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Assessment of Floristic Diversity and Vegetation Change by using Field Surveys and Remote Sensing in an Urban Green Space of Shuklapur, Dehradun, India

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Research Article

Keywords: Urban green space, floristic diversity, NDVI time series, vegetation greening, Sen's slope analysis, biological spectrum, raunkiaer spectrum

Posted Date: November 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11295623/v1

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Additional Declarations: No competing interests reported.

Abstract

Urban green spaces support great biodiversity and ecosystem services in growing cities, yet many remain poorly studied, particularly in rapidly urbanising regions like Dehradun Valley. This study presents an integrated field-based and remote sensing assessment of the Shuklapur Urban green space in Dehradun, combining a detailed floristic inventory with a 25-year (2000–2024) satellite-derived NDVI time series to evaluate its compositional richness and vegetation dynamics. Field surveys using the quadrat method recorded a total of 192 vascular plant species belonging to 165 genera and 61 families, dominated by angiosperms (99.48%), among which dicotyledons (85.42%) outnumbered monocotyledons (14.06%). The flora exhibited diverse growth forms, comprising 63 trees, 42 shrubs, 57 herbs, 22 climbers and 8 grasses. Native species accounted for 79.17% of the flora, while the remaining 20.83% comprised exotic and invasive taxa. The biological spectrum of plants showed a phanero-therophytic spectrum with positive deviations of both phanerophytes (64.58%) and therophytes (24.48%), whereas the proportions of hemicryptophytes, chamaephytes and cryptophytes were negatively deviated. NDVI showed considerable interannual variability, with marked dips in 2008 and 2013 (0.32) followed by sustained recovery from 2014. Mean NDVI rose from 0.54 in 2000 to 0.58 in 2024 (~ 9.2%*), and Sen's slope analysis showed that over 94% of the forest area had moderate to very high positive greening trends. These findings highlight the Shuklapur patch as a floristically rich, resilient Urban green space remnant and underscore the need for its protection, long-term monitoring and inclusion in future urban green-space planning.

1. Introduction

Urbanization is among the most transformative and irreversible forms of land-use change on Earth and it is now recognised as a leading driver of biodiversity loss and habitat fragmentation worldwide. As cities continue to expand, remnant forest patches embedded within or along the margins of the urban landscape have become increasingly important. These patches often represent the only remaining opportunity for urban residents to experience natural vegetation, while simultaneously serving as critical refugia for native flora and fauna that would otherwise be displaced by urban development and the continued expansion of built-up areas (Kowarik et al., 2025). Although these forest patches are often small and have been structurally modified by human activities, they can still support remarkably high levels of floristic diversity. Beyond conserving biodiversity, they continue to provide a wide range of essential ecosystem services, including local climate regulation, air purification, carbon sequestration, groundwater recharge, and valuable cultural and recreational benefits for urban residents (Kowarik, 2023).

Documenting the floristic composition of Urban green space fragments is therefore not merely a taxonomic exercise but a necessary first step toward their scientific management and conservation. Several floristic inventories from Indian and South Asian cities illustrate the ecological importance of such patches despite their limited spatial extent. For instance, a survey of the NEERI campus forest in Nagpur, occupying only about 43 hectares, recorded 135 vascular plant species across 115 genera and

53 families and highlighted the role this small Urban green space plays in moderating local temperature and humidity relative to the surrounding built environment (Gupta et al., 2008). Comparable inventories from other rapidly urbanising landscapes, such as the 136 species recorded across 107 genera and 53 families in the Urban green spaces of Chattogram City, Bangladesh (Nandi & Jashimuddin, 2025), and floristic assessments of semi-natural forest fragments elsewhere in India (Devi & Yadava, 2006), reinforce the view that urban and peri-Urban green spaces, although disturbed, can sustain a taxonomically diverse assemblage of trees, shrubs, herbs, climbers, and grasses.

While species richness provides a fundamental measure of biodiversity, the taxonomic structure of a flora offers additional insights into community composition. In particular, the relationship between the number of species and the number of genera (species-to-genus ratio) reflects the distribution of diversity across evolutionary lineages. A low species-to-genus ratio indicates greater generic diversity, with most genera represented by relatively few species, suggesting that the flora encompasses a broader range of evolutionary lineages rather than being dominated by extensive diversification within a limited number of genera. This concept has been widely applied in studies of taxonomic structure and diversification across both terrestrial and marine ecosystems (Krug et al., 2008). Consequently, the species-to-genus ratio provides a simple yet informative complement to conventional measures of species richness for assessing the floristic diversity of a study area.

Although field-based floristic surveys provide a detailed and reliable account of plant species composition at a given point in time, they offer limited information on long-term changes in vegetation condition, canopy cover, and overall ecosystem health. Satellite-derived vegetation indices, particularly the Normalized Difference Vegetation Index (NDVI), have therefore become indispensable tools for monitoring vegetation dynamics over seasonal to multi-decadal timescales (Rouse et al., 1974). NDVI is widely used to assess patterns of vegetation greening and degradation in urban and peri-urban landscapes in response to land-use change, climatic variability, and management interventions (Zhao et al., 2016). Integrating long-term NDVI data with a contemporary floristic inventory enables the condition of a forest patch to be evaluated from both compositional and functional perspectives (Pesaresi et al., 2020). Such an integrated approach is especially valuable in urban environments, where vegetation is continually influenced by anthropogenic pressures and rapid landscape transformation.

The importance of long-term vegetation monitoring is especially evident in the Doon Valley of Uttarakhand, where Dehradun has experienced rapid urbanization since its designation as the state capital in 2000. This largely unplanned expansion has transformed the landscape, with numerous remote sensing studies reporting a sustained decline in forest and vegetation cover across the district over the past three decades. Early change-detection work reported measurable reductions in forest area and seasonal water bodies alongside disproportionate growth of built-up land between 2000 and 2009 (Tiwari & Khanduri, 2011), while more recent multi-temporal assessments spanning 2000–2019 and 2000–2020 have confirmed continued declines in dense vegetation and green space in favour of urban land use, accompanied by a corresponding rise in land surface temperature (Jana et al., 2020; Jaiswal et al., 2025). Complementary analyses of land use, air quality and temperature dynamics across the district

likewise point to sustained pressure on the region's remaining natural vegetation (Dhankar et al., 2024). Within this broader context of regional forest and green-space attrition, individual Urban green space patches such as Shuklapur assume disproportionate ecological significance and an evidence-based understanding of their floristic wealth and long-term vegetation trajectory is essential for informing local conservation and urban-planning decisions.

Despite the growing body of land-use and land-cover literature on the Doon Valley, few studies have combined a systematic, ground-based floristic survey with a multi-decadal, satellite-derived vegetation index for an individual Urban green space patch within Dehradun. The present study addresses this gap by (i) documenting the vascular plant species occurring within the Shuklapur urban green space through intensive field survey, and (ii) analysing the NDVI trend of the same patch between 2000 and 2024 to assess long-term changes in vegetation condition. By bringing together these two independent lines of evidence, the study aims to provide a baseline assessment of an Urban green space that can inform its future management and conservation within an increasingly urbanising landscape.

2. Study Area

The present study was carried out in the Shuklapur, Dehradun, Uttarakhand, India. It is an Urban green space situated within the municipal limits of Dehradun and Asharodi forest range, Dehradun Division of Uttarakhand Forest, the capital city of the state of Uttarakhand, in the north-western Indian Himalayan foothill region. The valley experiences a sub-tropical to warm-temperate monsoon climate, with a high annual average rainfall of over 200 cm concentrated largely in the monsoon months of June to September, mild winters and warm summers conditions that historically supported extensive natural forest cover across the valley floor and adjoining foothills (Sharma et al., 2012).

The natural vegetation of the Doon Valley including the Shuklapur falls within the broad category of tropical moist and dry deciduous forest, historically dominated by Sal (*Shorea robusta*) in association with a diverse assemblage of associate tree, shrub, herbaceous species and interspersed with miscellaneous mixed forest types depending on local edaphic and hydrological conditions (Tiwari & Khanduri, 2011). However, in the last 30 years, the valley has undergone significant land-use changes due to Dehradun being declared state capital in 2000 and the population growth, infrastructure development and real-estate boom which has progressively taken over agricultural lands and fragmented the forest cover into patches (Jaiswal et al., 2025; Dhankar et al., 2024). The forest patch continues to exist as one such fragment within this rapidly urbanizing matrix, surrounded by residential and semi-urban land use. The Shuklapur urban green space is a Sal (*Shorea robusta*)-dominated patch characterized by associated tree species such as *Syzygium cumini*, *Mallotus philippensis*, *Litsea monopetala* and *Terminalia bellirica*. To enhance vegetation cover and ecological restoration, the Uttarakhand Forest Department in collaboration with the Himalayan Environmental Studies and Conservation Organization (HESCO) has undertaken afforestation initiatives within the forest using native and multipurpose tree species, including *Quercus leucotrichophora*, *Syzygium cumini*, *Mangifera indica*, *Acer oblongum*, and *Terminalia arjuna*. A perennial spring-fed stream traverses the forest patch,

creating a distinct riparian habitat that supports characteristic moisture-loving tree species such as *Trewia nudiflora*, *Bischofia javanica*, *Populus deltoids*. The green patch, located within the rapidly expanding urban landscape of the Doon Valley and is representative of many remnant forest fragments that persist amidst urban development. It still has a lot of indigenous flora of the valley, but is being more and more affected by other forms of human activity in the vicinity. Shuklapur is an ideal location to combine field and remote sensing efforts to determine vegetation composition and long-term ecological change, due to the richness of plant diversity and the continued anthropogenic pressure.

3. Methodology

3.1 Floristic Assessment

A floristic survey was conducted in Shuklapur urban green space during 2021–2022 to document the vascular plant diversity of the study area, with field visits undertaken across different seasons to ensure comprehensive phenological coverage of the flora. Sampling was carried out systematically across the principal habitat types within the patch, including Sal Forest interiors, forest margins, riparian zones and disturbed sites, using the quadrat method: 10 × 10 m quadrats for the tree layer, 5 × 5 m quadrats for the shrub layer, and 1 × 1 m quadrats for herbs and grasses. All plant species encountered within the quadrats were recorded; most were identified in the field, while photographs were taken for that could not be identified immediately, latter identification were done using regional floras, principally the Flora of Upper Gangetic Plain and Adjacent Siwalik and Sub-Himalayan Tracts (Kanjilal, 1928) and the Herbaceous Flora of Dehradun (Babu, 1977). The study was completely non-destructive in nature. For each recorded species, data on family, genus, growth habit, nativity status and life-form category were compiled.

Life-form analysis followed Raunkiaer's classification system (Raunkiaer, 1934), which groups species according to the position of their perennating buds relative to the soil surface during the unfavourable season. Each species was assigned to one of five life-form categories: Phanerophytes (Ph), Chamaephytes (Ch), Hemicryptophytes (He), Cryptophytes (Cr), and Therophytes (Th) & the biological spectrum of the study area was calculated as the percentage representation of each category relative to the total number of recorded species, using the formula below:

Life-form percentage (%) = (Number of species in a life-form category / Total number of species recorded) × 100

3.2 Landsat Data Acquisition

Landsat Collection 2 Level-2 Surface Reflectance imagery was accessed through the Google Earth Engine Data Catalog (Gorelick et al., 2017). The datasets included Landsat 5 Thematic Mapper (TM; LANDSAT/LT05/C02/T1_L2), Landsat 7 Enhanced Thematic Mapper Plus (ETM+; LANDSAT/LE07/C02/T1_L2), Landsat 8, Operational Land Imager (OLI; LANDSAT/LC08/C02/T1_L2), and Landsat 9 Operational Land Imager 2 (OLI-2; LANDSAT/LC09/C02/T1_L2). Imagery acquired during

May–June of each year from 2000 to 2024 was used to generate annual NDVI composites and assess long-term vegetation dynamics in the Shuklapur forest patch. The datasets are provided by the United States Geological Survey (USGS) and are publicly accessible through the Google Earth Engine Data Catalog.

3.2.1 Availability of Data and Materials

The Landsat Collection 2 Level-2 Surface Reflectance datasets analysed in this study are publicly available from the United States Geological Survey (USGS) through the Google Earth Engine Data Catalog.

Satellite sensor	Full name	Google Earth Engine dataset ID	Data source
Landsat 5 TM	Thematic Mapper	LANDSAT/LT05/C02/T1_L2	Access dataset
Landsat 7 ETM+	Enhanced Thematic Mapper Plus	LANDSAT/LE07/C02/T1_L2	Access dataset
Landsat 8 OLI/TIRS	Operational Land Imager / Thermal Infrared Sensor	LANDSAT/LC08/C02/T1_L2	Access dataset
Landsat 9 OLI-2/TIRS-2	Operational Land Imager 2 / Thermal Infrared Sensor 2	LANDSAT/LC09/C02/T1_L2	Access dataset

The data were accessed and processed using Google Earth Engine (https://earthengine.google.com/; Gorelick et al., 2017). Annual NDVI composites and the associated vegetation-trend results were derived by the authors from these datasets.

3.3 Image pre- processing

All Landsat image processing was conducted in Google Earth Engine. Landsat Collection 2 Level-2 products provide atmospherically corrected surface reflectance data; therefore, the prescribed scale factor and offset were applied to the red and near-infrared bands to obtain surface reflectance values before NDVI calculation. For each year from 2000 to 2024, available imagery acquired during May and June was selected. NDVI was calculated for each selected image, and the resulting NDVI images were combined using a pixel-wise arithmetic mean to generate one annual NDVI composite for each year. Using a common seasonal window helped reduce differences associated with vegetation phenology and facilitated comparison of interannual variations in vegetation greenness.

3.4 Calculation of Normalized Difference Vegetation Index (NDVI)

Vegetation conditions within the Shuklapur urban green space were represented using the Normalized Difference Vegetation Index (NDVI), which is closely associated with vegetation density, biomass, and

ecosystem productivity. Higher NDVI values generally indicate healthier vegetation conditions and greater ecological stability. NDVI is widely used to characterize vegetation greenness and spatial-temporal variations in vegetation condition. The index ranges from − 1 to + 1, with higher values generally indicating denser and healthier vegetation. In this study, NDVI was calculated using the following equation (Rouse et al., 1974).

NDVI= $\frac{NIR-RED}{NIR+RED}$ (1)

3.5 Spatial NDVI analysis

The annual NDVI composites were clipped to the delineated Shuklapur urban green space boundary to characterize the spatial distribution of vegetation greenness over the study period. Spatial NDVI maps were generated for four representative years: 2000, 2010, 2020, and 2024. A common NDVI visualization range of 0-0.8 was applied to all selected annual maps to facilitate direct visual comparison of vegetation greenness among the different years. Higher NDVI values were interpreted as areas exhibiting greater vegetation greenness and relatively higher vegetation density, whereas lower NDVI values represented comparatively sparse or less vigorous vegetation. The spatial patterns observed in the selected years were used to visually assess changes in vegetation greenness across the Shuklapur urban green space during the study period.

3.6 Temporal NDVI Analysis

To characterize the temporal dynamics of vegetation greenness, the annual NDVI composites were summarized over the Shuklapur urban green space boundary using a spatial mean reducer at a 30-m spatial scale. This produced one mean NDVI value for each year from 2000 to 2024. The resulting 25-year time series was used to examine interannual variability and the overall direction of vegetation greenness change. The annual NDVI trajectory was visualized using a time-series line graph, with year as the independent variable and mean annual NDVI as the dependent variable. This temporal analysis was used to identify periods of decline, recovery, and increase in vegetation greenness over the study period. The observed change between the initial and final years may additionally be expressed in Eq. 2.

$$Percentage\ change\ = \frac{NDVI_{2024} - NDVI_{2000}}{NDVI_{2000}} \times\ 100$$

2

where $NDVI_{2000}$ and $NDVI_{2024}$ represent the spatially averaged annual NDVI values for 2000 and 2024, respectively.

3.7 Pixel -wise Sens Slope Analysis

To quantify the spatial pattern and magnitude of long-term NDVI change, Sen's slope estimator was applied on a pixel-by-pixel basis to the annual NDVI time series from 2000 to 2024. For each 30-m pixel, the annual year was assigned as the independent temporal variable and NDVI as the dependent variable.

Sen's slope was then calculated from the median of all pairwise slopes between observations in the time series (Sen,1968). The Sen's slope can be expressed conceptually as:

$$Q_i = \frac{NDVI_j - NDVI_k}{j - k}, \quad j > k$$

3

where $NDVI_j$ and $NDVI_k$represent NDVI values at years j and k, respectively. The Sen's slope β is calculated as the median of all Q_i values.

$$\beta = median\,(Q_i)$$

Positive Sen's slope values indicate an increasing trend in vegetation greenness, whereas negative values indicate a decreasing trend (Sen, 1968).

3.8 Classification of NDVI Trends

For spatial interpretation, the continuous Sen's slope values were categorized into five descriptive trend classes according to the thresholds applied in the GEE analysis:

Class	Sen's slope range	Interpretation
1	< 0	Declining
2	0 to < 0.002	Slight increase
3	0.002 to < 0.005	Moderate increase
4	0.005 to < 0.008	High increase
5	≥ 0.008	Very high increase

These categories represent relative trend magnitudes within the study area and should not be interpreted as universally established ecological thresholds. The classified Sen's slope map was used to visualize the spatial distribution of increasing and decreasing NDVI trends across the forest patch.

4. Results

4.1 Floristic Composition

A total of 192 vascular plant species belonging to 165 genera and 61 families were recorded from the Shuklapur urban green space (Table 1). Angiosperms constituted the dominant component of the flora, represented by 191 species belonging to 165 genera and 60 families, accounting for 99.48% of the total recorded species. Within the angiosperms, dicotyledons were the most diverse group, comprising 164 species distributed among 139 genera and 50 families (85.42%), whereas monocotyledons were

represented by 27 species belonging to 25 genera and 10 families (14.06%). Gymnosperms were represented by a single species, *Araucaria columnaris*, belonging to one genus and one family, contributing 0.52% of the total flora (Table 2). The flora was represented by diverse growth forms, including 63 trees, 42 shrubs, 57 herbs, 22 climber/liana species **&** 8 Grasses (Fig. 2).

Table 1
Taxonomic composition of the flora recorded from the Shuklapur urban green space

Taxonomic Group	Families	Genera	Species	Percentage of Species (%)
Dicotyledons	50	139	164	85.42%
Monoctotyledons	10	25	27	14.06%
Gymnosperm	1	1	1	0.52%
Total	61	165	192	100

4.1.1 Family-wise Distribution

The recorded flora exhibited an uneven distribution among families. Fabaceae was the most species-rich family (17 genera, 20 species), followed by Asteraceae (13 genera, 13 species), Moraceae (4 genera, 10 species), Lamiaceae (8 genera, 9 species), Malvaceae (7 genera, 8 species) and Apocynaceae (8 genera, 8 species) (Fig. 3). Together, these six dominant families contributed 68 species, accounting for 35.42% of the total recorded flora.

4.1.2 Nativity Status

Analysis of species nativity revealed that **79.17%** of the recorded species were **native**, whereas **20.83%** were **exotic** in origin. Major Exotic/Invasive species recorded from the study area were *Ageratum conyzoides, Bidens pilosa, Broussonetia papyrifera, Ipomoea cairica, Ipomoea quamoclit, Ipomoea fistulosa, Lantana camara, Parthenium hysterophorus, Solanum torvum, Solanum viarum, Tridax procumbens*. The spread of these invasive species within the Sal-dominated Shuklapur urban green space is primarily attributable to habitat disturbance, climate change and ongoing human activities.

4.1.3 Biological Spectrum

The biological spectrum of the Shuklapur urban green space flora was dominated by phanerophytes, represented by 124 species (64.58%), followed by therophytes with 47 species (24.48%). Hemicryptophytes accounted for 8 species (4.17%), while chamaephytes and cryptophytes were represented by 7 (3.65%) and 6 (3.13%) species, respectively. Thus, the biological spectrum of the study area was characterized by a phanero-therophytic pattern, with woody perennial species forming the major component of the flora.

Comparison with Raunkiaer's Normal Spectrum (Table 2, Fig. 4) revealed marked deviations in life-form composition. Phanerophytes and therophytes both showed strong positive deviations (+ 18.58% and +

11.48%, respectively), reflecting the dominance of woody perennial vegetation alongside a notable proportion of short-lived annuals. In contrast, hemicryptophytes (− 21.83%), chamaephytes (− 5.35%) and cryptophytes (− 2.87%) were all under-represented relative to the normal spectrum.

Table 2
Biological spectrum (% of all life forms) of study site and its comparison with Raunkiaer's normal spectrum

Life Form	Present Study (%)	Raunkiaer's Normal Spectrum (%)	Percentage Deviation (%)
Phanerophytes (Ph)	64.58	46	+ 18.58
Therophytes (Th)	24.48	13	+ 11.48
Hemicryptophytes (He)	4.17	26	-21.83
Chamaephytes (Ch)	3.65	9	-5.35
Cryptophytes (Cr)	3.13	6	-2.87

4.2 NDVI trends analysis

4.2.1 Temporal Dynamics of NDVI (2000–2024)

The annual mean NDVI of Shuklapur urban green space exhibited considerable interannual variability between 2000 and 2024 (Fig. 1), with values ranging from 0.32 to 0.60. The lowest NDVI values were recorded in 2008 (0.32) and 2013 (0.32), whereas the highest values occurred in 2014 (0.60) and 2022 (0.59). Despite these short-term fluctuations, the overall trend indicates an improvement in vegetation condition over the study period. Mean NDVI increased from 0.54 in 2000 to 0.58 in 2024, representing a net increase of approximately 9.2% over the 25-year period. Following a phase of relatively low NDVI values during 2008–2013, vegetation greenness showed a marked recovery after 2014 and remained comparatively high during the subsequent years. The increasing NDVI values suggest an overall improvement in vegetation vigour and canopy condition within Shuklapur urban green space.

4.2.2 Spatial distribution of NDVI

The spatial NDVI maps revealed noticeable changes in vegetation conditions across Shuklapur urban green space between 2000 and 2024 (Figs. 6 and 7). In 2000, the forest was characterized by predominantly moderate NDVI values, indicating relatively healthy vegetation cover. A decline in vegetation greenness was evident in 2010, with larger areas exhibiting lower NDVI values, particularly along the urban green space margins. This pattern is consistent with the reduction in mean NDVI observed during the same period. The NDVI distribution improved considerably by 2021, with an expansion of areas showing moderate to high vegetation greenness. By 2024, the forest exhibited the highest spatial extent of high NDVI values, reflected by the dominance of green tones across much of

the study area. The central and northeastern portions of the forest showed particularly strong improvement in vegetation condition, while only small peripheral patches remained characterized by relatively lower NDVI values. Overall, the spatial maps indicate a recovery and enhancement of vegetation greenness after 2010, supporting the increasing NDVI trend observed in the temporal analysis.

4.2.3 Spatial Distribution of NDVI Trends Based on Sen's Slope Analysis

Sen's slope analysis revealed a predominantly positive vegetation trend across Shuklapur urban green space during 2000–2024 (Figure Y). The median Sen's slope value was 0.0054 NDVI units year^{-1}, with the 25th and 75th percentile values ranging from 0.0040 to 0.0066, indicating an overall increase in vegetation greenness throughout the study area. The maximum positive slope reached 0.0142, whereas the minimum value was − 0.0036, suggesting that vegetation decline was limited and localized. The classified Sen's slope map highlights distinct spatial patterns of vegetation change across the study area. High and very high positive trends were primarily concentrated in the central and northeastern portions of the study area, whereas negative trends were confined to a few isolated patches along the forest margins. Area statistics further confirmed the dominance of positive vegetation trends. Of the total forest area (0.976 km²), 46.4% was classified under high increase, followed by 38.4% under moderate increase and 9.9% under very high increase. In contrast, slight increase and degradation classes occupied only 4.4% and 1.0% of the total area, respectively. Overall, more than 94% of the forest area exhibited moderate to very high positive vegetation trends, indicating a substantial improvement in vegetation condition and canopy greenness during the study period. Area statistics derived from the classified Sen's slope map (Table X) further confirmed the dominance of positive vegetation trends across Shuklapur urban green space.

Table 4
Area distribution of NDVI trend classes in Shuklapur urban green space (2000–2024)

Trend Class	Area (km²)	Area (%)
Degradation	0.009	0.97
Slight Increase	0.043	4.36
Moderate Increase	0.375	38.41
High Increase	0.452	46.37
Very High Increase	0.096	9.89
Total	**0.976**	**100.00**

5. Discussion

The floristic inventory of the Shuklapur urban green space patch recorded 192 vascular plant species belonging to 165 genera and 61 families, a level of taxonomic richness that compares favourably with other urban and peri-Urban green space fragments in South Asia. The NEERI campus forest in Nagpur, of broadly similar extent, recorded only 135 species in 115 genera and 53 families (Gupta et al., 2008), and the Urban green spaces of Chattogram City yielded 136 species across 107 genera and 53 families (Nandi & Jashimuddin, 2025). The comparatively high species richness at Shuklapur may be related to the habitat heterogeneity of the urban green space, including Sal-dominated forest, forest margins, riparian habitat and disturbed microsites. The coexistence of different vegetation strata and a mixture of native species with naturalised and cultivated species may further contribute to the observed floristic richness. Despite its location within an expanding urban landscape and exposure to anthropogenic pressures such as encroachment, fuelwood and fodder extraction, trampling and the occurrence of exotic and ruderal species, the forest retains a substantial component of native vegetation.

The biological spectrum of the Shuklapur urban green space indicates a predominance of woody perennial life forms, resulting in a phanero-therophytic pattern. The dominance of phanerophytes is consistent with the Sal-dominated forest structure and indicates the importance of established woody vegetation in maintaining the overall physiognomy of the forest patch. The markedly higher percentage of phanerophytes (64.58%) compared with Raunkiaer's normal value (46%) is evidence that the climate of Dehradun is favourable for sustaining tree diversity. A similar phytoclimatic pattern has been reported by other workers from the Sal forest of Ranchi, Jharkhand, the Raipur forest range, Dehradun, and the Sal forest of Gorakhpur, Uttar Pradesh (Kumar et al., 2020; Pandey et al., 2024; Pandey et al., 2024). Therophytes were the second most dominant life form in the study area, indicating a considerable presence of annual plants. Their relatively high representation may be associated with disturbance within the forest (lopping, felling of trees, grazing and fuelwood extraction) and the favourable monsoon period for the growth of annual plants (Bharucha et al., 1944; Singh et al., 1974; Dobhal et al., 2010; Verma et al., 2022). Such conditions favour short-lived plants that complete their life cycle within a favourable period and survive the unfavourable season as seeds. The overall phanero-therophytic pattern suggests that the vegetation of the region reflects a combination of favourable climatic conditions and ongoing anthropogenic disturbance.

The 25-year NDVI time series (2000–2024) provides an important temporal dimension to these compositional findings. The overall increase in annual mean NDVI from 0.54 in 2000 to 0.58 in 2024, corresponding to a net improvement of approximately 9.2%, stands in notable contrast to the broader trajectory of forest and green-space loss documented for the Doon Valley and Dehradun district as a whole over comparable period. Regional assessments have consistently reported declining dense vegetation and forest cover alongside rising built-up area between 2000 and 2020 (Tiwari & Khanduri, 2011; Jana et al., 2020; Jaiswal et al., 2025; Dhankar et al., 2024), suggesting that, at the landscape scale, urban expansion has been the dominant driver of vegetation change in the valley. Therefore, even though the surrounding urban matrix has continued to intensify, the improving NDVI trend observed specifically for the Shuklapur patch indicates that this specific forest fragment for some extent has been shielded from the region-wide pattern of degradation, plausibly due to its retention as an identifiable

forest patch, canopy maturation and closure over time, reduced disturbance in more recent years or localized conservation and afforestation efforts.

The pronounced dip in NDVI observed in 2008 and 2013 (both 0.32) followed by a marked recovery from 2014 onward with peak values in 2014 (0.60) and 2022 (0.59) is also noteworthy. A variety of interrelated factors, such as abnormally low or uneven monsoon rainfall in those years, sporadic human disturbances like fuelwood extraction, fire, or encroachment-related clearing at the forest edge, or sensor- and atmospheric-related artifacts in the underlying satellite data can cause such short-term NDVI depressions. A process of vegetation regeneration and canopy closure is consistent with the subsequent sustained recovery after 2014 with NDVI values remaining relatively high through 2024. This is in line with the structurally mature, multi-layered vegetation profile recorded in the current floristic survey where a well-developed tree and shrub canopy would be expected to sustain consistently higher greenness signals once reestablished.

The subsequent sustained recovery after 2014 is consistent with a process of canopy closure and vegetation regeneration, with NDVI values staying quite high through 2024. This is consistent with the multi-layered, structurally mature vegetation profile found in the current floristic study. Once reinstated, a well-developed tree and shrub canopy should sustain continuously greater greenness signals. However, this view needs considerable care. The floristic survey represents composition at a single point in time rather than throughout the entire 25-year monitoring window, and the NDVI derived from moderate-resolution satellite sensors integrates reflectance from a mixed pixel that may include adjacent land uses at the forest edge. As a result, the NDVI trend cannot be directly attributed species-by-species to the recorded flora. Future studies would benefit from repeat floristic surveys and higher-resolution imagery to more precisely link compositional change to the observed greening trend.

These results highlight the ecological significance of keeping and actively safeguarding the Shuklapur as a functional Urban green space remnant from a management standpoint. Given the well-documented role that urban green spaces play in sustaining biodiversity and delivering ecosystem services to city residents even surrounded by intensive urban land use (Kowarik et al., 2025), and given the contrasting pattern of vegetation decline reported across the wider Doon Valley (Jaiswal et al., 2025; Dhankar et al., 2024). Shuklapur's comparatively favorable floristic and greening condition should be seen as an asset deserving of ongoing protection rather than an outcome that may be taken for granted in the absence of intentional management attention.

6. Conclusion

This study combined an intensive field-based floristic inventory with a 25-year satellite-derived NDVI time series to provide an integrated assessment of the Shuklapur urban green space in Dehradun. The floristic survey recorded 192 vascular plant species belonging to 165 genera and 61 families which are distributed across trees, shrubs, herbs, climbers/lianas and grasses, indicating a structurally diverse and multi-layered plant community. The relatively healthy vegetation and greening condition of Shuklapur is

an important asset that needs continued protection and careful management. It should not be taken for granted, as maintaining this condition will require sustained attention and conservation efforts. The accompanying NDVI analysis revealed considerable interannual variability in vegetation greenness between 2000 and 2024, including a period of comparatively low values during 2008–2013, followed by a marked and sustained recovery thereafter. Despite these short-term fluctuations, the overall 25-year trend shows a clear improvement. Mean NDVI increased from 0.54 to 0.58, which is about a 9.2% rise. This suggests that the vegetation health, vigour, and canopy condition of the Shuklapur urban green space have improved over the study period, even though the wider Doon Valley has experienced a decline in forest cover and green spaces due to continued urban expansion.

All of these findings suggest that the Shuklapur urban green space functions as a floristically rich and at present, ecologically resilient urban green space within an increasingly urbanising landscape. Its persistence and apparent recovery in vegetative condition underscore the importance of conserving such patches in growing cities, both as providers of the ecosystem services associated with urban greenery and as repositories of native floristic diversity. Considering the overall loss of forest cover in Dehradun district, the Shuklapur urban green space and other similar urban green space in the Doon Valley should be given priority for long-term monitoring and protection. Efforts should also be made to prevent further encroachment and include these forest patches in future urban green-space and development planning. Future studies should strengthen the floristic assessment by looking at species abundance, natural regeneration, and the conservation status of recorded species. Repeated field surveys should also be combined with higher-resolution satellite data to better understand how changes in plant composition are related to changes in vegetation greenness over time.

Declarations

Acknowledgements

The authors sincerely thank the Himalayan Environmental Studies and Conservation Organization (HESCO) for its encouragement and support throughout this study including the accessibility to the area. The authors sincerely thank Mr. Revan Chaudhari, Field Botanist at the Wildlife Institute of India, for his help with the taxonomic identification of the plant species recorded in this study.

Plant reproducibility

Field surveys were conducted in the unreserved Urban Green Space of Shuklapur, Dehradun District in Uttarakhand, India, between 2021 and 2022. No biological specimens were collected. Species were identified in the field, and images of unidentified species were captured for further analysis.

Permission to collect the plants/plant parts

The floristic survey involved non-destructive sampling of wild plant species for taxonomic identification and documentation purposes only. The study area is not a legally protected forest, national park, or

wildlife sanctuary. Therefore, no specific collection permits were required. The fieldwork was conducted with the knowledge and permission of local authorities and land managers, and no endangered or legally restricted plant species were destructively harvested. These sites are neither privately owned nor designated as government-protected areas. The study involved non - destructive observational data collection only, and no plant material was removed or harmed. Therefore, no specific governmental or private land permission was required.

Plant guidelines

The collection and documentation of plant materials complied with relevant institutional, national, and international guidelines, including the principles outlined by the International Union for Conservation of Nature (IUCN) for research involving plant biodiversity. Conservation status was verified using the IUCN Red List of Threatened Species. Special care was taken to avoid non-collection, particularly of endemic and vulnerable species. All field activities followed local and national biodiversity conservation regulations applicable in Uttarakhand, India.

Author Contributions

A.S. conducted the main field survey, prepared the manuscript, and wrote the original draft. S.R. assisted with the field survey, taxonomic identification and helped in the data analysis of the floral component. P.J. conducted the GIS analysis. All authors reviewed and approved the final manuscript.

Funding

The authors declare that they did not receive any funding from external agencies

Data availability

The satellite data analysed in this study are publicly available. Landsat Collection 2 Level-2 surface reflectance imagery (Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI and Landsat 9 OLI) for May and June of 2000 to 2024 was obtained from the United States Geological Survey (USGS) and accessed through the Google Earth Engine platform (https://earthengine.google.com). The datasets used were LANDSAT/LT05/C02/T1_L2, LANDSAT/LE07/C02/T1_L2, LANDSAT/LC08/C02/T1_L2 and LANDSAT/LC09/C02/T1_L2, described at https://developers.google.com/earth-engine/datasets/catalog/landsat. The same imagery can also be downloaded from the USGS EarthExplorer repository (https://earthexplorer.usgs.gov). The detailed links are also attached in section 3.2.1. The floristic field survey data generated during this study are included in this article (Annexure 1). The annual NDVI composites and Sen's slope outputs generated during the study are available from the corresponding author on reasonable request.

Clinical Trial Number:

Not Applicable

Declarations

Plant Identification

Plant identification was performed by Mr. Anikesh Sharma, Research Scholar Doon University, Mr Sachin Rawat, from the department of Zoology and Environment Science, Gurukul Kangri Deemed to be University, Haridwar, Uttarakhand, India and by Mr. Revan Chaudhari, Field Botanist at the Wildlife Institute of India using regional floras, principally the Flora of Upper Gangetic Plain and Adjacent Siwalik and Sub-Himalayan Tracts (Kanjilal, 1928) and the Herbaceous Flora of Dehradun (Babu, 1977). The identifications were further verified using the Plants of the World Online (POWO) database.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

References

1. Babu CR. Herbaceous flora of Dehradun. CSIR; 1977.
2. Bharucha FR, Dave RN. The biological spectrum of grassland associations. J Univ Bombay. 1944;13:15–6.
3. Dhankar S, Singh G, Kumar K. Impacts of urbanization on land use, air quality, and temperature dynamics in Dehradun district of Uttarakhand, India: A comprehensive analysis. Front Environ Sci. 2024;12:1324186. https://doi.org/10.3389/fenvs.2024.1324186.
4. Dobhal P, Bisht SL, Sawan S, Joshi V, Joshi SP. Life-forms and biological spectrum of a Riverine forest of the Doon Valley, Uttarakhand, India. Indian J For. 2010;33(4):585–98. https://doi.org/10.54207/bsmps1000-2010-4777T2.
5. Jaiswal R, Sharma A, Prakash D, Choudhary A, Verma S. Transforming landscapes: Mapping urbanization and forest cover degradation in Dehradun, Uttarakhand (2000–2020). Environ Earth Sci. 2025;84(3). https://doi.org/10.1007/s12665-024-12047-6. Article 84.
6. Jana C, Mandal D, Shrimali SS, Alam NM, Kumar R, Sena DR, Kaushal R. Assessment of urban growth effects on green space and surface temperature in Doon Valley, Uttarakhand, India. Environ Monit Assess. 2020;192(4):257. https://doi.org/10.1007/s10661-020-8184-7.
7. Kanjilal UN. Forest flora of the Chakrata, Dehradun, Saharanpur Forest Divisions, Uttar Pradesh. Government of India; 1928.

8. Kowarik I. Urban biodiversity, ecosystems and the city. Insights from 50 years of the Berlin School of urban ecology. Landsc Urban Plann. 2023;240:104877. https://doi.org/10.1016/j.landurbplan.2023.104877.
9. Kowarik I, Fischer LK, Haase D, Kabisch N, Kleinschroth F, Konijnendijk C, Straka TM, von Haaren C. Promoting urban biodiversity for the benefit of people and nature. Nat Reviews Biodivers. 2025;1(4):214–32. https://doi.org/10.1038/s44358-025-00035-y.
10. Kriegler FJ. (1969). Preprocessing transformations and their effects on multispectral recognition. In Proceedings of the Sixth International Symposium on Remote Sensing of Environment (pp. 97–131).
11. Kumar R, Saikia P. Floristic analysis and dominance pattern of sal (*Shorea robusta*) forests in Ranchi, Jharkhand, eastern India. J Res. 2020;31:415–27. https://doi.org/10.1007/s11676-018-0829-9.
12. Nandi R, Jashimuddin M. Unveiling the composition, diversity, and structure of the Urban green spaces in Chattogram City. Bangladesh Discover Cities. 2025;2., Article 131. https://doi.org/10.1007/s44327-025-00131-w.
13. Pandey M, Joshi SP, Sharma S, Dimari J. (2024). Floristic composition and biological spectrum of Raipur Forest Range Dehradun, Uttarakhand. *Journal of Soils and Crops*, 33(2), 277–282. https://zenodo.org/records/14189814.
14. Pandey SK, Pande S, Mishra AK. (2025). Assessment of plant diversity in sal forest of north Gorakhpur forest division, India. *Vegetos* 38, 1699–1706 (2025). https://doi.org/10.1007/s42535-024-00967-4
15. Pesaresi S, Mancini A, Casavecchia S. Recognition and characterization of forest plant communities through remote-sensing NDVI time series. Diversity. 2020;12(8):313. https://doi.org/10.3390/d12080313.
16. Raunkiaer C. The life forms of plants and statistical plant geography. Oxford: Clarendon; 1934. pp. 1–632.
17. Rouse JW, Haas RH, Schell JA, Deering DW. Monitoring vegetation systems in the Great Plains with ERTS. NASA Special Publication. 1974;351:309–17.
18. Sen PK. Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc. 1968;63(324):1379–89. https://doi.org/10.1080/01621459.1968.10480934.
19. Sharma A, Singh OP, Saklani MM. Climate of Dehra Dun. India Meteorological Department, Ministry of Earth Sciences; 2012. https://mausam.imd.gov.in/dehradun/mcdata/DEHRADUN_CLIMATE.pdf. Government of India.
20. Tiwari K, Khanduri K. Land use/land cover change detection in Doon valley (Dehradun Tehsil), Uttarakhand: Using GIS & remote sensing technique. Int J Geomatics Geosci. 2011;2(1):34–41.
21. Verma S, Joshi SP, Giri DD. Pattern of plant biodiversity of sub-tropical forest in Shivalik range of Doon valley, Uttarakhand. Biochem Cell Archives. 2022;22(2):4247. 10.51470/bca.2022.22.2.4247.
22. Zhao S, Zhou D, Zhu C, Sun Y, Wu W, Liu S. Spatial and temporal dimensions of urban expansion in China. Environ Sci Technol. 2016;49(16):9600–9.

23. Annexure. 1.

24. Checklist. of Plant species found in the Shuklapur forest.

Figures

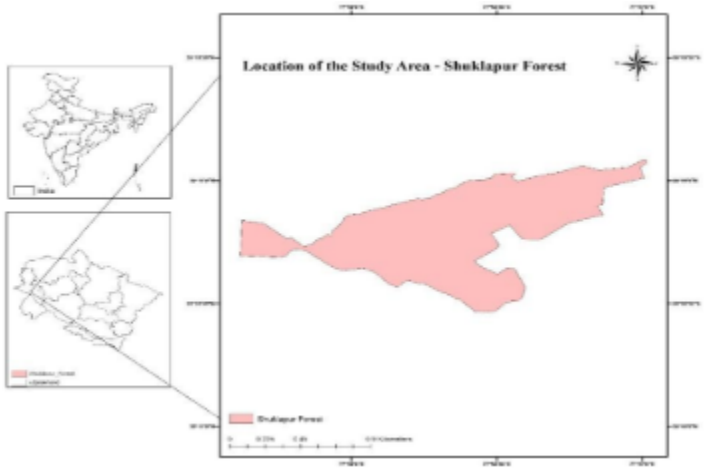


Figure 1

Map representing location of Shuklapur Urban Green Space

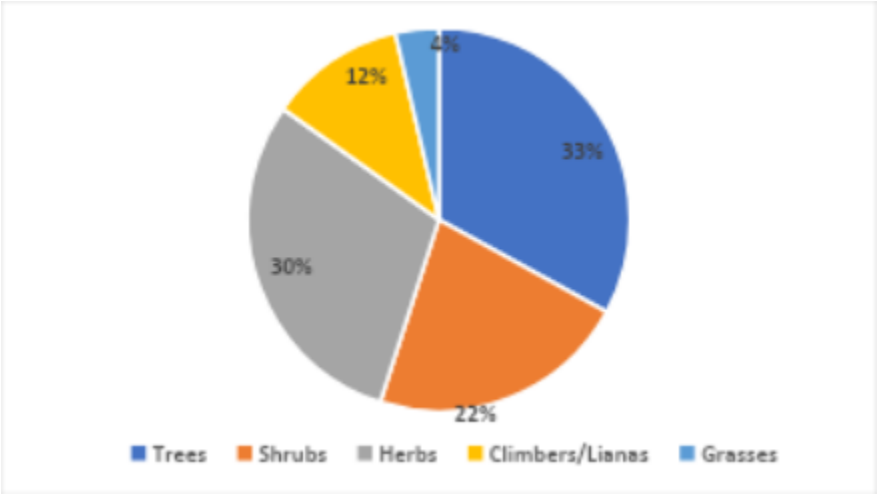


Figure 2

Fig showing Taxonomic composition of the flora recorded from the Shuklapur urban green space

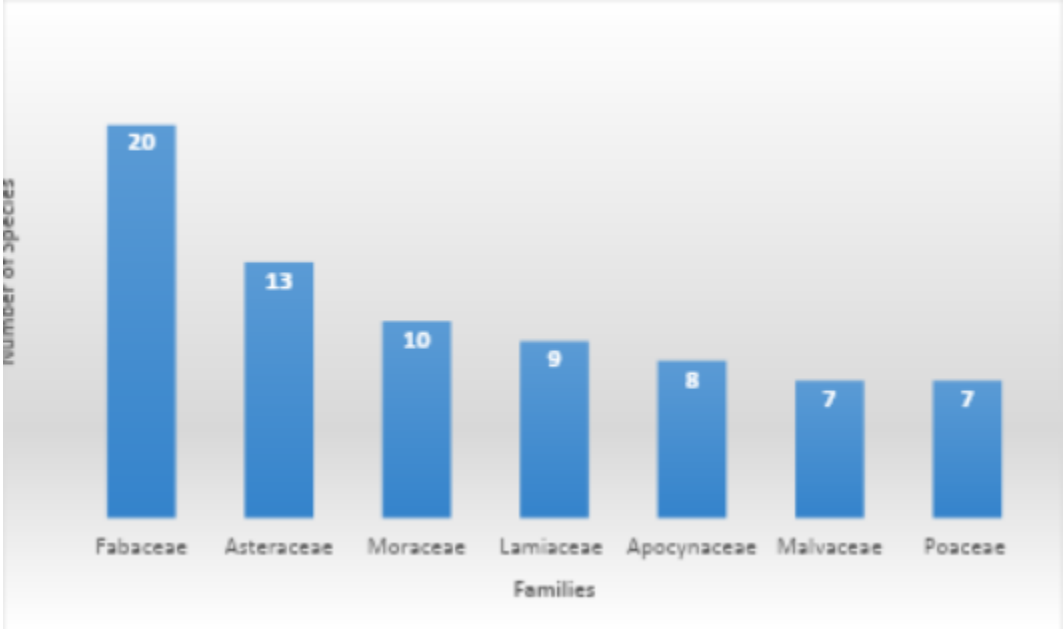


Figure 3

Fig showing Distribution of Species across Dominant Plant Families

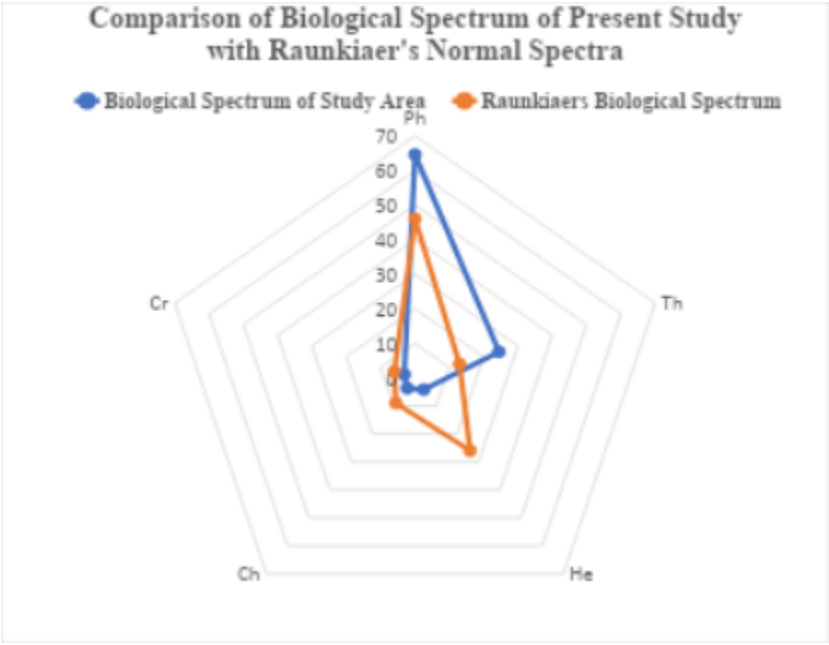


Figure 4

Fig showing Comparison of Biological Spectrum of Present Study with Raunkiaer's Normal Spectrum



Figure 5

Fig Showing Annual mean NDVI trend in Shuklapur urban green space during 2000-2024 derived from May-June Landsat imagery. The graph illustrates interannual variations in vegetation greenness and the overall temporal pattern of NDVI across the forest.

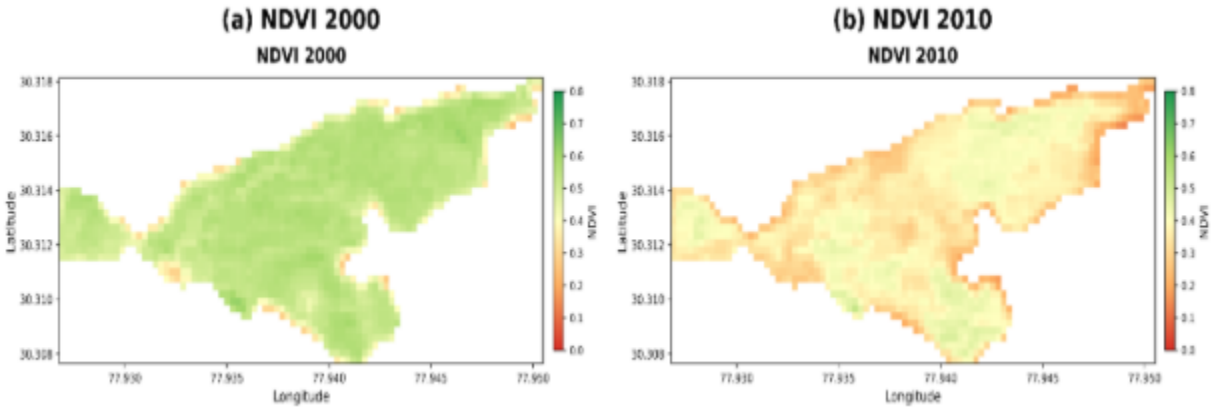


Figure 6

Spatial distribution of NDVI in Shuklapur urban green space for 2000 and 2010, derived from May–June Landsat composites. Green shades indicate higher vegetation greenness and canopy vigour, whereas yellow-orange shades represent relatively low

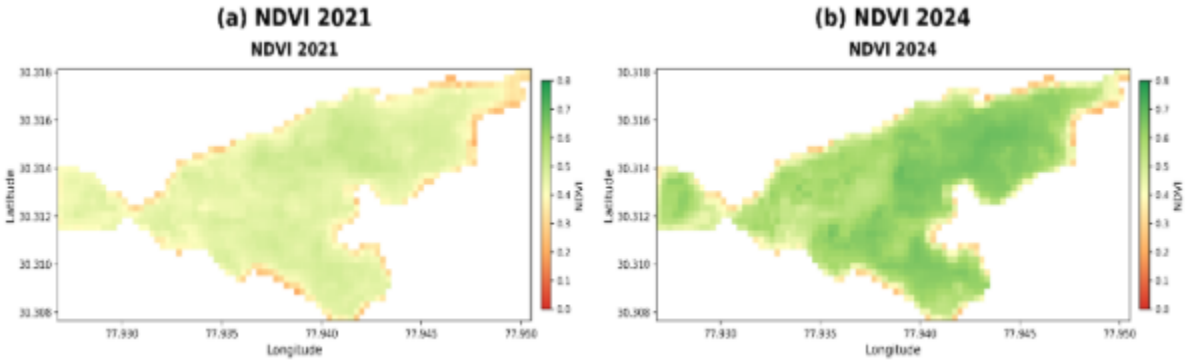


Figure 7

Spatial distribution of NDVI in Shuklapur urban green space for 2021, and 2024 derived from May–June Landsat composites. Green shades indicate higher vegetation greenness and canopy vigour, whereas yellow-orange shades represent relatively low

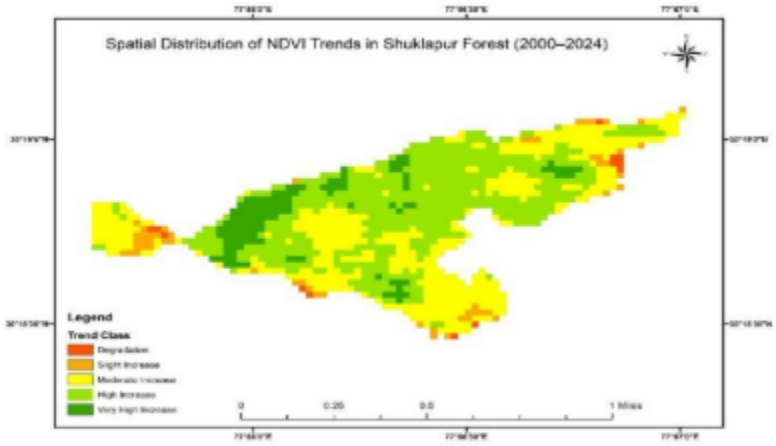


Figure 8

Spatial distribution of NDVI trend classes in Shuklapur urban green space during 2000-2024 derived using Sen's slope analysis. Trend classes represent degradation, slight increase, moderate increase, high increase, and very high increase in vegetation greenness.