majority of its annual rainfall during the southwest monsoons between June and September. The average annual rainfall is approximately 750 to 800 millimetres. Hyderabad has a mosaic of agricultural, hill terrain, waterways, and rocky outcrops. The Musi River and tanks and lakes like Hussain Sagar maintained the city's ecology. Since early 2000, the city has grown rapidly. Vast vegetation and agricultural land have been converted into residential, commercial, and industrial districts. Information technology corridors, transit infrastructure, and peri urban communities change the distribution of green areas in cities. Metropolitan Hyderabad, managed by the Greater Hyderabad Municipal Corporation, is the study area. Peri-urban and rural areas are being incorporated into urban fabric as the metro region expands outward. Fast rapid growth has put pressure on existing vegetation. This fragments and reduces green cover, especially in urban cores and newly developed periphery zones. The ecological impact of urbanization can be understood by studying Hyderabad's vegetation patterns. Hyderabad's varied land use pattern, climate variability, and long-term urban expansion make it ideal for multi-temporal NDVI-based urban vegetation change assessment.

#### Objectives of the study

- To analyse the spatial distribution of NDVI in Hyderabad for selected time periods.

- To examine temporal changes in vegetation cover between 2000–2024.
- To identify areas experiencing significant vegetation decline and areas where vegetation has remained relatively stable.

## Data and methodology

**Data sources:** This study uses multi-temporal satellite imagery to analyze vegetation dynamics in Hyderabad across three phases: 2000–2004, 2010–2014, and 2020–2024. Medium-resolution data were selected for consistency, long-term availability, and suitability for urban-scale analysis. Landsat imagery served as the primary data source, with Landsat 5 TM used for 2000–2004, Landsat 7 ETM+ for 2010–2014, and Landsat 8 OLI for 2020–2024. Images were acquired under cloud-free or minimal cloud conditions. The 30 m spatial resolution effectively captures vegetation patterns in heterogeneous urban landscapes. The satellite data which is obtained from the United States Geological Survey earth explorer platform. Administrative boundary data corresponding to the greater Hyderabad municipal corporations were used to extract the study area from the satellite imagery.

**Image preprocessing:** Prior to NDVI computation, standard image preprocessing steps were performed to ensure data quality and temporal compatibility. These included radiometric, atmospheric, and geometric corrections. Cloud-contaminated pixels were identified and excluded using quality assessment bands provided with the Landsat dataset. To minimize seasonal variability in vegetation reflectance, images from similar months were selected across all study periods, ensuring that NDVI variations primarily reflect long-term vegetation dynamics rather than short-term seasonal fluctuations. All processed images were clipped to the study area boundary for spatial consistency.

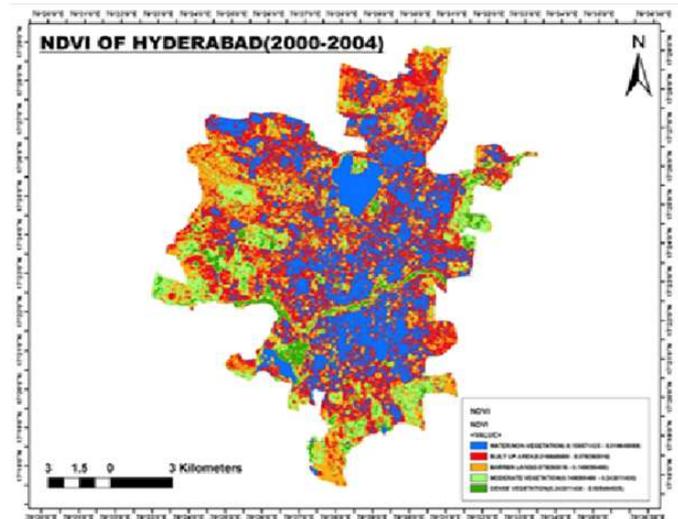
**NDVI Calculation:** The normalised difference vegetation index is widely used to assess the vegetation condition and the distribution across the region. It is widely used to spectral indexed derived from red and the near red infrared bands of satellite imagery (Tucker, 1979).

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

Where the NIR Represents reflectance in the near infrared band and the red represents the reflectance in the red band. The NDVI values range from -1 to +1 where the higher positive values are indicating dense and healthy vegetation, values near zero representing sparse vegetation or buildup services and negative values are corresponding to water bodies or barren land. The NDVI maps are generated separately to each study period to enable spatial and temporal comparison of the vegetation cover and to facilitate the interpretation the NDVI values are classified into categories such as low moderate and high vegetation density based on a standard threshold range commonly used in urban vegetation studies.

**Temporal and spatial analysis:** The temporal analysis carried out by comparing the NDVI maps across the 3 different time periods to identify the changes of vegetation cover and specially difference. The mean NDVI values and the areal extent of the different in NDVI classes were computed for each accordingly. Changes between consecutive periods were analysed to assess the trends in vegetation loss persistence or

transition. Spatial analysis is focusing on identifying zones of significant vegetation decline and also the areas where vegetation remains relatively stable overtime. The results were interpreted in relationship to the patterns of urban expansion. Basic descriptive statistics were employed to summarise NDVI variation and support special interpretation.



Source: Generated by author from Landsat satellite imagery

Figure 1. NDVI of Hyderabad (2000-2004)

## Data analysis and results

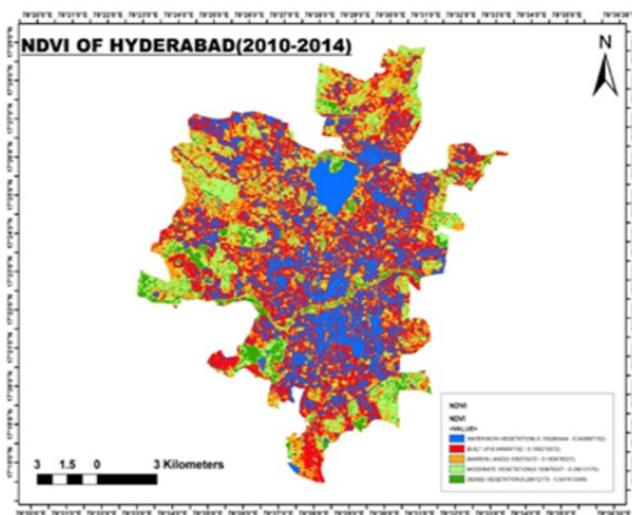
**Normalised Difference Vegetation Index (NDVI) of Hyderabad in 2000-2004:** The figure 1 represents the Normalized Difference Vegetation Index (NDVI) of Hyderabad during the period of 2000–2004. It is a widely used index which helps to study the density, health, and distribution of vegetation across different landscapes. Hence, the above image provides a valuable insight into the distribution and condition of Hyderabad's vegetation cover during 2000s and it also helps in distinguishing densely vegetated areas from barren, rocky, or built-up zones. Here the High NDVI value is 0.50549 and the Low NDVI value is -0.108571. These high and low values represent the differences in vegetation cover and land surface character.

### NDVI Specific Spatial Patterns

**High NDVI Zones (Green-Light green shades):** The image shows that areas with higher NDVI values are mainly concentrated in the eastern, southern, and parts of central Hyderabad. In the eastern region, high NDVI is observed along the Musi River, Uppal, and Ghatkesar, indicating dense vegetation, with notable green tones near the eastern edges of Hussain Sagar Lake. The southern region exhibits high NDVI over peri-urban agricultural areas around Shamshabad, Rajendranagar, and Hayathnagar. In central Hyderabad, green patches within KBR National Park, the Osmania University campus, and public gardens reflect the presence of urban greenery amid dense built-up areas.

**Low NDVI Zones (Red-Orange shades):** The image indicates that low NDVI values are mainly concentrated in the northern, northwestern, and western parts of Hyderabad. The northern region, including Begumpet, Secunderabad, Moulali, and Nacharam, shows dominant red to orange patches due to dense urban and industrial development with limited

vegetation. In the western areas such as Kukatpally, Miyapur, Madhapur, and Gachibowli, low NDVI reflects large-scale residential and IT corridor expansion that replaced scrublands. The northwestern region around Jeedimetla and Balanagar is characterized by barren and fragmented open spaces associated with industrial complexes.



Source: Generated by author from Landsat satellite imagery.

Figure 2. NDVI of Hyderabad (2010 -2014)

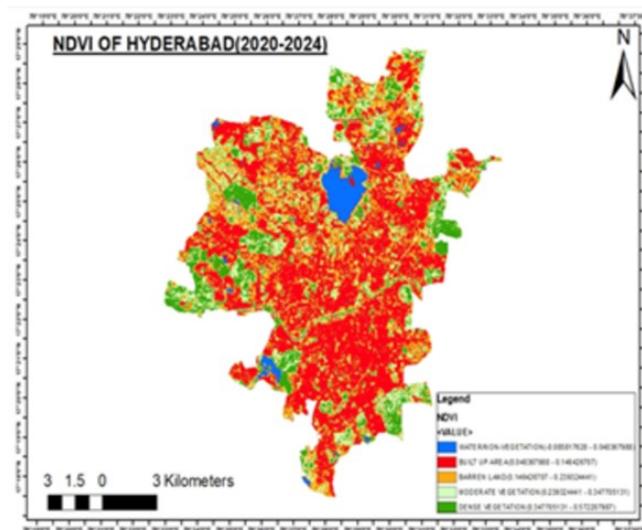
**Normalised Difference Vegetation Index (NDVI) of Hyderabad in 2010-2014:** The figure2represents the Normalized Difference Vegetation Index (NDVI) of Hyderabad during the time period of 2010–2014. NDVI indicates vegetation density and health. Here the High NDVI value is 0.54741 and the Low NDVI value is –0.155260. These high and low values represent the differences in vegetation cover and land surface character. In 2000–2004, High NDVI was 0.50549, and Low NDVI was -0.108571. The change in maximum NDVI shows reduced vegetation density and health, while the change in minimum shows expansion of barren/built-up lands.

**NDVI Specific Spatial Patterns**

**High NDVI Zones (Green-Light green shades):** The image shows that higher NDVI values remain concentrated in eastern, southern, and parts of central Hyderabad. In the eastern region, areas along the Musi River, Uppal, and Ghatkesar continue to exhibit high NDVI, though slightly reduced compared to 2000–2004. The southern peri-urban agricultural zones around Shamshabad, Rajendranagar, and Hayathnagar still show notable vegetation but have decreased in extent due to urban expansion. In central Hyderabad, green patches persist within KBR National Park and the Osmania University campus, although they appear more fragmented during 2010–2014.

**Low NDVI Zones (Red-Orange shades):** The image indicates that low NDVI values are concentrated in the northern, northwestern, and western parts of Hyderabad. The northern region, including Begumpet, Secunderabad, Moulali, and Nacharam, continues to exhibit low NDVI as in 2000–2004, with further vegetation decline due to urban expansion by 2010–2014. In the western areas such as Kukatpally, Miyapur, Madhapur, and Gachibowli, NDVI values have intensified from moderate to low as residential colonies and IT corridor development expanded. The northwestern region

around Jeedimetla and Balanagar shows increased dominance of red patches, reflecting continued industrial activity and further vegetation loss since 2000–2004.



Source: Generated by author from Landsat satellite imagery.

Figure 3. NDVI of Hyderabad (2020 -2024)

**Normalised Difference Vegetation Index (NDVI)of Hyderabad in 2020-2024:** The above image 3 depicts the Normalized Difference Vegetation Index (NDVI) of Hyderabad for the period 2020–2024. NDVI is widely used to assess vegetation density, health, and spatial distribution across landscapes. The image provides insights into the condition and distribution of vegetation in Hyderabad, clearly distinguishing densely vegetated areas from barren, rocky, or built-up zones. During this period, NDVI values range from a high of 0.57 to a low of –0.09, reflecting significant variations in vegetation cover and land surface characteristics across the city.

**NDVI Specific Spatial Patterns**

**High NDVI Zones (Green-Light green shades):** The image indicates that higher NDVI values are concentrated in the northern, eastern, and western regions of Hyderabad. In the northern part, areas such as Secunderabad, Alwal, Bolarum, Yapral, and Trimulgherry exhibit high NDVI due to the presence of preserved green patches. Defence and cantonment areas maintain substantial tree cover by restricting urban expansion, while lakes such as Kapra and Safilguda support riparian vegetation. Institutional lands also contribute to canopy cover. In the eastern region, areas like Uppal, Medipally, Keesara, and the fringes of LB Nagar show moderate NDVI with scattered agricultural fields and scrub vegetation. The western region displays strong green NDVI values around the catchments of Osman Sagar, Himayat Sagar, Gandipet, and the Chilkur belt, where lake ecosystems and institutional campuses such as the University of Hyderabad and IIT sustain dense vegetation.

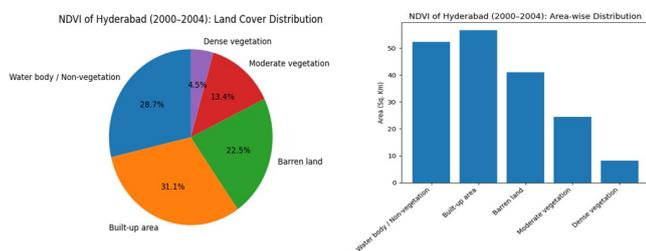
**Low NDVI Zones (Red- orange shades):** The image shows that low NDVI values in Hyderabad are mainly concentrated in parts of the northern, eastern, and western regions. In the northern region, highly urbanized areas of Secunderabad, along with commercial corridors, railway zones, and market precincts, display low NDVI, as do newly developed residential layouts on the city’s edges. In the eastern region,

rapidly urbanizing corridors along the Uppal–LB Nagar–Keesara axis and areas near highways show reduced vegetation due to the conversion of cropland and orchards into built-up areas and construction sites. In the western region, the IT and commercial spine encompassing Madhapur, Gachibowli, Kondapur, and the Financial District exhibits extensive low NDVI patches, with quarries, rocky surfaces, and active construction zones around Kondapur and Narsingi further contributing to reduced vegetation cover.

**Table 1. NDVI of Hyderabad (2000-2004)**

NDVI of Hyderabad(2000-2004)			
Sl.No	Features	Area(Sq.Km)	Percentage
1	Water Body/Non-Vegetation	52.31482147	28.65645685
2	Built Up Area	56.72613369	31.07283856
3	Barren Land	40.99689981	22.45684602
4	Moderate Vegetation	24.38412435	13.35687646
5	Dense Vegetation	8.136603372	4.456982111

Source: Generated by Author



Source: Generated by author

**Analysis of NDVI**

**Analysis of NDVI of Hyderabad during time period of 2000-2004:** The NDVI analysis for Hyderabad during 2000–2004 reveals the spatial distribution and condition of vegetation across the city. Built-up and non-vegetated areas dominate the landscape, indicating early stages of intense urbanization. Built-up areas account for 31.07% of the total area, while water bodies and non-vegetated surfaces occupy 28.65%, together covering nearly 60% of the land surface. Barren land constitutes 22.45%, reflecting substantial degradation of natural vegetation and conversion of open land into unproductive surfaces. Moderate vegetation covers 13.36% of the area, mainly in peripheral agricultural zones and scattered green patches. Dense vegetation is limited to only 4.46% and is confined to areas such as KBR National Park, the Osmania University campus, and select peri-urban green belts. This limited extent of dense greenery indicates early signs of ecological stress within the urban core. Overall, the results suggest that vegetation cover was already under pressure during this period, with urban and barren land uses dominating the city landscape. These conditions provide a baseline for understanding subsequent NDVI trends, which reflect further vegetation decline driven by continued urban expansion and infrastructure development.

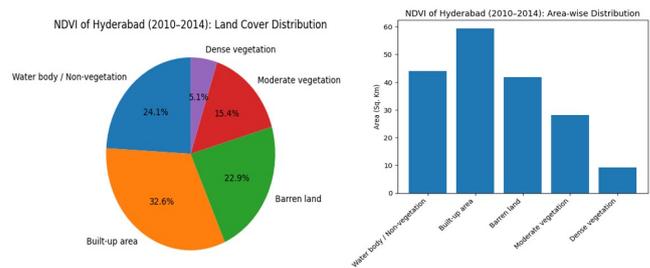
**Area analysis of Hyderabad during time period of 2000-2004:** The data show that built-up areas dominate Hyderabad, covering 56.73 sq. km (31.07%), reflecting the expanding urban core. Non-vegetated and water body areas account for 52.31 sq. km (28.65%), comprising rocky surfaces, degraded lands, and lakes. Barren land covers 40.99 sq. km (22.46%), representing transitional zones cleared for development. Moderate vegetation occupies 24.38 sq. km (13.36%), mainly in peri-urban agricultural areas and scrublands. Dense vegetation is limited to 8.14 sq. km (4.46%), confined to KBR National Park, Osmania University, and select green belts.

Overall, by 2000–2004, Hyderabad was already shifting toward a predominantly built-up landscape, with vegetation restricted to fragmented pockets.

**Table No.2.NDVI of Hyderabad (2010-2014)**

NDVI of Hyderabad(2010-2014)			
Sl.No	Features	Area(Sq.km)	Percentage
1	Water Body/Non-Vegetation	43.95333913	24.07593498
2	Built Up Area	59.43259968	32.55487373
3	Barren Land	41.81887891	22.90676043
4	Moderate Vegetation	28.09657846	15.39021629
5	Dense Vegetation	9.259900693	5.072214566

Source: Generated by Author



Source: Generated by Author

**Analysis of NDVI of Hyderabad during the time period of 2010-2014:** The NDVI analysis of Hyderabad for 2010–2014 indicates continued vegetation decline alongside rapid urban expansion. Built-up areas increased to 32.55% from 31.07% in 2000–2004, reflecting the growing urban footprint, particularly in the western and northern regions driven by IT and residential development. Water body and non-vegetated areas decreased to 24.08%, suggesting conversion of open spaces into built-up land. Barren land remained relatively stable at 22.90%, indicating gradual transformation of open land into construction zones.

Moderate vegetation increased slightly to 15.39%, mainly in peri-urban areas, while dense vegetation remained limited at 5.07%, confined to institutional campuses, parks, and riparian zones. Overall, urban growth continued to dominate the landscape, with vegetation under persistent pressure. The marginal increase in vegetated areas reflects localized green patches rather than ecological recovery, highlighting increasing vegetation stress and progressive urban ecological degradation during this period.

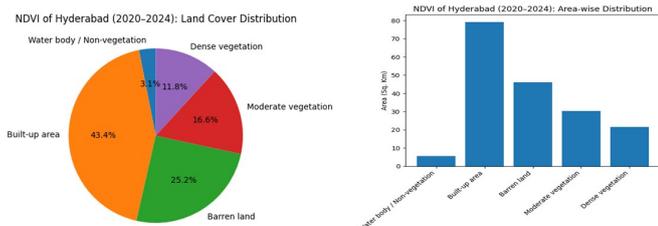
**Area analysis of NDVI of Hyderabad in the time period of 2010-2014:** Built-up area expanded to 59.43 sq. km (32.55%), reflecting a steady rise in urban land coverage compared to 2000–2004. This growth resulted from continued construction, road expansion, and conversion of open spaces into residential and commercial zones. Water bodies and non-vegetated areas declined to 43.95 sq. km (24.08%), indicating encroachment and shrinkage of lakes and open lands under development pressure. Barren land remained nearly constant at 41.82 sq. km (22.91%), representing areas under transition. Moderate vegetation increased slightly to 28.10 sq. km (15.39%), and dense vegetation to 9.26 sq. km (5.07%), possibly due to localized green initiatives or seasonal growth. However, these gains are insufficient to offset overall vegetation loss. Overall, urbanization dominated land-use patterns during 2010–2014,

with green cover largely confined to parks and peripheral areas, signaling growing ecological imbalance and pressure on urban microclimates.

Table 3. NDVI of Hyderabad (2010-2024)

NDVI Of Hyderabad (2020-2024)			
Sl.No	Features	Area(Sq.Km)	Percentage
1	Water Body/Non-Vegetation	5.623833403	3.080466847
2	Built Up Area	79.14925387	43.3541741
3	Barren Land	46.0011246	25.19721498
4	Moderate Vegetation	30.22941922	16.55822942
5	Dense Vegetation	21.56069057	11.80991465

Source: Generated by author



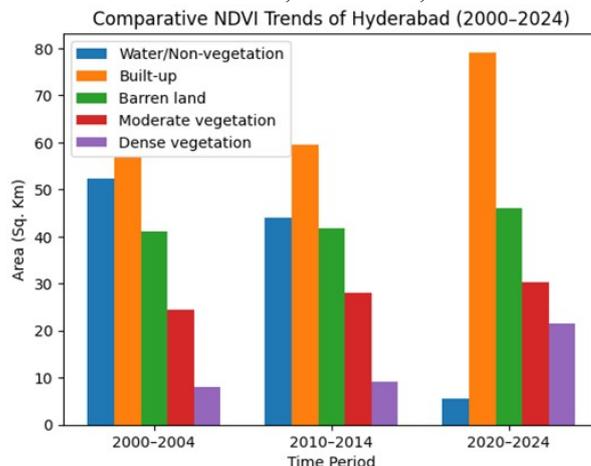
Source: Generated by author

**Analysis of NDVI of Hyderabad during the time period of 2020-2024:** The NDVI assessment of Hyderabad for 2020–2024 highlights the long-term impacts of rapid urbanization on vegetation health and distribution. Built-up areas now cover 43.35% of the city, a sharp increase from earlier periods, reflecting extensive infrastructure growth in western IT corridors, northern residential zones, and peri-urban townships. Barren land has expanded to 25.19%, indicating widespread land clearance and conversion into construction zones. In contrast, water bodies and non-vegetated areas have declined drastically to 3.08%, suggesting the shrinkage of lakes and riparian zones due to encroachment. Moderate (16.55%) and dense vegetation (11.81%) show slight improvement, likely due to localized greening efforts, institutional campuses, and lake restoration projects. However, these green areas remain fragmented within a predominantly urban landscape. Overall, the results reveal severe vegetation fragmentation and loss of natural ecosystems, emphasizing the urgent need for sustainable urban planning and ecological conservation measures.

**Area analysis of NDVI of Hyderabad during time period of 2020-2024:** The NDVI-based land cover analysis for 2020–2024 reveals intensified urban expansion and a marked decline in natural vegetation and water bodies in Hyderabad. Built-up areas increased sharply to 79.15 sq. km (43.35%), reflecting extensive infrastructural development, urban sprawl, and conversion of agricultural and vegetated land into residential, commercial, and industrial uses. Water bodies and non-vegetated areas declined drastically to 5.62 sq. km (3.08%), indicating widespread loss and degradation of lakes and wetlands due to encroachment and siltation. Barren land expanded to 46.00 sq. km (25.20%), representing cleared areas under active or future construction. Despite overall urban dominance, moderate vegetation (16.56%) and dense vegetation (11.81%) show slight improvement, likely due to localized greening initiatives, institutional campuses, and suburban vegetation. Overall, the results indicate that urban land expansion has overtaken natural ecosystems, emphasizing the urgent need for sustainable urban planning, water body

protection, and green space conservation to restore ecological balance.

**Comparative NDVI trend of Hyderabad 2000-2024:** The comparative NDVI-based land use and land cover analysis of Hyderabad across 2000–2004, 2010–2014, and 2020–2024



Source: Generated by author

Graph No.1 Bar graph on Comparative NDVI trends of Hyderabad 2000-2024

reveals significant spatio-temporal changes driven by rapid urbanization. Built-up area shows a consistent increase, rising from 56.73 sq. km in 2000–2004 to 59.43 sq. km in 2010–2014, and sharply to 79.15 sq. km in 2020–2024, highlighting accelerated urban expansion after 2010. In contrast, water bodies and non-vegetated surfaces declined drastically from 52.31 sq. km to just 5.62 sq. km over the study period, indicating severe stress on urban hydrological systems due to encroachment and land conversion. Barren land increased moderately from about 41.00 sq. km to 46.00 sq. km, reflecting transitional construction landscapes. Vegetation trends show mixed responses: moderate vegetation gradually increased from 24.38 sq. km to 30.23 sq. km, while dense vegetation expanded markedly from 8.14 sq. km to 21.56 sq. km by 2020–2024. This selective recovery suggests the influence of urban greening initiatives, afforestation, and peri-urban vegetation growth. Overall, the NDVI trends depict a landscape increasingly dominated by built-up areas, with substantial loss of water bodies and uneven vegetation recovery amid rapid urban growth.

## DISCUSSION

The spatio-temporal NDVI analysis of Hyderabad is revealing that there is significant changes in the urban vegetation patterns between 2000 and 2024. The maximum NDVI values show a marginal increase over the time. Where as the spatial distribution and extent of high NDVI zones have progressively fragmented. This is indicating that vegetation persistence is largely confined to the protected or restricted access area rather than being evenly distributed across the urban landscape.

**Urban expansion and vegetation decline:** The expansion of low NDVI zones across western, northwestern, and eastern Hyderabad closely corresponds with phases of intense urban growth. Areas such as Madhapur, Gachibowli, Kondapur, and the Financial District have undergone large-scale conversion of scrubland, agricultural land, and rocky terrain into

residential, commercial, and IT infrastructure. Vegetation loss has occurred along distinct urban growth corridors rather than uniformly. Peri-urban regions that exhibited high NDVI in the early 2000s show reduced vegetation in later periods, indicating the gradual absorption of rural landscapes into the urban fabric and highlighting these zones as areas of high ecological transition and vulnerability.

#### **Fragmentation and spatial reorganisation of green spaces:**

Beyond overall vegetation loss, NDVI analysis reveals increasing fragmentation of urban green spaces. Large contiguous vegetated patches present during 2000–2004 have been progressively broken into smaller, isolated fragments by road networks, residential layouts, and commercial development, reducing ecological connectivity and ecosystem service delivery (Grimm *et al.*, 2008). By 2020–2024, higher NDVI values are mainly confined to reservoir catchments such as Osman Sagar and Himayat Sagar, defence lands, institutional campuses, and protected parks. These areas remain relatively insulated from urban expansion due to regulatory controls. Similar patterns have been reported in other Indian cities, where vegetation persistence is largely linked to protected land parcels rather than integrated urban green planning (Ramachandra *et al.*, 2014).

#### **Implications for Urban Climate and Environmental Sustainability:**

Urban vegetation plays a crucial role in regulating microclimate, mitigating urban heat island effects, and improving environmental quality. The observed decline and fragmentation of vegetation cover in Hyderabad suggest increasing vulnerability to thermal stress, reduced evapotranspiration, and altered surface energy balance. Previous studies have demonstrated strong inverse relationships between NDVI and land surface temperature in urban areas, indicating that vegetation loss can intensify urban warming (Weng *et al.*, 2004; Bowler *et al.*, 2010). The spatial confinement of vegetation to limited zones also raises concerns about equitable access to green spaces. As urban expansion continues, the loss of distributed green cover may disproportionately affect densely populated residential areas, reducing environmental quality and urban liveability. These findings underscore the importance of integrating vegetation conservation into urban planning rather than relying solely on isolated green reserves.

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