Understanding the Vegetation Dynamics of NCT- Delhi Using Remote Sensing

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Abstract: Urban vegetation is a crucial ecosystem component that keeps the environment in check. The existence of a well-distributed vegetation cover helps to ensure the city's long-term sustainability and aesthetic appeal. Rapid urban expansion has direct and indirect effects on vegetation growth and its distribution. This paper studied the vegetation cover dynamics using remotely sensed Landsat series datasets in the National Capital Territory (NCT) of Delhi. The study examined the vegetation change over 28 years and observed a reduction of about 15% due to rapid urbanization. This work studied the prominent Green Spaces (GS) in NCT- Delhi and highlighted their significance. The study also investigated the district-wise change in the vegetation cover. The vegetation mapping of the region can be utilized as a tool for integrated spatial planning to address urban challenges like air pollution, reducing the effects of urban heat islands, and public health improvement.

Keywords: Vegetation cover, ecosystem, vegetation index, urban spread, Green Space (GS)

1. Introduction

Cities are growing, causing global climate change, which needs effective, and sustainable urban development. Urbanization swift imposes much pressure on land and drainage channels, subsequently putting pressure on floodplains, low-lying areas, green spaces, recreational areas, and heritage sites. Cities are marked by tremendous population growth; industries deteriorate air and water quality. The rapid increase in urban infrastructure transformed the green city into concrete space. Urban areas are complex organizations consisting of diverse elements that evolve over contrasting spatio-temporal scales (Blaschke et al., 2011). Human prosperity depends on infrastructure, defined as the interconnected systems supporting and supplying essential living conditions for humans to facilitate, sustain, or enhance society's living status. The ecological infrastructures are defined as the structural landscape network that constitutes the essential landscape elements and spatial patterns that are vital for preserving the integrity and identity of the natural and cultural landscapes, as well as ensuring sustainable ecosystem services, cultural heritage protection, and recreational events (Yu, 2012). These include water and vegetation near the built environment, which delivers ecosystem services at different spatial scales. The ecological infrastructure comprises all 'green and blue spaces' that may be settled in urban and peri-urban areas. The ramification of urbanization on biodiversity and ecosystems, as well as the potential benefits from urban ecosystem restoration, are still inadequately understood (McDonald and Marcotullio 2011). Green spaces are an intrinsic component of the urban landscape, demonstrate essential functions like urban heat island mitigation (Susca et al., 2011; Yuan and Bauer, 2007), reducing carbon emissions (Nowak and Dwyer, 2007; Seto et al., 2012), reducing air pollution (Nowak et al., 1998) and promoting general human health (Tzoulas et al., 2007).

The term 'urban vegetation' represents the total assemblage of plants (including urban forests) within and on the periphery of cities and towns. It comprises a diversity of plants in a wide range of habitats. They are set up and managed for various reasons and exhibit economic, social, aesthetic, and ecological value (Carne 1994). Urban vegetation cover is a critical component in mitigating climate change impacts (Cadenasso et al., 2006). It maintains environmental sustainability and helps in various ecosystem services, including air purification, water infiltration, noise reduction, and carbon sequestration (Elmqvist et al., 2013). The planting habitats consist of sidewalks and highways, urban squares and plazas, parks, institutional grounds, industrial and residential areas. The urban environment provides opportunities for conservation outside natural habitats, necessary in protecting biodiversity, for instance, botanic gardens.

The quantification and mapping of the vegetation cover in the urban area play an essential role in assessing urban structural changes and achieving a sustainable environment (Chikr El-Mezour et al., 2010). Vegetation cover mapping is imperative for urban planning, natural resource management, ecological studies, and hydrological modelling (Su et al., 2016). Thus, the identification, evaluation, and characterization of urban vegetation remain a high priority for environmental research policy.

Remote sensing is the study of acquiring information, used to gather information about any feature without coming into physical contact (Joseph 2005). Multispectral remote sensing imageries are valuable for better understanding the earth's environment (Ahmadi et al., 2010). These data have been widely used as a cost-effective tool in mapping and monitoring large areas (Gould, 2000; Freeman et al., 2002). The application and scope of remote sensing are comprehensive (Shimoda 2013). Integrating remotely sensed data and ancillary data has many applications, including land cover classification, forest classification, soil moisture measurement, snow mapping, sea ice type classification, etc. Remote sensing is widely used in land cover classification, including vegetation mapping (Abd Latif et al., 2011). The application of satellite data to monitor vegetation dynamics was an excellent achievement for vegetation studies in the 20th century. The spectral characteristics of vegetation reflectance can indicate the strength of vegetation activity. Thus, vegetation indices are extensively used in agriculture, biology, geography, urban planning, hydrology, and forestry research (Zhao et al., 2012).

Urban areas have evolved as the focal point of the environment involving large consumers and acting as distributors of various services. The poor urban ecosystem caused local and broader environmental degradation, social problems, economic decline, human health issue, and further disconnection from nature (Teodorescu, 2010). Delhi is one of the megacities globally, combating rapid haphazard urban development and exhibiting massive pollution levels from industries, residential complexes, and transportation systems (Singh 2015). With the rapid growth of the population in Delhi, the region is facing many problems associated with housing, waste disposal, air pollution, traffic congestion, shortage of electric power, and security (Singh et al., 2020). According to a United Nations report, Delhi will replace Tokyo and become the world's biggest megacity by 2030 (UN, 2018). Delhi is a significant attraction for migrants from all over the country due to its flourishing service economy, other opportunities, and infrastructure. The neighboring cities of Delhi, like Gurugram, Noida, Ghaziabad, Faridabad, Sonipat, and Bahadurgarh, have also experienced urban growth over the past three decades. The region spread in the fertile Indo-Gangetic plain, having a variety of vegetation covers, including forests, ridge vegetation, and many ecologically sensitive areas.

Considering urbanization and its negative impact on vegetation, it is imperative to protect, promote and enhance the existing vegetation cover of the city. This study aims to provide the spatio-temporal perspective on urban vegetation cover that has taken place in the last 28 years in NCT- Delhi, and examine the importance of green spaces in NCT-Delhi. The study also put forward several suggestions and recommendations based on temporal vegetation cover analysis.

2. Study area and data

2.1. Study area

The study covers the National Capital Territory (NCT)-Delhi region, which is located between the 28º24′17″N and 28º53′00″N latitudes and 76°45′30″E and 77º21′30″E longitudes with a geographical area of 1,490 km² (Figure 1). It is part of the Indo-Gangetic alluvial plains, at an elevation of 198 - 220m above mean sea level (Bidhuri & Khan, 2020). The region's climate is semi-arid; both summer and winter are severe. The climate in NCT- Delhi is influenced by its location and the air prevailing throughout the year. The average daily temperature is 40.9° C in summer, whereas, in the winter, it is only 8 °C (Tiwari et al., 2009). The topography of Delhi is divided into the Ridge, the Yamuna floodplain, and the plain. The ridge region is the most dominating physiographic feature and provides suitable factors that facilitate the growth of acacias and other cacti. During the monsoon season, herbaceous plants grow in abundance in the ridge region. Shisham trees are found in the plains region of Delhi (Gosain et al., 2009). The Yamuna Floodplains are low-laying and sandy. The floodplain region is subject to frequent floods during the monsoon season. The region is drowning in floodwater after the flood subsides, leaving moisture in the soil, making the land rich in fertility. The vegetation of Delhi mainly consists of medium-sized trees and herbs (Khera et al., 2009). The region is also known for its diverse flowering plants. According to Census 2011, 16.7 million population live in Delhi (Census of India, 2011).

2.2. Data

In this research work, medium-resolution multispectral Landsat satellite datasets were used, including Landsat 5 for 1992 and Landsat 8 for 2020. The satellite datasets have been acquired from https://earthexplorer.usgs.gov/. While downloading the satellite images for monitoring the vegetation, it was kept in mind to acquire images of same time periods when vegetation cover was at its peak. Generally, the best month to map vegetation cover on satellite imagery are October-November and February-March. Due to availability of cloud free data of Landsat imagery, March month has been acquired for assessing the vegetation cover of NCT- Delhi. The details of satellite datasets have been given in Table 1.

Table 1. Satellite dataset

Satellite images	Sensor	Date	Spatial resolution
Landsat 5	Thematic Mapper (TM)	16 March 1992	30m
Landsat 8	Operational Land Imager (OLI)	18 March, 2020	30m

3. Methodology

Figure 2 summarizes the methodology adopted for the study. In the present study, 'urban' refers to the central urban area and outlying suburban. Thus, it incorporates commercial and industrial, residential areas, transportation corridors, and peripheral areas, which serve as the interface between the suburbs and hinterlands.

3.1. Data processing

The remotely sensed Landsat series datasets were used in the study. The images are cloud-free and belong to the same period. QGIS open software has been used to carry out satellite image processing. The preprocessing involved the radiometric calibration and clipping of datasets as per area of interest.

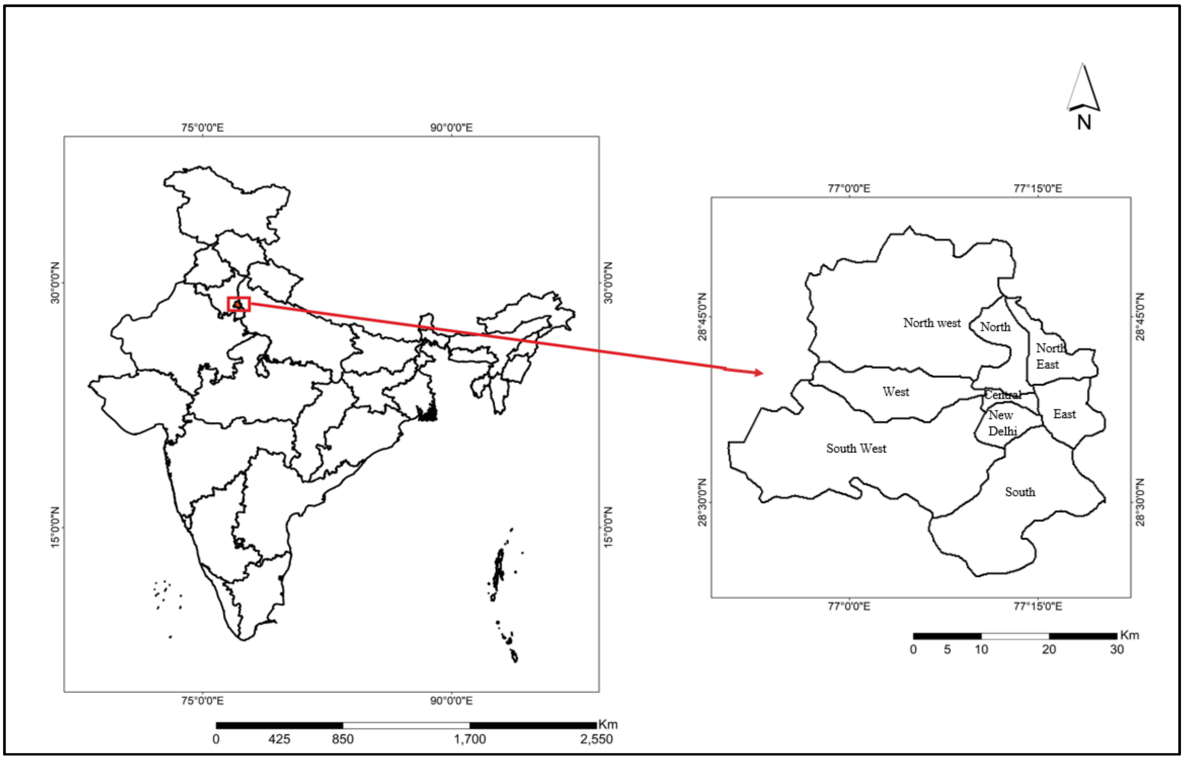

Figure 1. Location of the study area

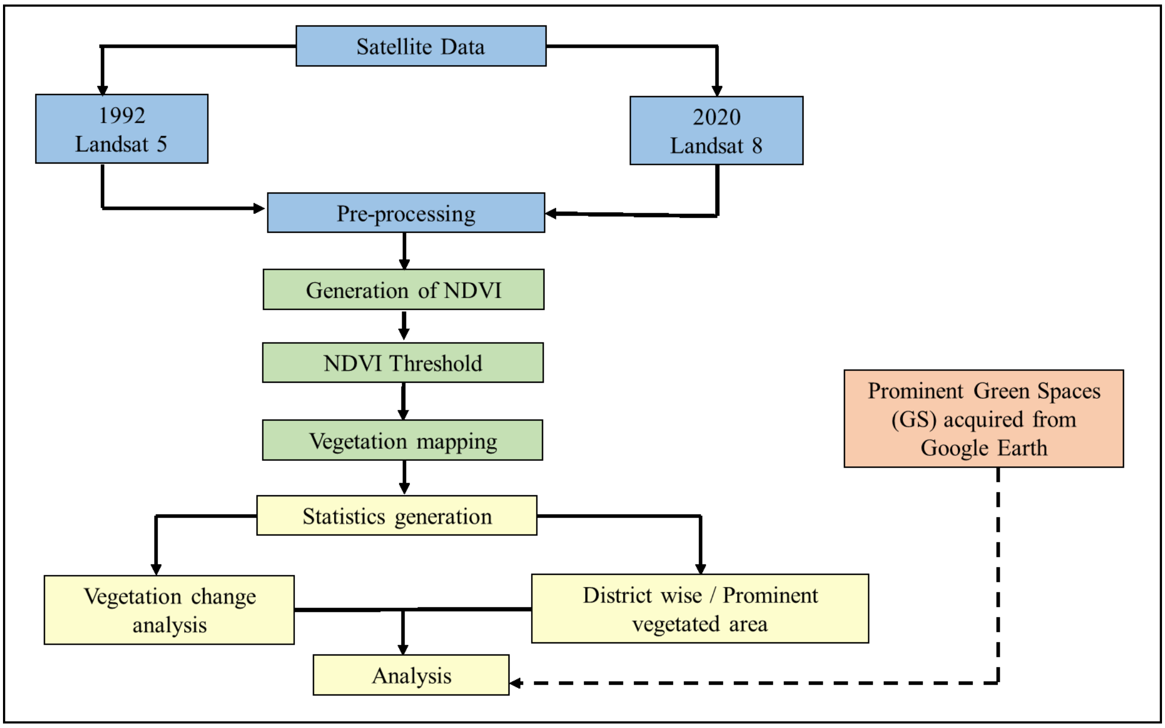

Figure 2. Methodology workflow

3.2. Calculation of Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is the most widely used vegetation index, developed by Rouse et al. (1974) from the Remote Sensing Centre of Texas University. It is the NIR and Red band ratio, ranging between -1 to 1.

$$\mathbf{NDVI = (NIR - RED) / (NIR + RED)}$$

The NDVI is capable of detecting changes in land cover caused by human activities such as construction and other developments. The negative NDVI values (values approaching -1) indicate water. NDVI values near zero (-0.1 to 0.1) are typically associated with barren land and sand. Low, positive values depict the little green cover region such as grassland and the scrub (approximately 0.2 to 0.4), while high NDVI ranges (values approaching 1) correspond to lush and healthy vegetation. The NDVI values adopted for mapping vegetation in the region are presented in Table 2. The present study calculates NDVI on temporal Landsat series datasets to analyze the spatio-temporal vegetation cover over 28 years period in NCT-Delhi.

3.3. Vegetation Change and Green Spaces (GS)

In the present study, the classification was primarily aimed at assessing the vegetation cover change in NCT Delhi. The spatio-temporal transformation in the vegetation category has been detected using NDVI threshold values. "NDVI values were implemented to reclassify NDVI output with reference to the land cover based on its spectral properties; earlier similar method was employed by Bharathkumar and Mohammed-Aslam (2015) while performing crop pattern mapping of Tumkur taluk.

Table 2. Vegetation classes and NDVI value

Classes	Description	NDVI values
Other	Built-up, road network, follow and barren land	-1 to 0.19
Scrub/ Tree	Scrub, urban green spaces	0.2 to 0.5
Crop/ plantation	Dense vegetation region	0.5 to 1

The different landcover categories were identified using the spectral property of the features with their respective NDVI values. The concept of Green Spaces (GS) has been discussed in the study with reference to NCT-Delhi. The GS locations were obtained from Google Earth. Assessing the GS contributes to a more holistic explanation of the significance of the urban vegetation in the region

4. Results and discussion

4.1 NDVI generation

In this study, vegetation is defined as the area under scrub, cultivated land, and vegetation inside the city. Vegetation inside the city means the plantation along the roads, urban green spaces, gardens, parks, etc. As the temporal datasets belong to the same month, so it is considered that there should be minimal difference in cultivated land.

The NDVI output of 1992 was between -0.355 to 0.644, and NDVI values for 2020 lie between -0.109 to 0.52 (Figure 3 (a)). It was observed that the area under cultivation (cropland) showed higher NDVI values; simultaneously, the region under water and built-up showed lesser NDVI values.

The NDVI outputs generated vegetation cover maps by assigning the NDVI threshold values. This approach efficiently differentiates the vegetation class from the other classes. This method provides powerful insights and makes visualizing the vegetation cover and its health easier. Three land cover classes have been made for vegetation analysis, namely, tree/ scrubs, crops/ plantation, and others (Figure 3 (b)). The tree/scrub category represents the low and sparse vegetation, including the city vegetation (gardens, parks, urban green spaces, etc.) and scrubland. The crops/plantation landcover category indicates the dense vegetation cover, mainly seen in agricultural land. The other class represents the built-up, fallow/open land, and water. It was observed that in 1992 vegetation cover was evenly distributed. The built-up is concentrated in the city's core, and the peripheral region showed dense vegetation indicating agricultural land. In 2020, there was a huge loss in vegetation cover in North West, West, and South West districts due to the transformation of agricultural lands into residential layouts and commercial complexes.

The New Delhi district accounts for less vegetation loss because its infrastructure was mainly occupied by the government headquarters, offices, and government residential complexes developed since the British period. The British Architect Edwin Lutyens and Herbert Baker planned and constructed several buildings in New Delhi, such as Rashtrapati Bhavan, Parliament House, the Secretariat building, and many other administrative blocks built by these two architects. These buildings are still in their earlier form, with a vast area covered by greenery is still present there. The vegetation cover area derived from the vegetation maps is given in Table 3. In 1992, 56% area was under vegetation, which reduced to 41% in 2020.

Table 3. Vegetation cover statistics

Landcover	1992 Area in km2	1992 Area in %	2020 Area in km2	2020 Area in %
Tree/ scrub	468	31%	331	22%
Crops/ plantation	371	25%	276	19%
Others	651	44%	883	59%

4.2 Urban vegetation cover district-wise analysis

Vegetation cover change is determined as the changes in the vegetation-cover area and mean NDVI per unit area in the region. The change in vegetation cover is the direct response to anthropogenic activity, which leads to climate change. Based on the spatio-temporal vegetation cover study, a vegetation change map highlighting the positive change, negative change, and the areas with no changes was presented (Figure 4). Positive changes indicated the densification and spread of vegetation, which is seen as the change in other classes of vegetation category (including sparse and dense vegetation), negative changes show the land transformation of vegetation class to other class, primarily attributed to the establishment of new residential layouts, development, and construction of commercial infrastructure. The no-change category represents the areas having no changes in land cover.

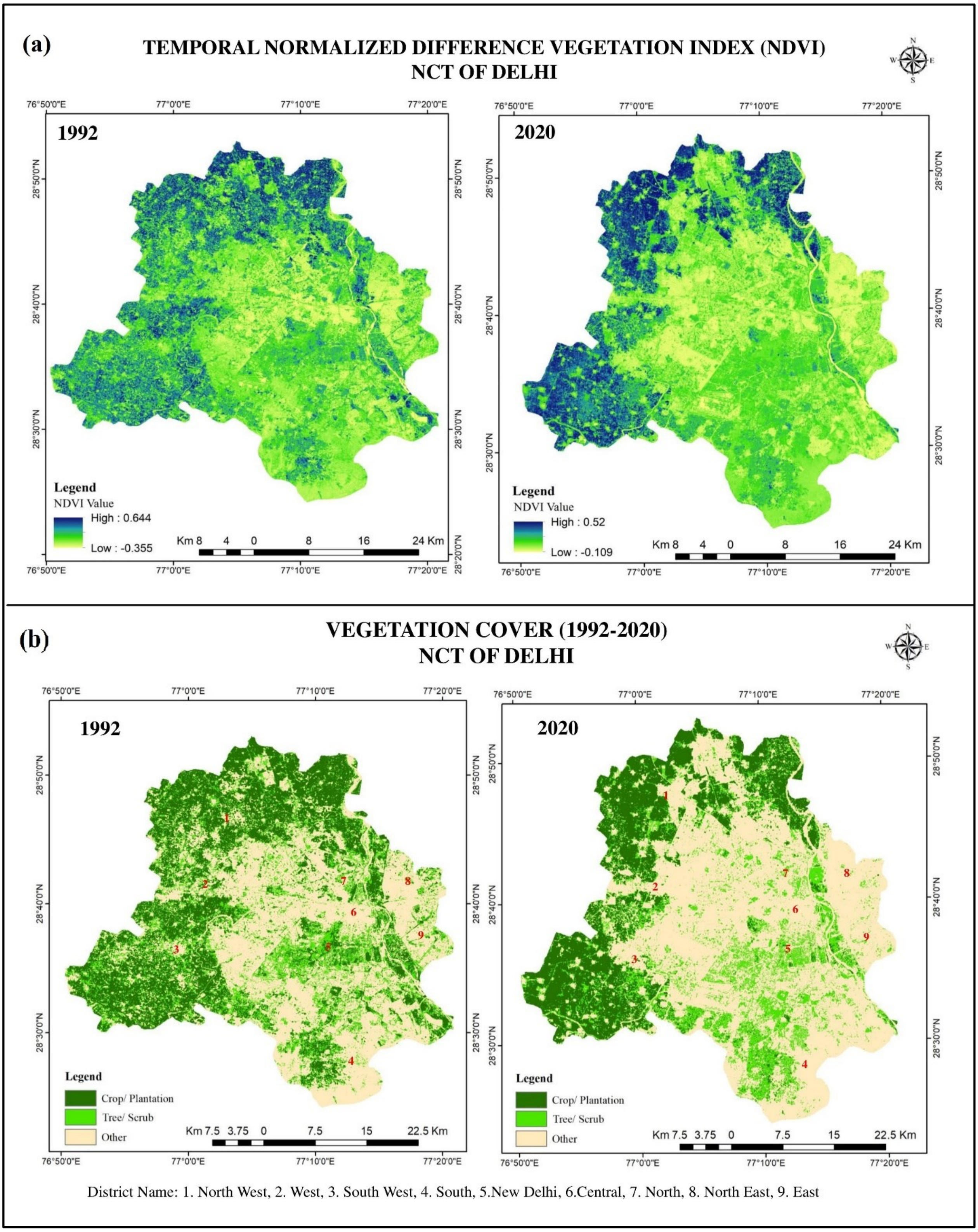

Figure 3. (a) NDVI maps derived from Landsat 5 (1992), and Landsat 8 (2020), Figure 3(b): Temporal vegetation cover of NCT- Delhi (1992-2020)

It was observed that the core of the city has permanent vegetation covers in government offices, education institutions, and research centers premises, cantonment areas having a large patch of greenery, and a Ridge. The city core has a vegetation spread varied from small patches to large adjoining vegetation patches. Vegetation cover exists in a linear pattern along the roads. The city is extending in a radial pattern and multi-nuclei form and experiencing horizontal and vertical urban spread.

From the district-wise comparative analysis, it was observed that the North East and East district of Delhi, which was already occupied by dense settlement, represented the least greenery in the entire region and showed less reduction in the vegetation cover (Figure 5).

The vegetation greenness was almost balanced in New Delhi and Central Delhi due to administrative units like the central secretariat (north and south block), Rashtrapati Bhavan, Rajpath, and India Gate, reflecting healthy tree cover. The NDVI values of these areas range from 0.4 to 0.6. Along the Yamuna river, the floodplain, which is the most fertile part of the region, also shows relatively higher NDVI values because of the presence of agricultural land.

Substantial changes of around 188km^2 in the vegetation cover have been seen in the North West and South West Delhi due to the development of residential layouts like Rohini, Janakpuri, Dwarka, and Najafgarh.

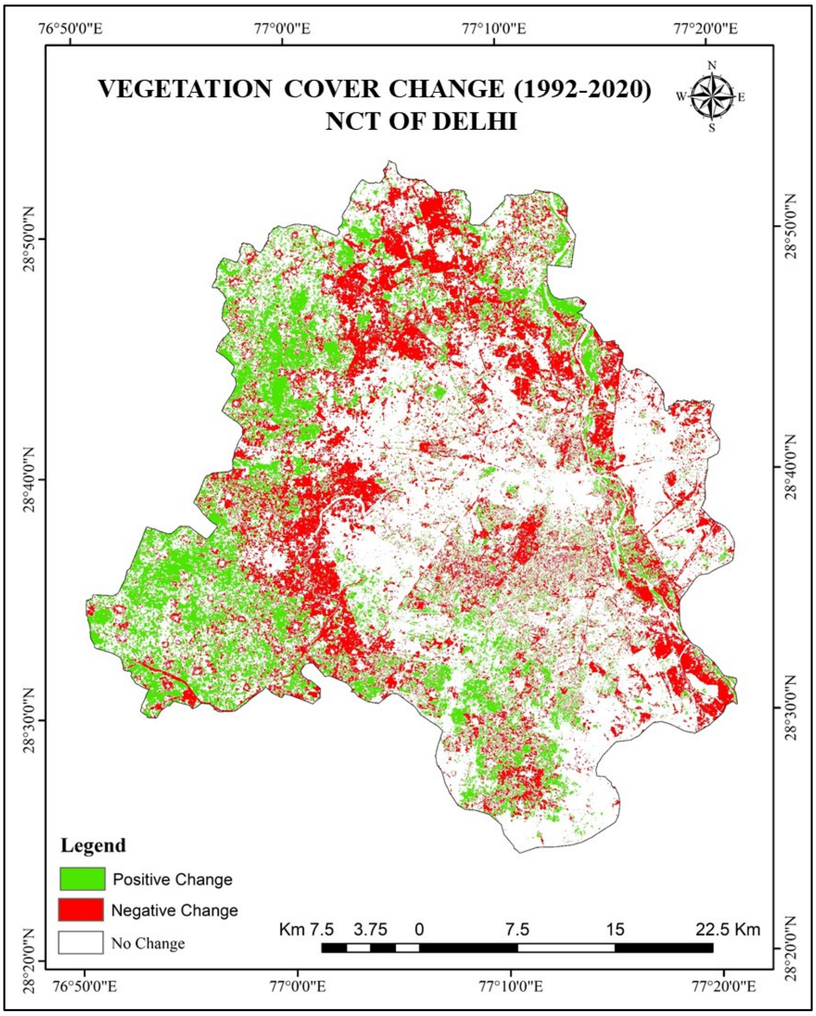

Figure 4. Vegetation cover change of NCT- Delhi

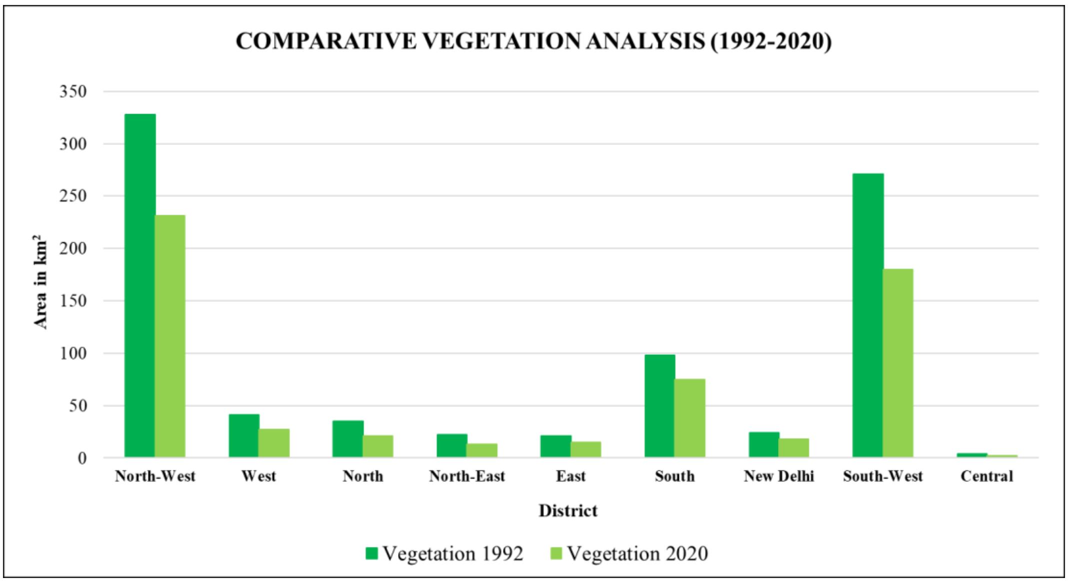

Figure 5. Comparative district-wise vegetation cover change of NCT- Delhi (1992-2020)

From the vegetation change analysis, it is evident that in 28 years, the region experiences a considerable reduction of about 15% in vegetation cover, primarily due to an increase in residential layout and rampant infrastructural development.

4.3 Green spaces and their importance

Green spaces are the essential component of green infrastructure, immensely vital for developing countries like India and China (Turaga et al., 2020). Green spaces and recreational or open spaces consist of community parks, gardens, schoolyards, playgrounds, cemeteries, etc. These areas are wholly or partially covered with trees, shrubs, grass, and other vegetation types. In India, the concept of 'urban green spaces' is comprehensively used for trees in urban parks, forests, and canopy cover along roads, which positively contribute to the city's greenery, human health, and biodiversity conservation (Bhalla & Bhattacharya, 2015). Green spaces are providing a new concept that is an intelligent method for natural preservation and urban planning. Green infrastructure planning is an approach that advocates an equal role for ecological resources within a human-centered understanding of how landscape and other built infrastructures interact (Elliott et al., 2020).

Delhi primarily has two prominent natural features, the Yamuna River floodplain, and the Delhi Ridge (Kumar et al., 2011). The Ridge is the remnant of Aravalli Hills in NCT- Delhi, which functions as a lung for the city. Delhi, the greenest city, despite all the unprecedented and rapid urbanization in Delhi, led to extensive pressure on the physical environment with a high pollution level. Significant urban green spaces of NCT- Delhi are depicted in Figure 6. Delhi Ridge is considered the lungs of the city. The Ridge has been divided into four fragmented zones: Northern Ridge, Central Ridge, South Central Ridge, and Southern Ridge. Typically, the ridge forests are covered with thorny scrubs adding little greenery and having native vegetation species. But due to increasing urbanization pressure on the land, a considerable portion of the Ridge was converted to new residential spaces and business complexes. Some part of the Ridge was given legal rights for protection, but further Ridges areas, unfortunately, did not hold such protection and faced a continuous reduction in green cover (Sinha, 2014). From the study, it was observed that the major significant green spaces lie around the Ridge and Yamuna Flood Plain.

Delhi has six biodiversity parks that are extremely prosperous in flora and fauna species (Koul, 2017). The biodiversity parks are distinct landscape that functions as the habitat of native flora, fauna, and microbial species. They provide various ecological functions like recharging the groundwater, sinking the CO_2, conserving the natural heritage, including native species of plants and animals, and serving as a recreational activity (Dhote and Mukherjee, 2018). These parks have been developed by Delhi Development Authority. Yamuna biodiversity park, situated on the Yamuna Riverfront, is a habitat of migratory and resident birds (Saxena et al., 2021). It enhances groundwater recharge and conserves the wild genetic resources of crops. Aravalli biodiversity park is situated northwest of Vasant Vihar. The park suffers from mining, and overexploitation of medicinal plants and is near to its extinction. The prime motive of this biodiversity park is to promote environmental awareness among the public. Neela Hauz Biodiversity park lies in South Central Ridge, next to Sanjay Van (Sonowal et al., 2019). This is mini biodiversity having a wetland area along the Aruna Asaf Ali Road. The park has around 90 native plant species and 70 bird species, including migratory birds. The Northern Ridge, also known as Kamla Nehru Ridge, is situated near Delhi University. The Ridge has various recharging depressions to activate the aquifers. Tughlaqabad Biodiversity Park resides on the Southern Ridge, including the Tughlaqabad Fort (Panwar & Dhote, 2022). Tilpath Valley biodiversity park is spread over Southern Ridge, well connected to valleys of Asola and Bhatti Wildlife Sanctuaries. This valley received drainage from all nearby hill ranges, facilitating recharge of the aquifer network.

Significant and crucial changes were observed around the Delhi Ridges, the dense urban growth and scale down of vegetation in and around Delhi Ridge have been considered as the loss of biodiversity and cause instability in the urban environment. There are indicative substantial changes that have been seen in Northern Ridge due to the extension of various educational institutions, like the University of Delhi and Indraprastha college. The Central Ridge is enclosed by New Delhi in its East, residential areas such as Kirti Nagar and Patel Nagar, and industrial locality like Mayapuri, which is a major hub of heavy metal and small-scale industries, facing dense urban growth and loss of vegetation in the nearby areas. Likewise, South Central Ridge and Southern Ridge also possess a huge reduction and variation in the densification of vegetation cover due to new infrastructural development and expansion of residential layout. In the study, the Delhi Ridge vegetation comes under the category of Tree/Scrub, showing 31% vegetation cover in 1992, which reduced to 22% in 2020. The overall 9% loss of greenery has been seen due to the rapid urban growth, which resulted in the transformation and distribution of vegetation cover in and around Delhi Ridge.

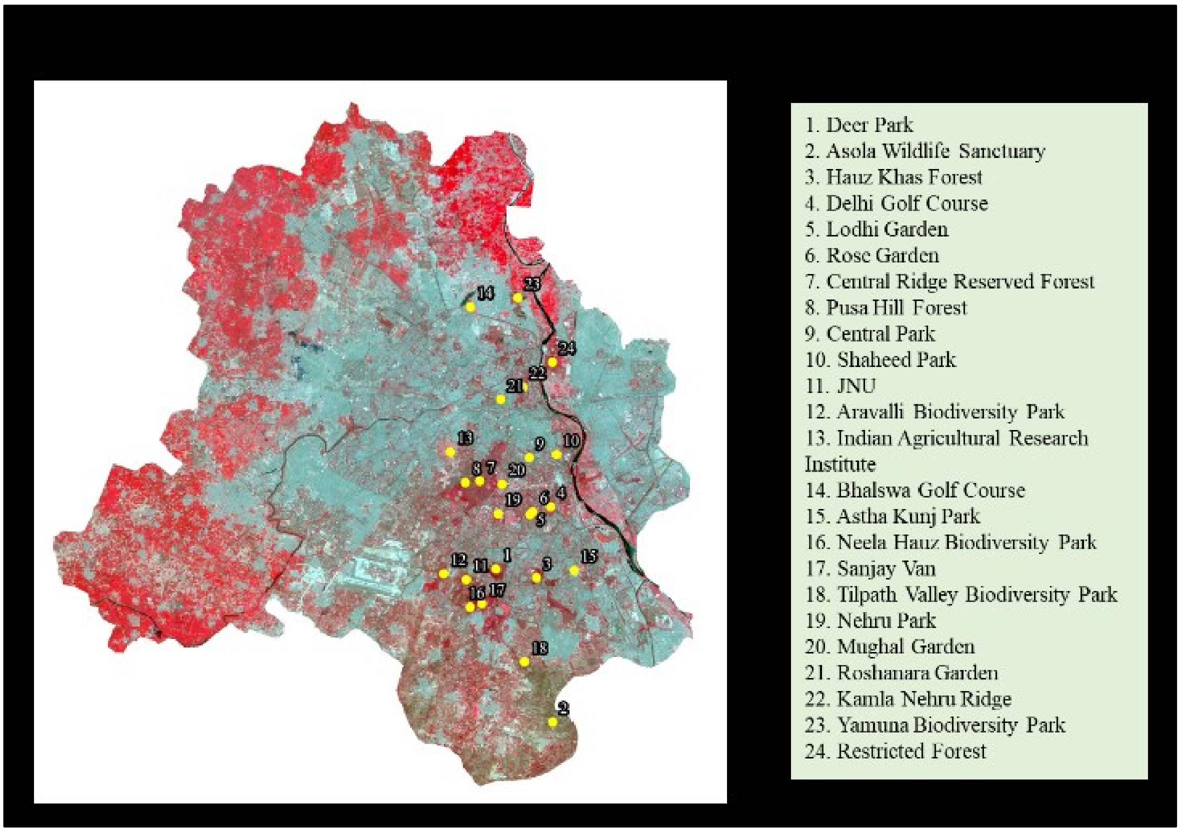

Figure 6. Major green spaces of NCT- Delh

5. Conclusions

Cities are complex places, continuously undergoing structural changes, growth, and renovation (Rydin et al., 2012). They are engines of economic and cultural growth, as well as change drivers (Vliet et al., 2002). The NCT of Delhi's rise as a leading center, owing to its administrative importance, location, infrastructure, and other amenities have resulted in rapid population growth. The city's rampant expansion and sprawling emphasize sustainable, affordable, and environment-befitting planning and development. The study attempts to evaluate vegetation cover dynamics over 28 years in the NCT of Delhi and examines the region facing a reduction in overall vegetation cover.

The result showed a considerable loss in vegetation cover due to the extensive conversion of agricultural lands to the built-up category, encroachment, and densification in and around Delhi Ridge.

The harsh reality of the 21st century is climate change and environmental pollution, and cities all over the world are battling to deal with the new environmental issues. Nature-based solutions have a crucial role in achieving a future compact city that is liveable and sustainable. The concept of green buildings, eco-roofs, and vertical gardens need to be promoted. Native indigenous vegetation, which serves as an ecologically beneficial aspect of biodiversity conservation, can help improve vegetation density in parks and forests.
The Government of India, along with the state governments, have taken several initiatives, such as management of solid and liquid waste, protection, preservation, rejuvenation, and management of lakes, ponds, rivers, wetlands, and forests. Swachh Bharat Mission-Urban (SBM-Urban) is a flagship initiative of the Government of India; it aims to keep Indian cities clean by setting up 100% door-to-door waste collection and working toward making cities garbage-free. Recently, SBM-Urban 2.0 was introduced to maintain the sanitation and solid waste management results attained and accelerate the momentum generated. To promote healthy cities and provide universal access to safe, inclusive and accessible green and public spaces, the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) mission is promoting green and open spaces in cities.

This study can contribute to the conservation of the region's green areas and the sustainability of the urban environment. Mapping vegetation cover is vital for spatial planning to conquer urban challenges. Further research can illustrate the fine-scale changes in vegetation cover by using sub-pixel analysis using high-resolution multitemporal remotely sensed datasets.

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