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RESEARCH PAPER

# Spatiotemporal change analysis of land use/land cover in NCT of Delhi, India using geospatial technology

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## Abstract

Increasing anthropological and economic activity has transformed human–environment connections. Using remote sensing and geographic information system (GIS), severe issues connected to rapid growth, such as supplemental infrastructure, informal residents, demolition of ecological construction, shortage of natural resources, and environmental contamination, have been studied for a fast-growing metropolis like Delhi. Industrialization accelerates urbanization, resulting in land transformations, which are one of the major uses of natural resources. In a fast-growing city like Delhi, the development has been rapid, and it is important to investigate the factors behind these shifts. For the present study, remote sensing and GIS models are used for land use and land cover (LULC) change detection. The applied model in the study uses the satellite datasets of two different satellites, i.e., Landsat 5 (TM) of 2010 and Landsat 8 (OLI) of 2021, from November with little or no cloud cover, which could block the LULC features. The study compares the temporal LULC map and analyzes the change and increase in urbanization for two periods, 2010 and 2021. In the study, it is revealed that urbanization causes constant shifts in vegetation, built-up area ratio, and land-use patterns. To confirm the same, indices like the normalized difference vegetation index and the normalized difference building index are also studied. Inequitable land use is a major contributor to environmental degradation. The spatial datasets from two time periods used in the study and the database results are helpful in extensive LULC investigations, land use planning, spatial growth, and urbanization patterns in the NCT of Delhi. Further, the change detection model used in the study was supported by the standard accuracy assessment of the Kappa coefficient. Overall accuracy in 2010 was 89.52% with a Kappa statistic of 0.863 and 89.92% with a Kappa statistic of 0.868 in 2021. Such studies using remote sensing and GIS are extremely helpful in understanding and monitoring urban sprawl patterns.


**Keywords** Industrialization · Urbanization · Land use and land cover (LULC) · Remote sensing and GIS techniques · Change detection

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## Introduction

Urbanization is mostly caused by the exponential growth of the global population. Urbanization is a universal trend that increased significantly after the twentieth century (Srivastava et al. 2013). Urbanization is a gift to human civilization if it is supervised, synchronized, and planned; otherwise, it becomes a curse (Mohan et al. 2011). Changes in land use patterns are influencing and increasing with increasing urbanization (Vitousek et al. 1997). The increase in population also increases the need for land use, including built-up areas. In contrast, other land cover classes, such as vegetation, bare land, and forest cover, decrease as a result of the accelerated need for built-up area (Naikoo et al. 2020). Changes in LULC have demonstrated both direct and indirect effects on the many components of the environment

(Patra et al. 2018). Changes in land use and land cover have a variety of negative effects, including a negative influence on air and water quality, global warming, and more. The increase in city temperatures, which has drawn more attention globally, is also one of the major impacts of urbanization (Nalini 2021). With more than 50% of the population living in cities, urbanization has significantly contributed to global warming (Chen et al. 2006).

The majority of Indian cities are experiencing rapid growth, which is severely harming the environment, ecology, and biosphere (Tripathy and Kumar 2019). Megacities in developing nations are under a great deal of environmental stress (Brennan 1999). Urbanization in developing nations is accelerating at a rate that is subtly harming the environment. Increased population has caused incompetent housing, poor sewage, inconsistent electric supply, inadequate drinking water, necessitous transportation system, etc. Land cover has changed as a result of anthropological changes like deforestation, population change, urban development, construction activities, water diversion, etc. on the surface of the Earth. Since prehistoric times, patterns of societal development and land use have impacted the local environment as well as the global environment. Urbanization is speeding up for higher quality of life and job prospects. Therefore, the land is constantly under stress, or we could say that the amount of land available per person is continuously declining.

In India, the percentage of people living in urban areas increased from 17.97% in 1961 to 31.16% in 2011 (Census of India 2011), and the trend is continuing to rise. Tamil Nadu (Chennai), Kerala (Malappuram), Maharashtra (Mumbai), Delhi NCR (National Capital Region) zones, etc., are the most urbanised states in India. Urbanization is accelerating at a rapid rate in cities like Delhi, and understanding the causes and effects of these changes is crucial. India's capital city, Delhi, has the second-highest population in the world (Dutta et al. 2021). Out of all the Indian megacities, Delhi has the highest pace of growth in high-rise buildings (Sivam 2003). According to the UN, Delhi's population has rapidly expanded from 16,787,941 in the Census of India from 2011 to 31,181,377 in 2021 (World Urbanization Prospects 2018). Delhi's population is expanding quickly, and a growing population will also need places to work and a comfortable lifestyle with an emphasis on health and education. Expeditious population growth may lead to a decreased per-capita approach to survival resources as resource replication is incapable of keeping pace with the increasing demands (Buhaug and Urdal 2013). Urbanization has advantages and disadvantages, and we all will eventually have to pay a price for development. It has significant environmental effects (air, water, land, etc.). And here, technology plays an important role in understanding the changes in the land cover. Land use and land cover change (LULCC) is one of the most important variables influencing resource organisation and prevention (Weng 2007). Land conversion is a common occurrence that cannot be stopped but can be managed (Rahman et al. 2012). Information on land usage is therefore essential for the spatial planning, management, and utilisation of our available land resources (Vivekananda et al. 2021). Remote sensing and geographic information system tools are the best available and most economical methods in real-time for studying LULC because they have a dynamic component. Therefore, the current study uses geographic information systems (GIS) and remote sensing techniques to examine urbanization and land use/land cover decadal changes in Delhi during the period 2010–2021.

The term "land cover" refers to the surface cover that exists on the ground, which may include vegetation, urban infrastructure, water, bare soil, or other types of surfaces, whereas the term "land use" is used for the part of the land surface utilised by humans (Ellis and Pontius 2007). Mapping, and monitoring are essentially carried out in remote sensing, and these two terms are often used interchangeably, but their actual meanings are quite distinct (Saputra and Lee 2019). LULC monitoring detects environmental changes and helps maintain limited resources or controlling factors (Jain et al. 2016). In the last few years, remotely sensed data has been utilised in most cases when scrutinising the changes in LULC (Gadrani et al. 2018). New opportunities for the use of remotely sensed data are revealed by freshly launched satellites' improved spatial and spectral resolution (Tuia et al. 2009). It is essential to recognise the changes that have occurred in order to support sustainable development at local, regional, and global levels without complicating the link between the natural environment and living beings (Liu et al. 2021). The goal of the current study is to create LULC maps for the study region for the years 2010 and 2021, compare the LULC maps throughout time, and assess how urbanization has changed during the course of time.

## Study area

India's national capital, also known as the nation's heart, was designed by British architects Edwin Lutyens and Herbert Baker. It is one of the most populated metropolitan cities located in the Indo-Gangetic plain northern region of India and is situated between the coordinates of 76.96° E, 28.44° N, and 77.40° E, 28.76° N (Fig. 1). The area covers 1,484 $km^2$ and has a population of 16.78 million in metropolitan area as per the census of India (2011). Delhi is divided into 11 districts and 33 subdivisions. Haryana and Uttar Pradesh are the neighboring states of Delhi. The altitude range of Delhi is 190–300 m. Delhi has a moderate climate where summers (April–July) are too hot and humid (25–45 °C) and winters (December–January) are too cold and foggy (22–5 °C). The monsoon starts in late June and

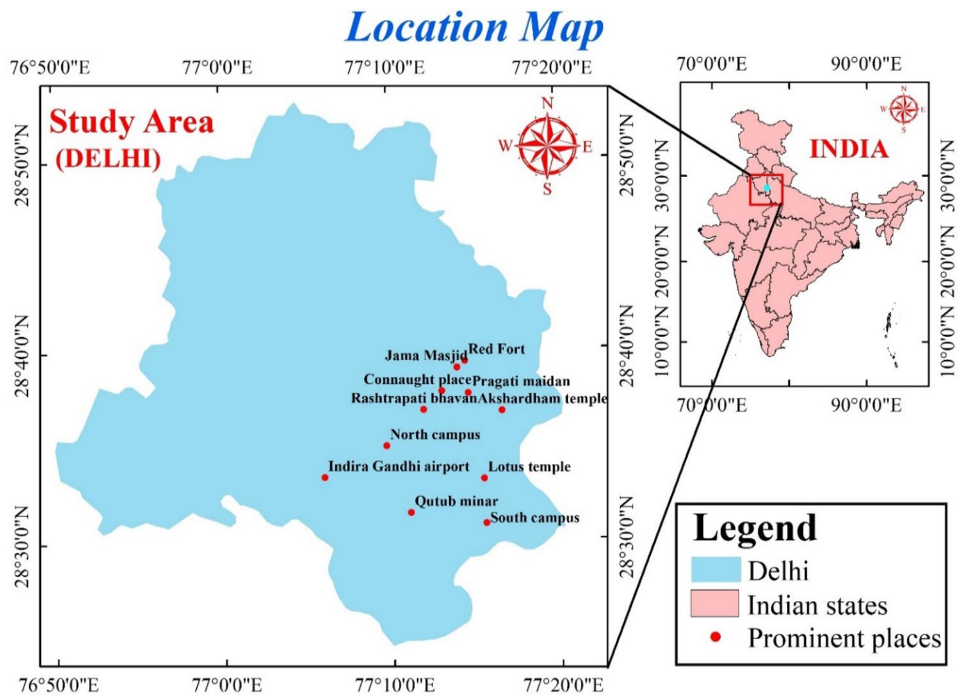


**Fig. 1** Study area location map

lasts mid-September. The average temperature ranges from 25 to 2 °C. August is the rainiest month. Delhi receives rainfall mostly from southwest monsoons. According to Koppen's climate classification, Delhi has a monsoon influence humid subtropical (Koppen-Cwa) and semi-arid (Koppen-BSh). Delhi is vulnerable to major earthquakes and falls under seismic zone IV. State forest report of 2021 says Delhi has a forest cover of 195 km$^2$ (FSI 2021).

## Methodology

For the current study, LANDSAT satellite data for two periods i.e., 2010 and 2021 for the month of November was downloaded from the USGS website (Figs. 3 and 4). Image processing was done by using a standard method (Camps-Valls et al. 2011). Thereafter mosaic image stacking was created in ERDAS imagine software and by using the Delhi Metropolitan City authorized boundary shape file, Area of Interest (AOI) subdivisions were created for all the stacks. Images were re-projected to UTM WGS 1984 Zone 43N projection. Preparation of thematic maps from the digital satellite data was done by using ERDAS Imagine ver. 2015, ArcGIS ver. 10.7.1. and Google Earth Pro ver. 7.3.4.8642 (64 bit). Standard methods, which involved the use of image elements like shape, colour, tone, pattern, position, size, height, shadow, texture, site, associated relationship or context, etc., of digital image processing were carried out for LULC (land use and land cover) mapping. The

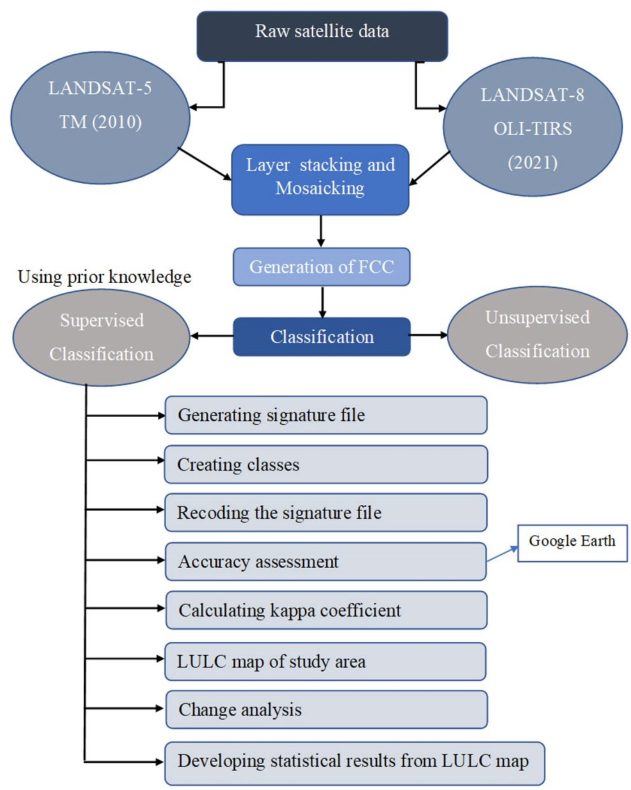


**Fig. 2** Flow diagram of the methodology adopted for the study

methodology adopted in the present study is shown in Fig. 2.

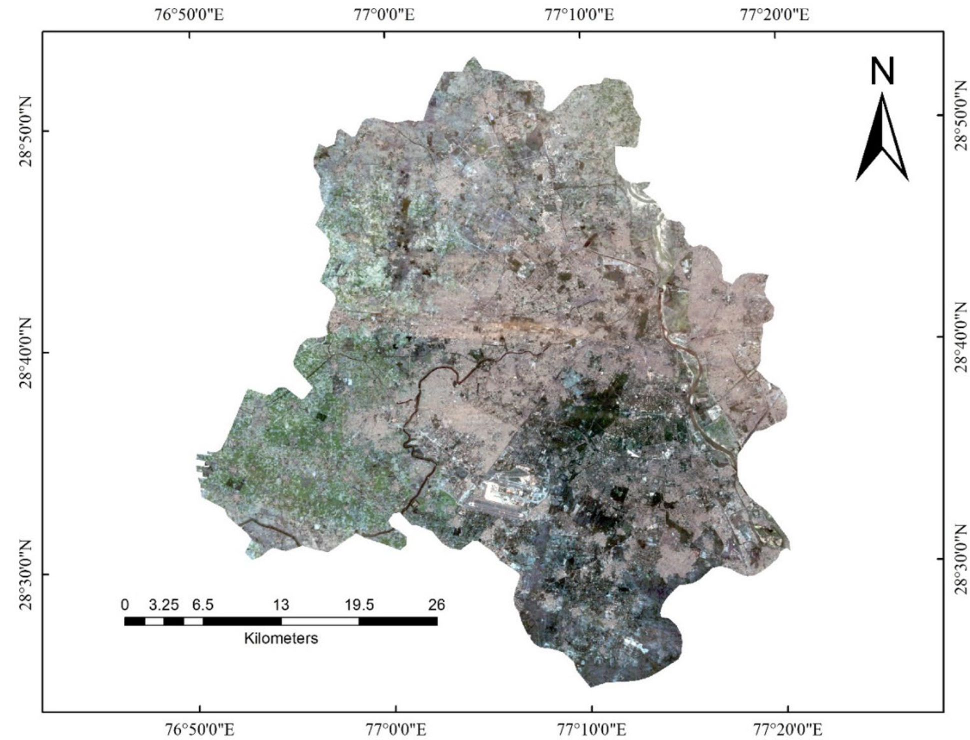


**Fig. 3** Landsat 5, 2010 satellite imagery scene of the study area

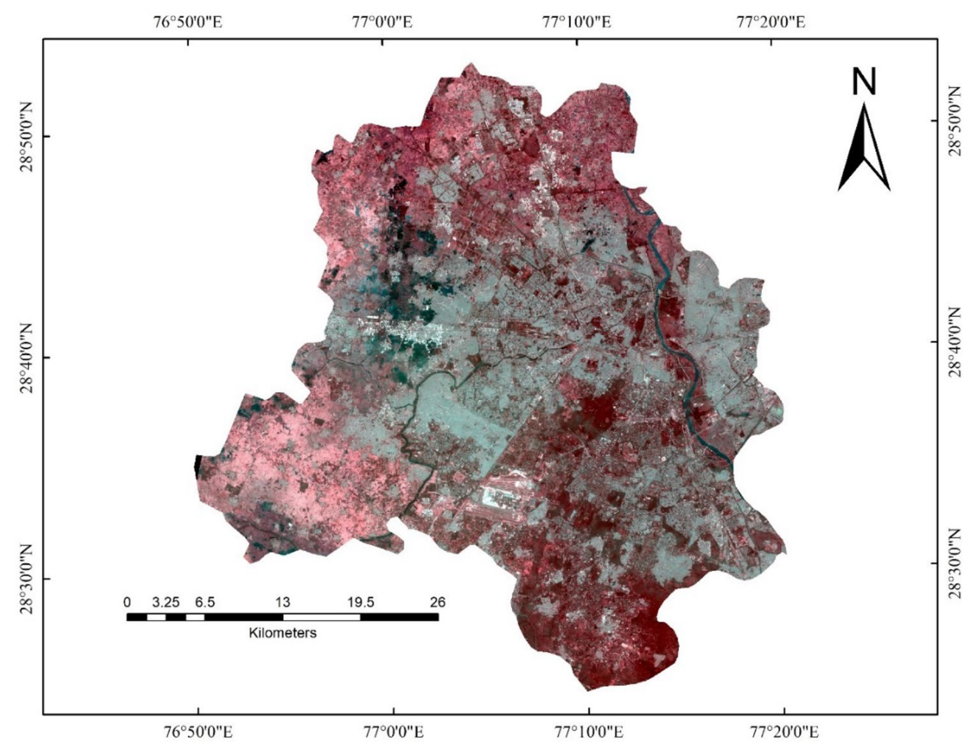


**Fig. 4** Landsat 8, 2021 satellite imagery scene of the study area

Bands Green, Red, and NIR of both the imageries were utilized to create the False Colour Composite (FCC) maps. Six different Land Use classes were prepared—high-density built-up, low-density built-up, open/scrub land, vegetation, agriculture, and water. It is often seen that certain features like water bodies are misinterpreted as vegetation. Therefore, for accurate final output, these and many other misinterpreted patches among all the classes need to be recoded to the correct and accurate class. Supervised classification was carried out on the preliminary unsupervised

**Table 1** Primary data used for the present study

| S. no. | Year | 2010 | 2021 |
|---|---|---|---|
| 1 | Satellite | LANDSAT-5 | LANDSAT-8 |
| 2 | Sensor | Thematic Mapper (TM) | Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) |
| 3 | Dataset | 29/11/2010 | 26/11/2021 |
| 4 | Date of Acquisition | 04/03/2022 | 07/04/2022 |
| 4 | Cloud Cover | 0% | 0.13% |
| 6 | Band List | (1, 2, 3, 4, 5, 6, 7) | (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11) |
| 7 | Band used | (1, 2, 3, 4, 5, 6, 7) | (1, 2, 3, 4, 5, 6, 7) |
| 8 | UTM Zone | 43 | 43 |
| 9 | Datum | WGS84 | WGS84 |
| 10 | Map Projection | UTM | UTM |
| 11 | Path | 146 | 040 |
| 12 | Row | 146 | 040 |
| 13 | Resolution | 30 m | 30 m |

classification output to produce the final LULC output class for the 2 different periods.

Maps of LULC of the above-mentioned periods were created to study the urban rise over the last 11 years and correlate the changes in the built-up area and vegetation area. These maps for the two image sets were created by using the supervised classification technique in ERDAS Imagine software.

Essential variables such as LULC, normalized difference vegetation index (NDVI), and normalized difference building index (NDBI) are used in direction to develop their spatial and temporal dependencies. Analysis and impact assessment has been done to experiment with the use of using RS technology for these types of studies (Table 1).

## Results and discussion

LULC maps of two different years (2010 and 2021) are compared. The LULC of the study area changed intensely over 11 years. Thus, the data interpretation and data analysis are grounded on the comparison of LULC for two different periods during the 11 years.

Environmental sustainability for urban areas specifically metropolitan cities like Delhi can be evaluated and judged by studying different factors such as built-up areas, Land-use, Temperature variations, Vegetation, etc. Changes in the LULC pattern over some time show the city's ability to efficiently balance and regulation of its natural resources with progress. Changes such as agricultural land and related upsurges in urban areas, decrease in vegetation cover, open land, and decent indicators of city urbanization. Overall accuracy for 2010 was 89.52% with kappa statistics of 0.8637 and overall accuracy for 2021 was 89.92% with kappa statistics of 0.8681 (Tables 2 and 3).

**Table 2** Accuracy assessment for classified map 2010

| Accuracy assessment of classified map 2010 | | | |
|---|---|---|---|
| Category | Producer's accuracy (%) | User's accuracy (%) | Overall accuracy (%) |
| High built-up density | 100 | 96.67 | |
| Low built-up density | 100 | 100 | |
| Open/ scrubland | 100 | 75 | 89.52 |
| Vegetation | 100 | 77.78 | |
| Agriculture | 100 | 91.18 | |
| Water bodies | 100 | 100 | |

**Table 3** Accuracy assessment for classified map 2021

| Accuracy assessment of classified map 2021 | | | |
|---|---|---|---|
| Category | Producer's accuracy (%) | User's accuracy (%) | Overall accuracy (%) |
| High built-up density | 96.15 | 89.29 | |
| Low built-up density | 100 | 89.19 | |
| Open/ scrubland | 100 | 100 | 89.92 |
| Vegetation | 100 | 75 | |
| Agriculture | 100 | 97.14 | |
| Water bodies | 100 | 100 | |

### LULC analysis

LULC maps prepared for Delhi mega city for the years 2010 and 2021 are shown in Figs. 5 and 6. A study of the changes shows that dense urban built-up areas have been

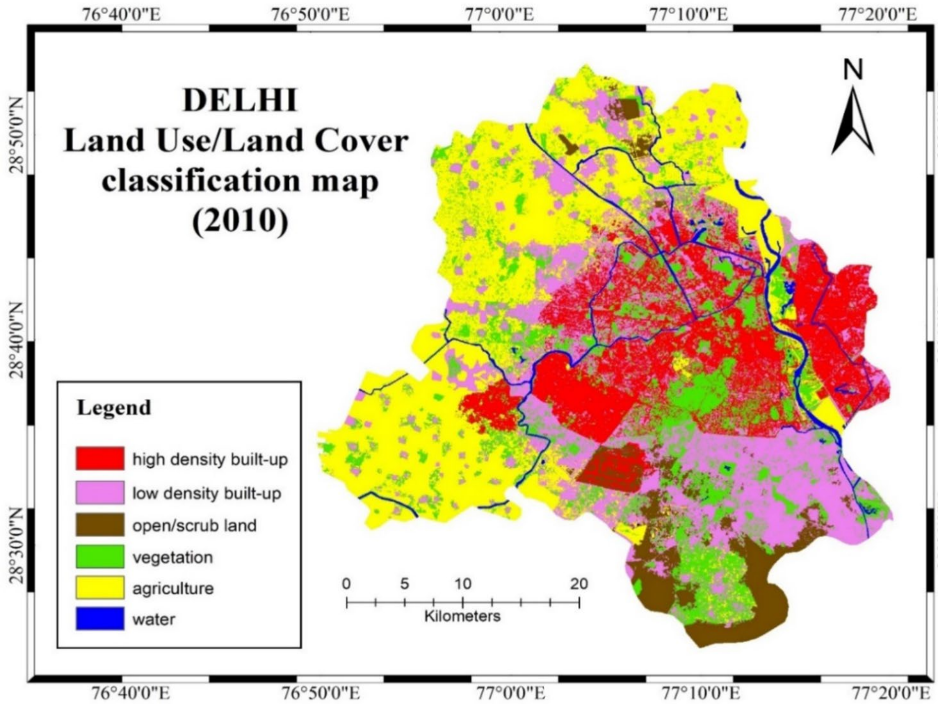


**Fig. 5** LULC map of Delhi for 2010

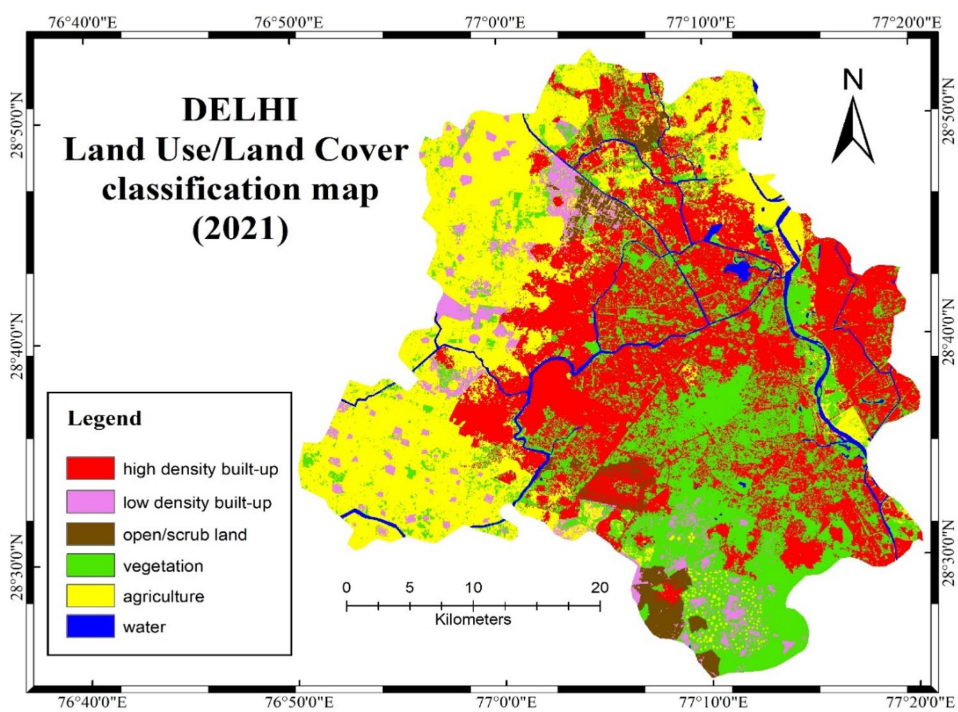


**Fig. 6** LULC map of Delhi for 2021

fully-fledged by nearly doubled in the past 11 years and scattered urban built-up areas have decreased as the same have been transformed into compact urban sprawls. It is clear that urban expansion, and development activities in the Delhi mega-city, may have crucially supported the conversion of natural lands into built-up areas (Faizan 2021). Low-density built-up, Open/scrubland, and Agricultural land in West and North West Delhi has decreased by nearly 81%, 54%, and 7% respectively as the same has been converted into high-density built-up areas by building industrial, residential, commercial areas, and offices (Fig. 7, Table 4). Also, land has been used in building substructures like highways, roads, flyovers, metro lines, etc. to cater to the growing population in the city. The

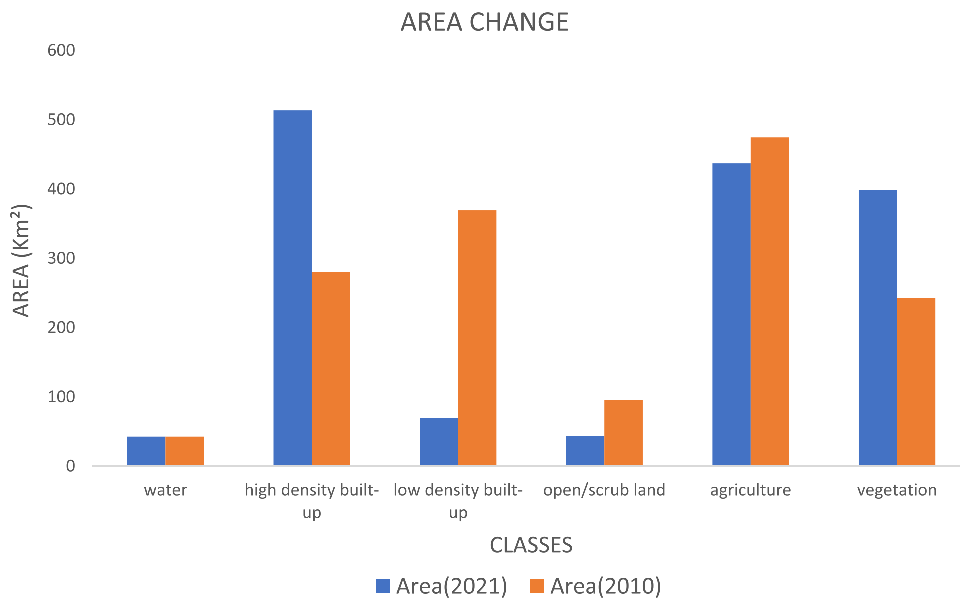


**Fig. 7** Changes in the area under various LULC Classes

**Table 4** LULC changes in Delhi from 2010 to 2021

| LULC classes | Area ($Km^2$) 2010 | Area ($Km^2$) 2021 | Area change ($Km^2$) | Change percentage (%) |
|---|---|---|---|---|
| Water | 42.46 | 42.45 | 0.01 | 0.024% |
| High density built-up | 279.84 | 513.42 | 233.58 | 83% |
| low density built-up | 369.25 | 69.21 | – 300.04 | 81% |
| open/scrubland | 95.31 | 43.73 | – 51.58 | 54% |
| agriculture | 474.48 | 436.85 | – 37.63 | 8% |
| vegetation | 242.81 | 398.49 | 155.68 | 64% |
| TOTAL | 1504.15 | 1504.15 | 0.0 | 0.0 |

only positive thing about this enormous urban growth is the growth of vegetation cover in Delhi over a period of 11 years. The vegetation growth was mainly seen in the East, Central, and South Delhi district areas. With many conservation efforts by the Delhi government to maintain a state of equilibrium within the ecosystem. Many action plans are in the running phase to recover the vegetation cover. Many government organizations like Green Action Plan and non-governmental organizations like Mission Green Delhi, and Delhi greens are functioning and operating to protect the environment they work with the agenda of safeguarding environmental harmony and sustainable urbanization. These types of organizations are reaching more and more people day by day appealing to schools and colleges, citizens, and companies. Promoting environmental education nationally has created a positive impact. Many other organizations such as "Swechha", "Sankalp", and "clean Delhi green Delhi" are working towards it. There has been a rise of nearly 64% with East, Central, and South Delhi areas increasing their vegetation cover over the past 11 years. Faizan (2021) concluded that an increase is seen in forest land (50.65%), built-up area (42.18%), and a decrease in agricultural land (50.54%) over the last 10 years (2000–2010) in Delhi and (Talukdar et al. 2022) stated that open and urban areas are increased by 2.40% and 13.44% respectively, with a considerable decrease in cropland (10.88%) from 1989 to 2020 and forest area increased due to restoration programs by 3.48% in the national capital region.

A news report in "The Hindu (1st Jan 2020)" says forest cover in Delhi has grown by three square kilometers based on the satellite imagery of November 2017 from the prior assessment which was in October–December 2015, according to the biennial Indian State of Forest Report (ISFR) which was made public. (https://www.thehindu.com/news/cities/Delhi/marginal-rise-in-delhis-forest-cover/article30447328.ece).

On January 13, 2022, ISFR (Indian State of Forest Report) declared by the Union Environment Ministry, disclosed that Delhi's green cover has improved from 21.88 to 23.06% of its geographical area in the past two years. The

**Table 5** NDVI changes in the area under various range

| NDVI range | Area ($Km^2$) 2010 | Area ($Km^2$) 2021 | Area change ($Km^2$) |
|---|---|---|---|
| A (− 0.1209 to − 0.0453) | 2.451 | 262.524 | 260.073 |
| B (− 0.0453 to − 0.0267) | 2.470 | 349.702 | 347.232 |
| C (− 0.0267 to − 0.1020) | 3.674 | 351.968 | 348.294 |
| D (− 0.102 to − 0.0073) | 3.701 | 394.86 | 391.159 |
| E (− 0.0073–0.1603) | 531.669 | 145.061 | − 386.608 |
| F (0.1603–0.4675) | 960.150 | NA | NA |
| Total | 1504.115 | 1504.115 | NA |

**Table 6** NDBI changes in the area under various range

| NDBI range | Area ($Km^2$) 2010 | Area ($Km^2$) 2021 | Area change ($Km^2$) |
|---|---|---|---|
| A (− 0.176187 to − 0.14059) | 50.959 | 235.769 | 184.81 |
| B (0.14059 to − 0.068437) | 197.087 | 0.009 | 197.078 |
| C (− 0.068437 to − 0.016188) | 343.104 | 2.199 | 336.573 |
| D (− 0.016188–0.31085) | 345.50 | 6.531 | 338.969 |
| E (0.31085–0.297306) | 567.466 | 11.499 | 555.967 |
| F (0.297306–0.503266) | NA | 1248.318 | NA |
| Total | 1504.116 | 1504.116 | NA |

ISFR also said that Delhi's tree cover grew from 129 square km in 2019 to 147 square km in 2021 (Tables 5 and 6).

In general, the total green cover (forest cover and tree cover) is grown by 324.44 $(km)^2$ to 342 $(km)^2$, according to the reports. (https://economictimes.indiatimes.com).

## Normalized difference vegetation index analysis (NDVI)

The results of the LULC study of Delhi have shown that vegetation cover has increased in the state between 2010 and 2021. However, LULC does not give a precise analysis of the categories and stretches of this cover. Thus, NDVI maps for the city are produced using LANDSAT imageries for the same period and are shown in Figs. 8 and 9. The NDVI analysis shows that there has been a massive decrease in the dense cover of trees possibly due to continuous deforestation for infrastructure expansion. Low and medium NDVI values have increased indicating an upsurge in green cover due to scattered trees and grass planting in gardens and sideways of the roads (Fig. 10). India State of Forest Report-2015 stated that the whole Forest and Tree Cover of NCT of Delhi was 299.77 sq. km (20.22%) while, a counter ISFR-2013 stated 297.81 sq. km. (20.08%). This makes up 111 sq. km. of tree cover and 188.77 sq. km. of forest

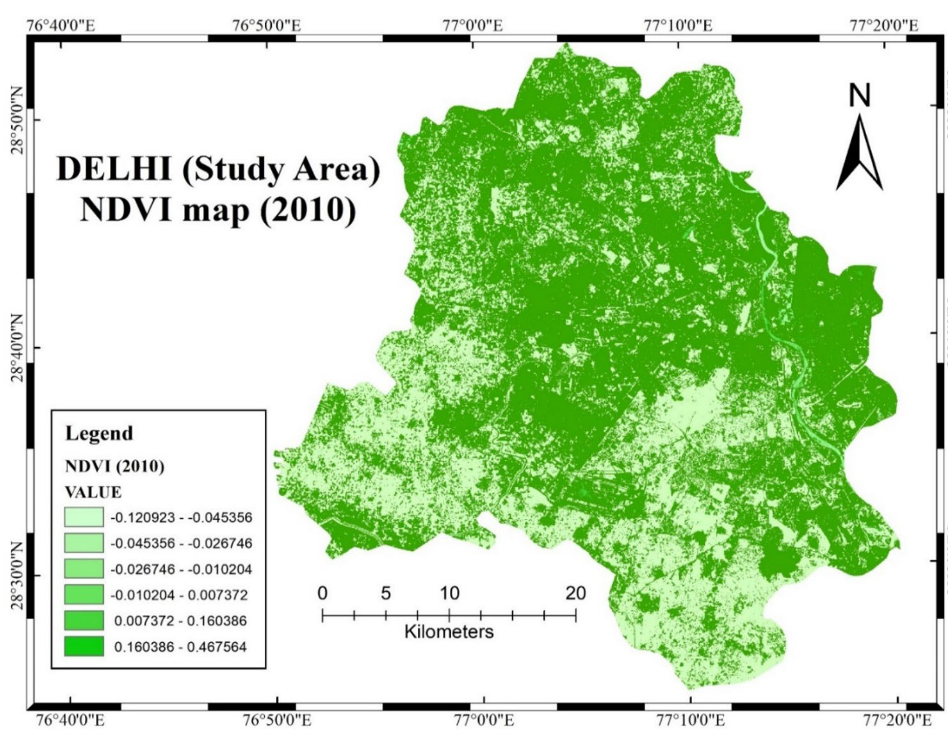


**Fig. 8** NDVI map of Delhi for 2010

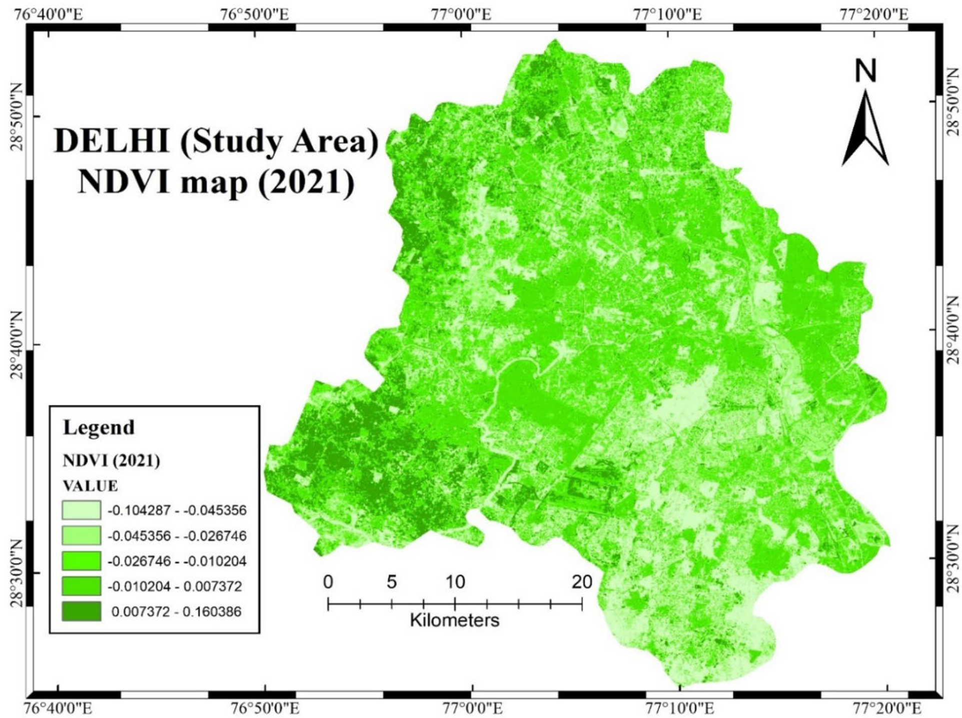


**Fig. 9** NDVI map of Delhi for 2021

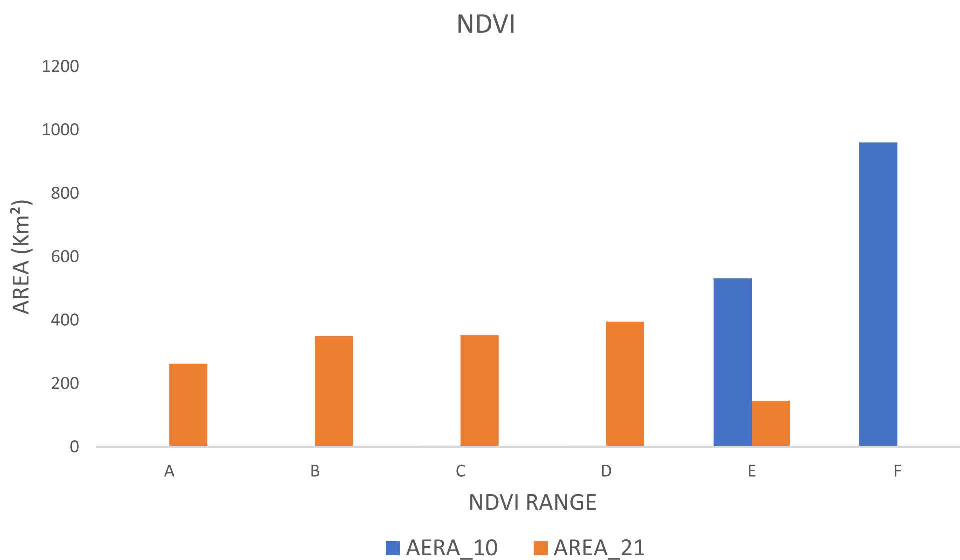


**Fig. 10** NDVI density changes in Delhi from 2010 to 2021

cover assembling a total of 299.77 sq. km. Thus, there is an upsurge in the Green Cover of Delhi from 20.08 to 20.22% which comes out to 0.14% of the geographic area (Forest Survey of India, Ministry of Environment and Forests, GoI, 2021).

## Normalized difference building index analysis (NDBI)

NDBI has given a good valuation of urban sprawl in an area. NDBI maps for Delhi were developed for the study period to map the urban sprawl in Delhi (Figs. 11 and 12) and its relationship with LULC, and NDVI. The results show large areas of North West, West, Central, and South West Delhi comes under urbanization over the past 11 years. A very slight increase in urbanization has been seen in Central Part and New Delhi areas because of previous saturation and stern control on construction projects respectively. North, North West, and West Delhi have seen the highest increase in urban areas with the conversion of open/scrubland and agricultural land into commercial complexes and residential areas. The graphical representation is shown in Fig. 13.

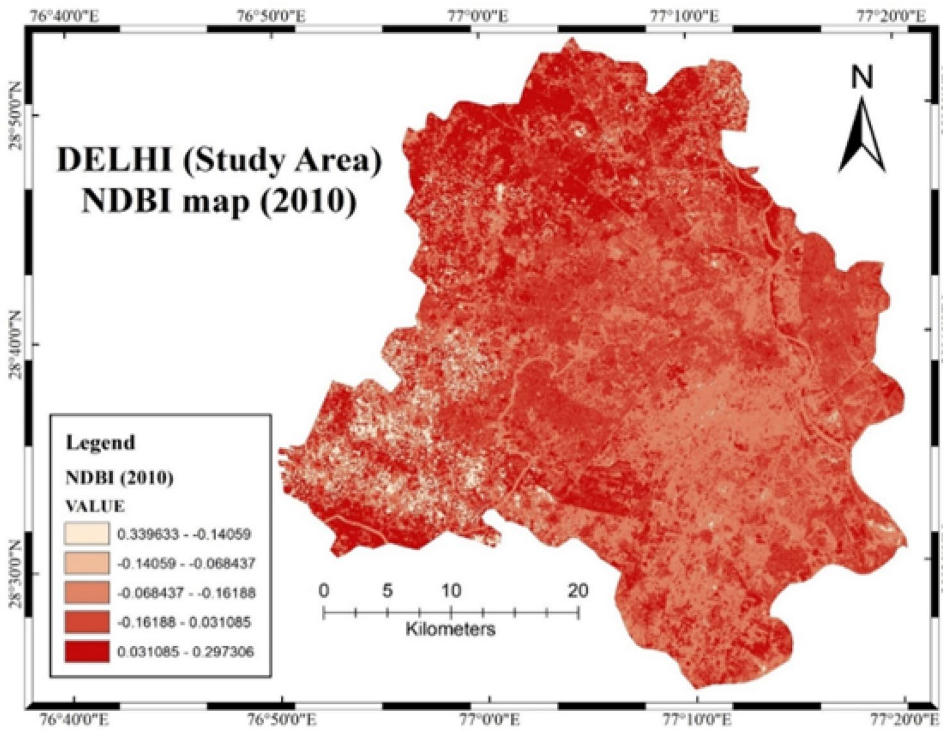


**Fig. 11** NDBI map of Delhi for 2010

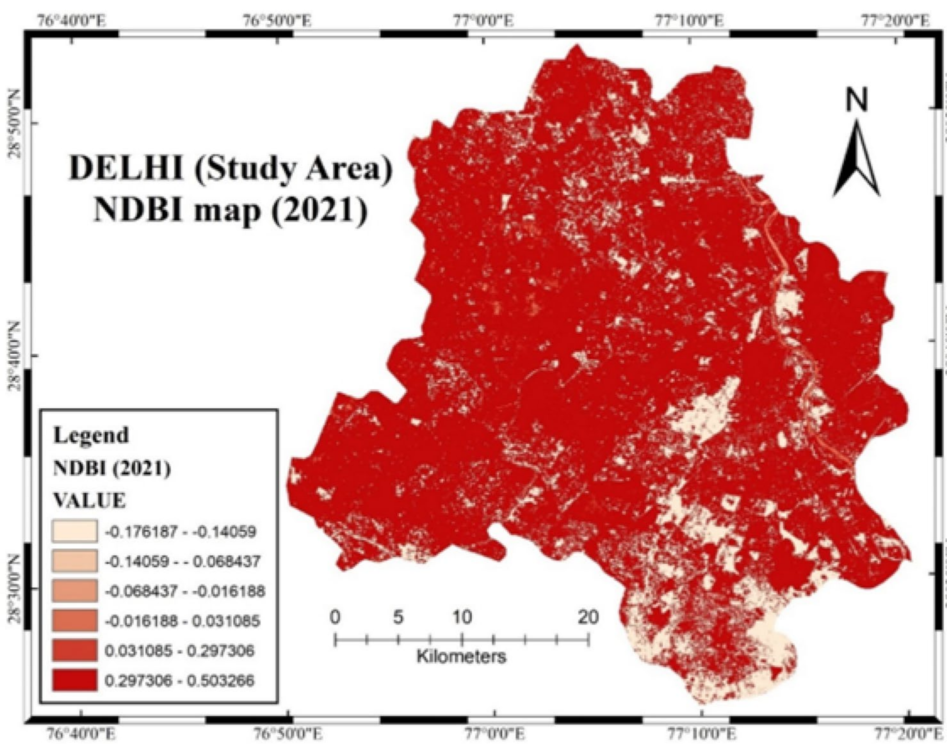


**Fig. 12** NDBI map of Delhi for 2021

## Conclusion

This research shows the capabilities of GIS and RS in scrutinising spatio-temporal data. An effort has been made in the current study to develop a spatial–temporal database of the LULC of Delhi Mega City. It is inferred that using satellite images of the earth and the resulting datasets, a precise and comprehensive study can be conducted to evaluate the impacts of variations in land use, urban area, and vegetation cover on the ecological sustainability of a metropolitan

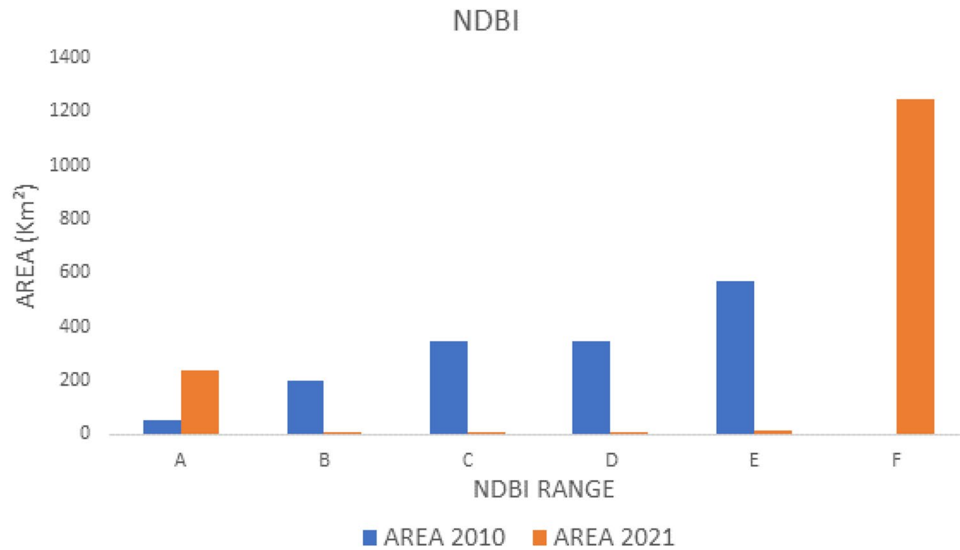


**Fig. 13** NDBI density changes in Delhi from 2010 to 2021

city like Delhi. A comprehensive LULC map was developed for two different time periods of over 11 years to study the urban expansion in Delhi. LULC was developed for each study period, but with more stress on the built-up area to understand and quantify the urbanization. Landsat and IRS (Indian Remote Sensing) data were found to be good sources of information for studying how Delhi is growing and changing quickly. Remote sensing and related technologies such as GIS can precisely map and evaluate changes in different factors affecting the environmental susceptibility of an area. The use of such tools is an unavoidable necessity for the present-day supervision of both non-urban and urban areas and for projecting the upcoming land-use pattern. The results from these earth observation data sets are accurate, easy to get, cheap, and consistent with field data sets. The present study has revealed that changes in LULC classes in Delhi have given rise to a change in the equilibrium of built-up and vegetation-cover in the city. The population increase and the increase in the built-up area show a positive relationship, i.e., the higher the population growth, the higher the urban sprawl or built-up area. The built-up area has spilled over, making Delhi a borderless city because of the non-stop stretch beyond the borderline of the NCT of Delhi. It is well known that factors that lead to urban expansion bring a lot of economic opportunities and are also the main reason why landscape and ecological risks are rising in cities. In recent years, urban expansion has also resulted in an increase in land surface temperatures (Kumar et al. 2012). The temperature rise is contributing to climate change, along with unpredictable and extreme rainfall and greater surface runoff because of more urbanization. Therefore, affecting the quality of life, human health, and the nationwide future of the city and its populations. In this study of change detection, a decrease has been shown by 81%, 54%, and 7% in low-density built-up, open/scrubland, and agricultural land, respectively, in West and North West Delhi. But an increase of 64% is seen in vegetation cover, mainly in the East, Central, and South Delhi districts, during the research period. The LULC classification methodology coordinated very well for this study, and the accuracy of the same was validated with a Kappa accuracy assessment. An accuracy of 89.52% was obtained for the 2010 map, and an even better accuracy of 89.92% was obtained for the 2021 map. In future studies, accuracy improvement should be given more time and effort, as the accuracy of classification is very important for the results of LULC. Refining the accuracy of classification will boost the value of the results, and the statistical data of variations in the land resource will also be more precise. Future study is feasible with shorter temporal intervals and high-resolution satellite images for finer and superior analysis of the variations, but more of it depends on image cloud cover and accessibility. Ecological sustainability takes into consideration factors like the least impact on the climate, sustainable urbanization, and conserving existing ecosystems. However, in the case of Delhi, this sustainability is at alarming risk because of unmaintained and unintended planning and practices. Some of the common mitigation measures to combat the problem could be establishing public–private partnerships to deliver essential services like garbage collection and housing to the public. Planting trees and making the maintenance of urban green spaces a central part of urban design should be prioritised. Its application is significant for city administrations and management authorities in site selection for progressive work. Before it is too late and the city descends into a major environmental catastrophe, the city developers and stockholders of Delhi need to debate and decide on their preferences.

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## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest.

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