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Role of landscape change mapping in ecosystem services analysis: a case study of Delhi-NCR region

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Abstract

The Yamuna River and its wetlands in the Delhi National Capital Region (NCR) are globally significant due to their biodiversity. However, land use changes (LUC), population growth, and pollution pose threats to these ecosystems. This study employed remote sensing (RS) and geographic information system (GIS) methods using Landsat satellite data from 1998 to 2018 to evaluate anthropogenic changes along a 22 km stretch of the river. This study focused on assessing LUC in the Yamuna River corridor from Wazirabad Barrage to Okhla Barrage. Land use land cover (LULC) maps derived from satellite data were utilized to analyze changes in the river's size and surrounding land use. The results reveal a substantial increase in built-up areas along the river, with a growth of 1.92% between 1998 and 2008 and 8.91% between 2008 and 2018. Cropland/agricultural land expanded by 3.96% between 1998 and 2008 but experienced a slight decline of -5.34% during 2008 to 2018. The forest land showed a reduction from 111.33 km² (10.13%) in 1998 to 74.90 km² (6.82%) in 2008, with a modest growth of 76.48 km² (6.96%) identified in 2018. The study highlights an alarming rate of deforestation, as reflected by the negative dynamic index of the forest land. Water bodies exhibited a consistent negative trend over the research period, while the area covered by barren land expanded. This study underscores significant LUC along the Yamuna River from 1998 to 2018, characterized by increased built-up areas and reduced forest cover. The decline in water bodies and expansion of barren land further emphasize the need for monitoring LUC and its impact on the river and its wetlands. The findings provide valuable insights for policymakers to develop strategies aimed at protecting the region's biodiversity and mitigating threats facing the Yamuna River and its wetlands.

Keywords

LULC change, Supervised, Wetlands, Ecosystem services, Delhi NCR.

1.Introduction

The availability of automated, trustworthy, and near-real-time remote sensing (RS) data has emerged as the most crucial data source for obtaining spatially explicit knowledge of the state, distribution, and spatial organisation of wetland ecosystems on a local to global scale [1]. Intensive human activities have resulted in significant and complicated changes in land use land cover (LULC) pattern, with intensive agricultural production and urbanization having the greatest impact on the environment.

The quantity and quality of ecosystem services (ES) demand and supply are accordingly altered [2, 3]. Marginal regions such as water, rocky areas, and lake perimeter, which were initially allowed for natural vegetation to develop, are being turned into farms and communities as the human population grows and poverty worsens. Wetland habitats, for example, supply a variety of ES to the local community. LULC dynamics, on the other hand, have had a detrimental impact on lake ES and have fostered environmental disservices (ED) [4].

Wetlands make up just three to six percent of the earth's land surface area, yet they provide a variety of

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products and services to the human population, such as water quality management, agriculture production, fisheries, and recreation. Despite these benefits, wetland conversion to other land uses has always been an issue, and it continues to be so today. Wetland habitats have not gotten the attention they need from planners and policymakers, despite their tremendous biodiversity potential. Delhi supports and sustains different and distinct wetland ecosystems because of its vast geographic expanse, varied topography, and climatic circumstances. Rapidly rising human populations, large-scale changes in LULC, booming development projects and improved watershed management have all contributed to a significant reduction in the country's wetland resources [5, 6].

As a result, it is vital to recover and restore this wetland environment so that it may be used to its full potential. Conventional surveys are a time-consuming and hard procedure for estimating the area quickly. RS and geographical information system (GIS) might help in a cost-effective way, for example, by quickly assessing and mapping wetland cover for long-term wetland management. As a result, service workers in India have attempted to employ RS data in wetland mapping. One of the main challenges faced in previous literature is the lack of consistent and accurate data for monitoring LULC changes over large areas and long time periods. This has made it difficult to accurately assess the extent and impacts of LULC changes, as well as to develop effective strategies for managing and mitigating these changes. The purpose of this research is to determine the size of the Yamuna River and to track changes in the Yamuna River’s area from 1998 to 2008 and 2008 to 2018.

The motivation behind this study is to address some of the challenges and limitations faced in previous literature and to develop more accurate and reliable methods for monitoring LULC changes using RS and GIS. Specifically, the study objectives to analyze and compare the LULC changes in a specific area over two different time periods, and to identify the driving factors behind these changes. The Yamuna has been portrayed as a primal goddess in myth and faith, in prose and poetry, and she has served as an agricultural lifeline for numerous communities that have existed prior to modern-day population Delhi. In the past, Delhi and Yamuna were united. In the city, wetlands on the edges of river channels are considered a resource for various land use plans. For sustainable development of urban ecosystems, a high priority on the preservation and enhancement of essential natural and man-made ecosystems [7]. Over the past decades, the capital city of Delhi has been exhibiting several negative aspects that a river system (Yamuna) may suffer from, making it ever more susceptible to disasters such as occurrences of flooding, water shortages, and disease outbreaks [8].

On the Yamuna River, several past eruptions were discovered between 1998 and 2018. The Yamuna, which is almost 1,300 km long and supplies water to more than half of the nation's capital, is one of the most polluted rivers in the nation. Even though just 2%, or 22 km, of the Yamuna flows through Delhi, the national capital is responsible for 98% of the river pollution because of the untreated or only partially treated industrial effluents and sewage that are dumped into the river along this 22 km stretch. After passing through Uttarakhand, Himachal Pradesh, Haryana, and Delhi, it merges into the Ganges near the Sangam in Prayagraj, Uttar Pradesh [9].

With a population of approximately twenty million, Delhi, the capital of the greatest democracy in the world, has an extraordinary challenge: the Yamuna, a sacred river, is among the most polluted in the world. To meet the city's fresh water needs, the whole volume of fresh water entering New Delhi is diverted. From the Wazirabad barrage, when it enters the capital city, to the Okhla barrage, where it departs in the south, the Yamuna exclusively carries treated and untreated sewage and other harmful waste [9]. Without dissolved oxygen in the water, the water to the north is effectively "dead," affectation serious health risks to the people of Delhi [10].

The objective of the current study is to map and examine the LULC changes in a specific area between two different time periods using RS and GIS to assess the current activity in the Yamuna River within a 5 km buffer zone. To identify the driving factors behind the observed LULC changes. Additionally, the supervised classification technique is used to evaluate anthropogenic change with the accuracy and reliability of the RS and GIS methods used in this study from 1998 to 2018 using Landsat satellite datasets. To develop recommendations for improving the accuracy and reliability of LULC monitoring using RS and GIS.

The study presented here contributes significantly to the research on LULC change by offering a detailed analysis of changes that ensued in a specific area over two different time periods like 1998-2008 and 2008-2018. This analysis allows for a comprehensive understanding in LULC changes, as well as the factors driving them. In addition, this study provides valuable recommendations for addressing these driving factors, which can help to mitigate harmful effects on the environment and local communities. The use of RS and GIS methods in this study was evaluated for accuracy and reliability, which further contributes to the development of more accurate and reliable methods for monitoring LULC changes. Overall, the contributions of this study are four-fold. Firstly, it provides a comprehensive analysis of LULC changes in the study area. Secondly, it identifies the driving factors behind these changes and offers recommendations for addressing them. Thirdly, it evaluates the accuracy and reliability of RS and methods used in this research. Fourth, to the development of more accurate and reliable methods for monitoring LULC changes using RS and GIS.

The remaining sections are organized as follows: Section 2 provides a detailed literature review of RS and GIS applications in LULC monitoring and describes the study area. Section 3 presents the methods and materials used for mapping and analyzing the LULC changes. Section 4 presents the results of the analysis and the identification of driving factors. Section 5 discusses the implications and limitations of the study. Finally, Section 6 presents the conclusions and recommendations for future research.

2.Literature review

LULC changes have a significant impact on various environmental factors, both directly and indirectly [11]. Previous research has shown that rapid changes in LULC have contributed to changes in climate, particularly in urban areas [12, 13], and have had a harmful impact on biodiversity [14]. Additional research is required because of the region's predicted rise in human activities, development of the urban environment, and shifting agricultural patterns. LULC related these changes to variations in surface temperature [15]. As human activities, urban development, and agricultural patterns continue to evolve, further research is needed to better understand the effects of LULC changes on the environment [16]. The use of geo-information technology to create practical-based theoretical models of urban thermal environments can aid in regional planning and decision-making [17]. Urban expansion and population growth have put a strain on public open spaces, leading to a decline in the quality of the urban environment [18, 19]. The amount of airborne particulate matter is a major driver of changes in LULC [20]. Therefore, sustainable strategies for managing local ecosystems must be developed by planners and scientists to mitigate the effects of LULC changes on the environment [21].

As the population of urban areas grows, built-up areas expand, causing environmental pollution, degradation of urban ecology, and climate change [22]. Human activities and natural forces have caused land use changes (LUC) that alter ecological processes and services, leading to a loss of native biodiversity [23–25]. The conversion of forests into cultivated land to meet the mandate for food products is a significant contributor to LULC shifts [26].

This research aims to investigate the changes in ES and LULC mapping in the Delhi National Capital Region (NCR) between 1998 and 2018. With the population density of Delhi increasing from 6,352 people per km^2 in 1991 to 11,297 people per km^2 in 2011 (Census of India, 2011), it is critical to understand the patterns of LULC changes in this region. This study focused on the wetlands and floodplains of the Yamuna River in the Delhi NCR. By measuring changes with high precision, we aim to gain a clearer understanding of the factors contributing to LULC shifts in this area.

3.Materials and methods

3.1Study area

The research area anthropogenic changes along a 22 km stretch of the Yamuna River in Delhi NCR. These areas are among India most developed and densely populated, and they are seeing rapid urbanization and development, as well as a rising socio-economic activity [21]. Rapid development, on the other hand, is accompanied with an increase in the problem of air pollution. As a result, the Delhi NCR region is experiencing significant air pollution, with Delhi being named the most polluted city [27].

One of India's most significant and revered rivers is the Yamuna. It is the Ganga's most important tributary. It flows from the Yamunotri glacier in the Mussoorie range of the lower Himalayas to Allahabad, where it meets the Ganga after a 1,376-kilometer journey. The Yamuna basin covers 366,233 km^2 and is divided into seven states: Delhi, Haryana, Himachal Pradesh, Madhya Pradesh, Rajasthan, Uttarakhand, and Uttar Pradesh [28]. Giri, Hanuman Ganga, Rishi Ganga and Tons are the four primary tributaries of the Yamuna River in the Himalayan area. The Hindon, Chambal, Sind, Betwa, and Ken are the principal tributaries of the plains. The river water is commonly utilized for irrigation, drinking, and industrial purposes, as well as mass bathing, washing, animal bathing, and cremation ash discharge. Within the municipal borders, the Yamuna River travels 48 kilometres from where it enters Delhi at Palla to where it leaves the city at Okhla. About 26 kilometres after Palla, in Wazirabad, there is a barrage that prevents the river from supplying areas of Delhi with potable water. Water flow is quite low downstream of Wazirabad, and the 22-kilometer section of the river between Wazirabad and Okhla receives canal water from the Western Yamuna Canal (WYC) as well as mostly treated, partially treated, or untreated domestic and industrial waste-water from 22 drains [29]. This astounding expansion has led to significant alterations in LULC, which have drawn several investigations in recent years [17, 18, 30].

The study area was located between latitudes 28°5'0" N to 28°55'0" N and longitudes 77°5'00" E to 77°35'0" E. The total study area is 1098.65 km^2. This study focused on assessing the LUC and ES in the Yamuna River corridor, specifically within a 5 km buffer zone on both sides of the river, from Wazirabad Barrage to Okhla Barrage (*Figure 1*).

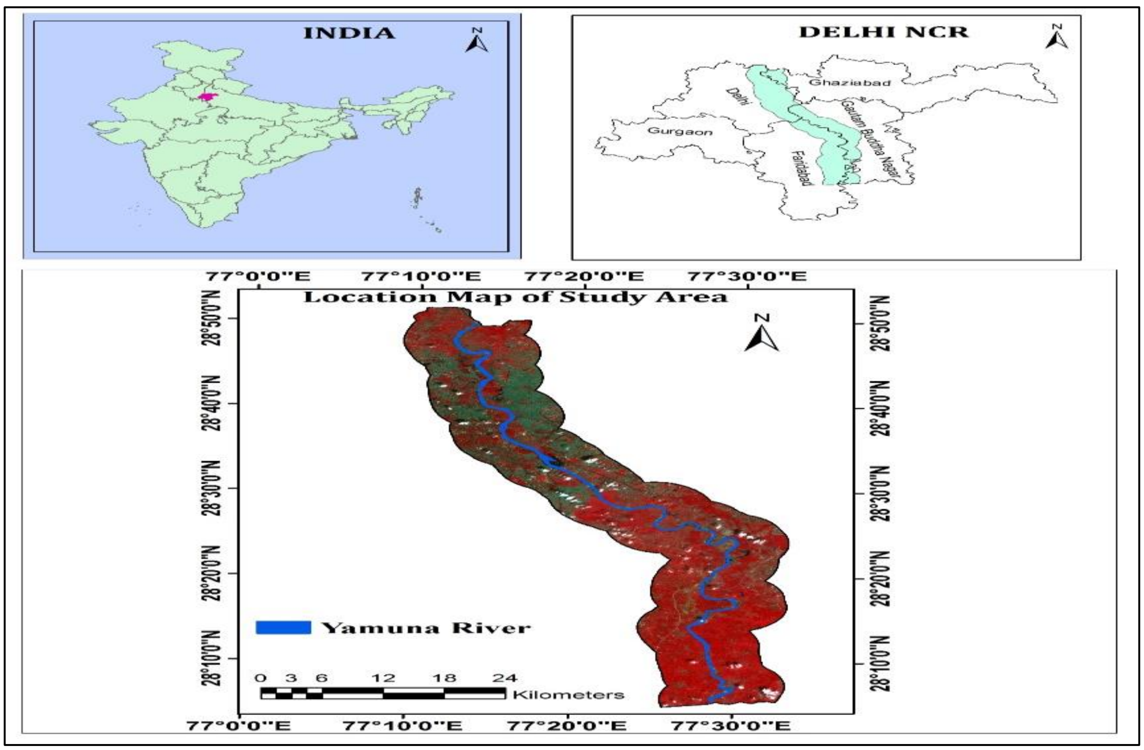


Figure 1 Location of the study area

The *Table 1* shows the LULC classification and the corresponding area in km^2 for three different years: 1998, 2008, and 2018. The LULC classifications include barren land, built-up land, cropland/agriculture, plantations/forest, and water bodies. The *Table 1* also includes a serial number (S. No.) and a total row, which shows the total area for each year. As we can see, there are some changes in the LULC areas between the three years. For example, the area of built-up land has increased from 233.88 km^2 in 1998 to 352.88 km^2 in 2018, while the area of barren land has decreased from 60.53 km^2 in 1998 to 4.10 km^2 in 2018.

Table 1 Identified LULC classes in the research area

S. No.	**LULC classification**	**LULC (1998) area (km^2)**	**LULC (2008) area (km^2)**	**LULC (2018) area (km^2)**
1	Barren Land	60.53	33.82	4.10
2	Built-up Land	233.88	254.94	352.88
3	Cropland/Agriculture	659.56	703.10	644.45
4	Plantations/Forest	111.33	74.90	76.48

S. No.	LULC classification	LULC (1998) area (km^2)	LULC (2008) area (km^2)	LULC (2018) area (km^2)
5	Water Bodies	33.35	31.89	20.74
Total		1098.65	1098.65	1098.65

3.2Materials

The data from Landsat-5 (TM) for 1998 and 2008, as well as the data from Landsat-8 (OLI/TIRS) for 2018, were obtained free from the United States Geological Survey (USGS), Earth Explorer and used for LULC mapping and anthropogenic changes analysis in this study. Landsat-5 (TM) is 30 m of spatial resolution, and that of Landsat 8 (OLI/TIRS) is 15-meter panchromatic and 30-meter, Multi-spectral Scanner (MSS) of spatial resolution. *Table 2* provides in following information about the satellite imageries utilized in this research area: The map of the study region at 1:50,000 scale was acquired from the Survey of India (SOI) Toposheet.

Table 2 Information about the satellite data

S. No.	Satellite	Sensor	Spectral Bands	Month/Year of Acquisition	Path/Row	Average Cloud Cover	Spatial resolution
1	Landsat-5	TM	7	March, 1998	146/40, 146/41, 147/40	0.3%	30 meters
2	Landsat-5	TM	7	April, October, 2008	146/40, 146/41, 147/40	4.1%	
3	Landsat-8	OLI/TIRS	11	April, May & June, 2018	146/40, 146/41, 147/40	02%	15-meter panchromatic and 30-meter MSS

3.2.1Satellite images pre‑processing

A geometrical rectification and an atmospheric correction were conducted prior to interpretation. The catchment, phenology of the vegetation, the classes of imageries (haze and cloudiness), and existing multi-temporal images [4]. We extracted vector data of the Yamuna River basin from the finalized data of satellite images after pre-processing the final processed data of Landsat satellite images. We have done all types of satellite image preprocessing using ERDAS Imagine and ArcGIS software.

3.2.2Data processing

LULC mapping and subsequent quantitative change detection necessitate geometric registration and radiometric rectification to compensate for changes in atmospheric conditions, viewing geometry, and responses [31], as well as sensor noise. ERDAS Imagine and ArcGIS software were used to process Landsat images. In order to investigate the spectral features of several forms of LULC, a multi-band combination of Landsat images was created. To match the Landsat imagery and minimize inaccuracies caused by the location of the sun angle and angle of sensor, geometric correction of RS images was performed using the Universal Transverse Mercator Projection (UTM) WGS_1984_UTM_Zone_43N, based on a topographic map scale of 1:50,000.

3.2.3Image enhancement

The present known LULC location points were associated with the classified data to determine whether the LULC-classified images obtained after using the land classification tool in ArcGIS 10.2 were applicable. A Garmin global positioning system (GPS) was used to gather coordinates for 30 distinct training stations. For each point, observations were made on the present LULC. Various characteristics on the images were recognized using the false-color-composite (FCC) using band combinations of 4, 3, and 2 for Landsat-5 and 5, 4 and 3 for Landsat-8 respectively. The vegetation in this conventional false color composite appears in tones of red, the water is blue, and the soil is dark grey.

3.3Methods

3.3.1Method for LULC classification

LULC classification is a widely used method for extracting information from satellite imagery in the field of RS and GIS [32]. The two most used LULC classification methods are supervised and unsupervised classifications [33, 34]. The usage of a training set, which is present in supervised classification but lacking in unsupervised classification, distinguishes these two approaches [4]. The idea of internal homogeneity in spectral values inside a feature space and outward heterogeneity of the same among feature spaces is the foundation for supervised categorization [31]. The maximum likelihood classifier approach has been employed in earlier research on LULC change in Delhi Metropolitan City and Delhi NCR. However, in this research, supervised classification method was applied using two software i.e., ERDAS Imagine 2014 version and ArcGIS 10.2 versions. Five LULC classes, namely built-up land, barren land, cropland/agriculture, plantations/forest, and water bodies, were identified based on the National Remote Sensing Centre (NRSC) level I classification pattern. The selected LULC classes were then further confirmed using ground validation, in addition to post-classification field visits and the usage of GPS. The final step was to create multi-temporal raster layers for 1998, 2008, and 2018 and compare the corresponding data to estimate the LULC change. The following flow chart has using methodology.

The methodology employed in the following flowchart (*Figure 2*) is as follows:

1. Data collection: Satellite imagery such as Landsat-5 and Landsat-8, as well as ground truth data, are collected for the study.
2. Preprocessing: The collected data undergoes preprocessing to ensure its suitability for analysis. This includes tasks such as image calibration, atmospheric correction, and geometric correction, which enhance the quality and accuracy of the data.
3. Image classification: The preprocessed data is subjected to image classification techniques to categorize different LULC types. Supervised classification approaches are utilized, considering the availability of training data and the research objectives.
4. Accuracy assessment: The accuracy of the classified image is evaluated using various assessment techniques, including the Kappa coefficient, error matrix, or validation with ground truth data. This step helps determine the reliability and precision of the classification results.
5. Change detection: For LULC change analysis, a change detection process is applied by comparing classified images from different time periods, such as 1998 to 2008 and 2008 to 2018. This allows for the identification of areas undergoing LULC transformation or experiencing transitions over time.
6. Spatial analysis: Spatial analysis techniques are employed to examine the spatial patterns, relationships, and distributions of LULC classes. This involves analyzing the spatial characteristics and interactions between different LULC types.
7. Data interpretation and visualization: The final step involves interpreting the results of the analysis and presenting them in a visually appealing manner. Thematic maps, graphs, and spatial visualizations are used to facilitate a better understanding of the study findings.

3.3.2Accuracy assessment

Several researches have previously employed approaches like the error matrix, kappa coefficient and indices-based techniques to analyze the accuracy of LULC maps created [34, 35]. The categorization accuracy assessment the quality of maps produced and aids in determining a map's suitability for a certain application [21]. Classification accuracy is a crucial measure that assesses the quality of produced maps and aids in evaluating their suitability for specific purposes. To ensure accurate interpretation and identification, the minimum accuracy of a classified map should ideally exceed 80% [36]. Several techniques, such as the Kappa coefficient, error matrix, and indices-based techniques, have been previously employed in various research to assess the accuracy of LULC maps [21, 22, 34].

In this study, the Kappa coefficient method was utilized to estimate the accuracy of LULC maps for the Delhi NCR. A total of 300 randomly selected points were chosen to ensure adequate coverage of each LULC class in a balanced manner across the entire study area. Ground observations for the years 1998 and 2008 were sourced from Google Earth Pro, as field data was unavailable for those specific years. For 2018, a combination of field visits and Google Earth Pro was used to obtain ground observations, particularly in areas with limited accessibility or no access at all. The accuracy assessment results (*Table 3*) indicated an overall accuracy level of 84.51%, 84.54%, and 85.05% for the years 1998, 2008, and 2018, respectively. The corresponding Kappa Coefficient was calculated as 0.8066, 0.8092, and 0.8184 for the respective years. These measurements are calculated as shown in Equation 1 to Equation 4:

$$\text{Producer Accuracy } (\text{PA}_\text{k}) = \frac{X_{kk}}{X_{k+}} \quad (1)$$

$$\text{User Accuracy } (\text{UA}_\text{k}) = \frac{X_{kk}}{X_{+k}} \quad (2)$$

$$\text{Overall Accuracy (OA)} = \frac{\sum X_{kk}}{\text{N}} \quad (3)$$

$$\text{Kappa Coefficient (KC)} = \frac{\text{N}\sum X_{kk} - \sum X_{k+} + X_{+k}}{N^2 - \sum X_{k+} + X_{+k}} \quad (4)$$

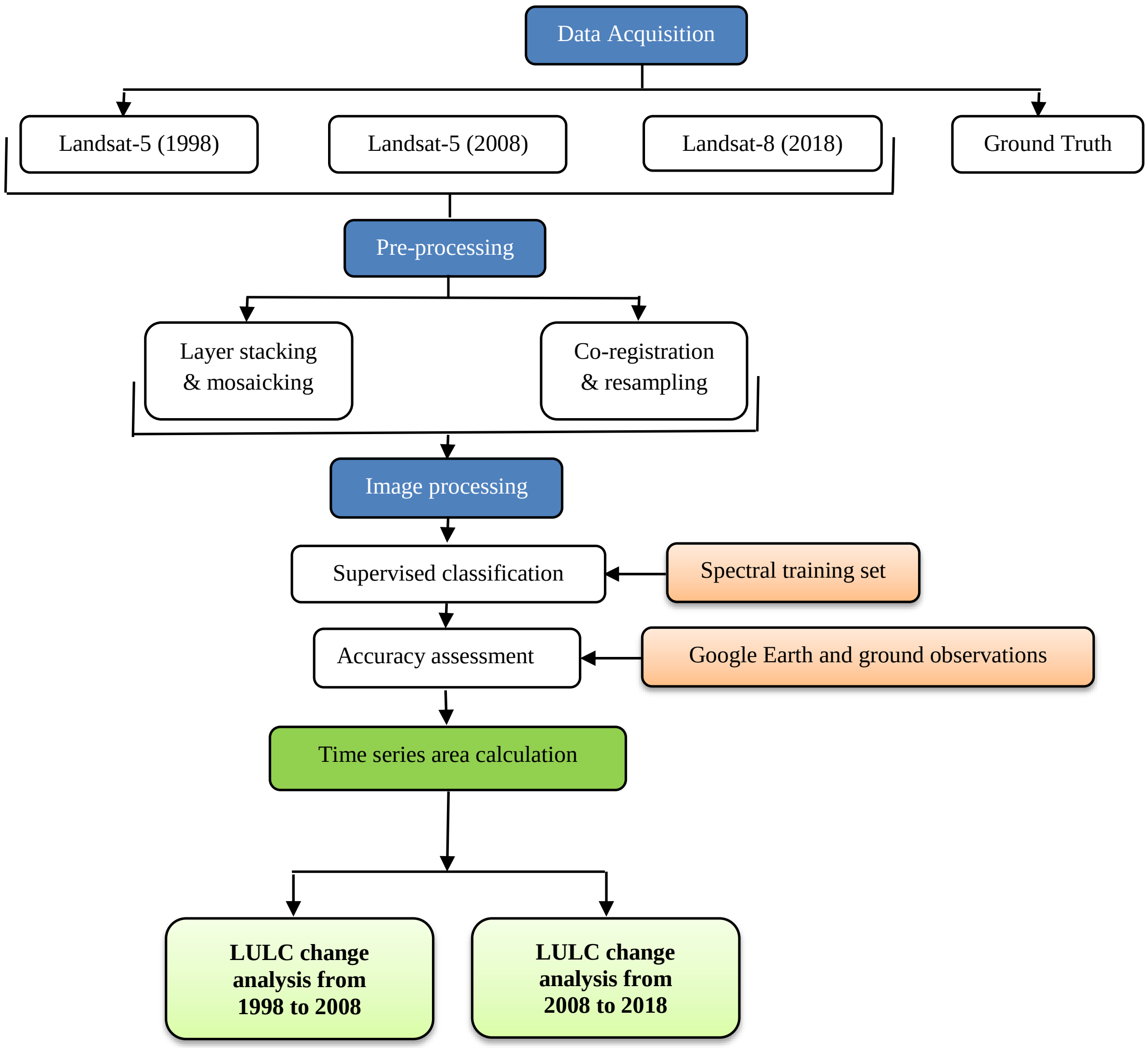


Figure 2 Flow chart of the methodology

Equation 1 represents the producer accuracy (PA) of a particular class k. It is calculated by dividing the number of correctly classified instances for that class X_kk (Xkk) by the total number of instances that belong to that class (X_(k+)).

Equation 2 represents the user accuracy (UA) of a particular class k. It is calculated by dividing the number of correctly classified instances for that class (X_kk) by the total number of instances that the model predicted as belonging to that class (X_(+k)).

Equation 3 represents the overall accuracy (OA) of the classification model. It is calculated by summing up the number of correctly classified instances for all classes (ΣX_kk) and dividing it by the total number of instances (N).

Equation (4) represents the kappa coefficient (KC), which is a measure of the agreement between the predicted and actual classifications. It is calculated by subtracting the expected agreement (based on chance) from the observed agreement and then normalizing the result. N represents the total number of instances, ΣX_kk represents the sum of correctly classified instances for all classes, ΣX_(k+) represents the sum of instances that belong to each class, and ΣX_(+k) represents the sum of instances that the model predicted as belonging to each class.

Table 3 Kappa coefficient, overall accuracy, user accuracy and producer accuracy results obtained from Landsat-5 (1998), Landsat-5 (2008) and Landsat-8 (2018) classified image

	Landsat - 5 (1998)				**Landsat - 5 (2008)**				**Landsat - 8 (2018)**			
Class	**User Accuracy**	**Producer Accuracy**	**Overall Accuracy**	**Kappa**	**User Accuracy**	**Producer Accuracy**	**Overall Accuracy**	**Kappa**	**User Accuracy**	**Producer Accuracy**	**Overall Accuracy**	**Kappa**
Water Bodies	90.48%	90.48%			90.48%	88.37%			90.91%	86.96%		
Cropland/ Agriculture	85.71%	82.76%			86.89%	84.13%			86.67%	83.97%		
Plantations / Forest	87.84%	80.25%	84.51%	0.8066	85.51%	78.67%	84.54%	0.8092	84.93%	80.52%	85.05%	0.8184
Built-up Land	79.73%	86.76%			81.25%	89.04%			83.33%	88.61%		
Barren Land	78.95%	85.71%			79.49%	83.78%			80.00%	86.49%		

4.Results

4.1Spatio-temporal distribution of LULC

The study evaluated the spatio-temporal distribution of LULC in a research area from 1998 to 2018. The classification accuracy testing was done using a confusion matrix, which gave overall good accuracy for five classification points and established LULC classes.

In 1998, cropland/agriculture dominated the landscape, interspersed with built-up land in the crucial region, which represented the numerous metropolises and settlements of the research area. Barren land was largely found in the western and south-central parts of the research area, and it lined itself along the southwest to northeast path. Plantations/forests were primarily found around water bodies running north-south, but pockets of plantations/forests were present across the research area. In 2008, the perceptibility of built-up area increased into other land use categories. The preponderance of barren land changed from the west to the southwest. Built-up areas had an obvious advantage in 2018. Not only had large cities grown, but so had smaller, scattered settlements.

Both class-specific producer and user accuracy were at least 80%, indicating that a significant portion of pixels was properly identified. *Figures 3*, *4*, and *5* showed the LULC dynamics from 1998 to 2018 based on image categorization. *Table 4* showed the variations in the size of five land use groups. When comparing land use in 1998, 2008, and 2018, there was a clear difference in LULC. Over the research period, the amount of barren land, built-up land, cropland/agriculture, plantations/forest, and water bodies all increased. The built-up area increased by 1.92% and 8.91% between 1998-2008 and 2008-2018, respectively. Cropland/agriculture land expanded by 3.96% from 659.56 km^2 to 703.10 km^2 in the period 1998-2008 and decreased marginally by -5.34% in the period 2008-2018. During the research period, in plantations/forest land, a similar pattern could be seen. It decreased from 111.33 km^2 (10.13%) in 1998 to 74.90 km^2 (6.82%) in 2008, and then grew very modestly to 76.48 km^2 (6.96%) in 2018. Its negative dynamic index value was the highest of all land use types, indicating an accelerated amount of deforestation in the study area. The water body declined by 33.35 km^2 (3.04%) in 1998, 31.89 km^2 (2.90%) in 2008, and 20.74 km^2 (1.89%) in 2018. Throughout the research period, the water body had a negative trend. During the research period, the area covered by barren land expanded by 60.53 km^2 (5.51%) in 1998, 33.82 km^2 (3.08%) in 2008, and 4.10 km^2 (0.37%) in 2018, decreasing on the western side of the study area.

The passage highlights some of the drivers of LULC dynamics. These drivers include population growth, climate change impacts, government policy disputes, poverty, poor governance, and inadequate education. The passage also notes that climate change, bad governance, and related factors received the lowest scores, while the impact of climate change was significantly connected to the fluctuation of water bodies, characterized by high temperatures and falling rainfall in the Yamuna River basin. The loss of forest land was connected to increased population growth, government policy disagreements, and poverty. Furthermore, the increase in built-up land was strongly related to increases in human population, implying that as the human settlement grows, extra land for human township will be essential at the expense of forest land outflow. Finally, the passage notes that from 1998 to 2008, all LULC classes except water bodies saw higher changes, even though the number of years was greater from 2008 to 2018. This suggests that the rate of change in LULC was higher during the earlier period.

4.2Dynamics change in LULC between 1998-2008 and 2008-2018

Table 5 provides information about the changes in five LULC classes over two time periods: 1998-2008 and 2008-2018. The first column lists the serial number of the LULC class changes. The second column presents the type of change that has occurred between two LULC classes, such as barren land to built-up land, or cropland/agriculture to water bodies. The third column shows the area change in km^2 for the 1998-2008 period, while the fourth column displays the area change for the 2008-2018 period. According to the *Table 5*, the most significant changes in LULC classes occurred in built-up land and cropland/agriculture. The area of built-up land increased from barren land by 14.36 km^2 between 1998 to 2008 and 18.79 km^2 between 2008 to 2018. Similarly, the area of cropland/agriculture increased from built-up land by 60.62 km^2 between 1998 to -2008 and 135.08 km^2 between 2008 to 2018. The changes between barren land and cropland/agriculture were also substantial. Between 1998 to 2008, the area of cropland/agriculture increased from barren land by 39.98 km^2, while between 2008 to 2018, it increased by 12.38 km^2. In contrast, the area of barren land decreased by 39.98 km^2 between 1998-2008 and by 12.38 km^2 between 2008-2018. The changes between other LULC classes were relatively small. For instance, the area of plantations/forest increased from cropland/agriculture by 33.29 km^2 between 1998-2008 and by 30.14 km^2 between 2008-2018. The area of water bodies increased from cropland/agriculture by 7.38 km^2 between 1998 to 2008 and by 5.17 km^2 between 2008 to 2018. It is easily identified and map in *Figure 6.* The changes between barren land and water bodies and between plantations/forest and water bodies were also small, indicating a relatively stable condition for these LULC classes. Overall, the *Table 5* provides insights into the changing patterns of LULC classes over time, which can help planners and decision-makers develop appropriate policies for sustainable land management.

Table 4 Year wise LULC classes change in area (km^2)

Wetland Name	LULC Classification	LULC (1998)		LULC (2008)		LULC (2018)	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Yamuna River Buffer (5 km)	Barren Land	60.53	5.51	33.82	3.08	4.10	0.37
	Built-up Land	233.88	21.29	254.94	23.20	352.88	32.12
	Cropland/Agriculture	659.56	60.03	703.10	64.00	644.45	58.66
	Plantations/Forest	111.33	10.13	74.90	6.82	76.48	6.96
	Water Bodies	33.35	3.04	31.89	2.90	20.74	1.89
Total		1098.65	100.00	1098.65	100.00	1098.65	100.00

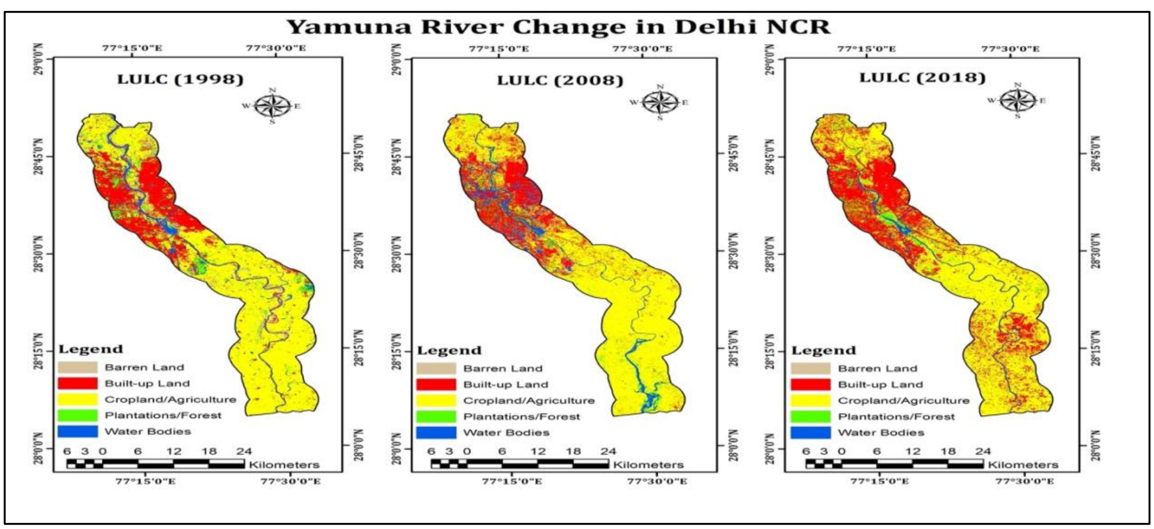


Figure 3 LULC change in 5 Km buffer zone of Yamuna River in Delhi NCR

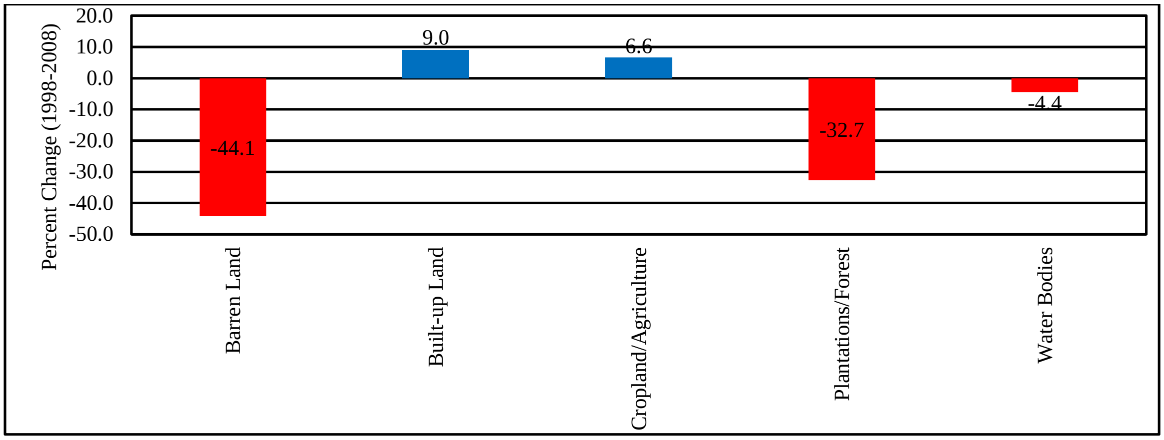


Figure 4 Net percent change in LULC classes in Decade 1998-2008

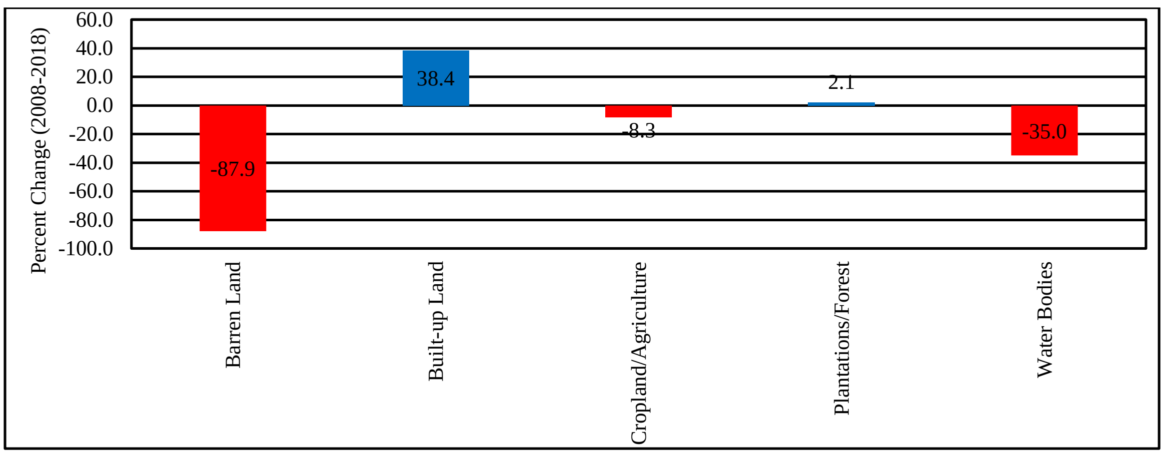


Figure 5 Net percent change in LULC classes in Decade 2008-2018

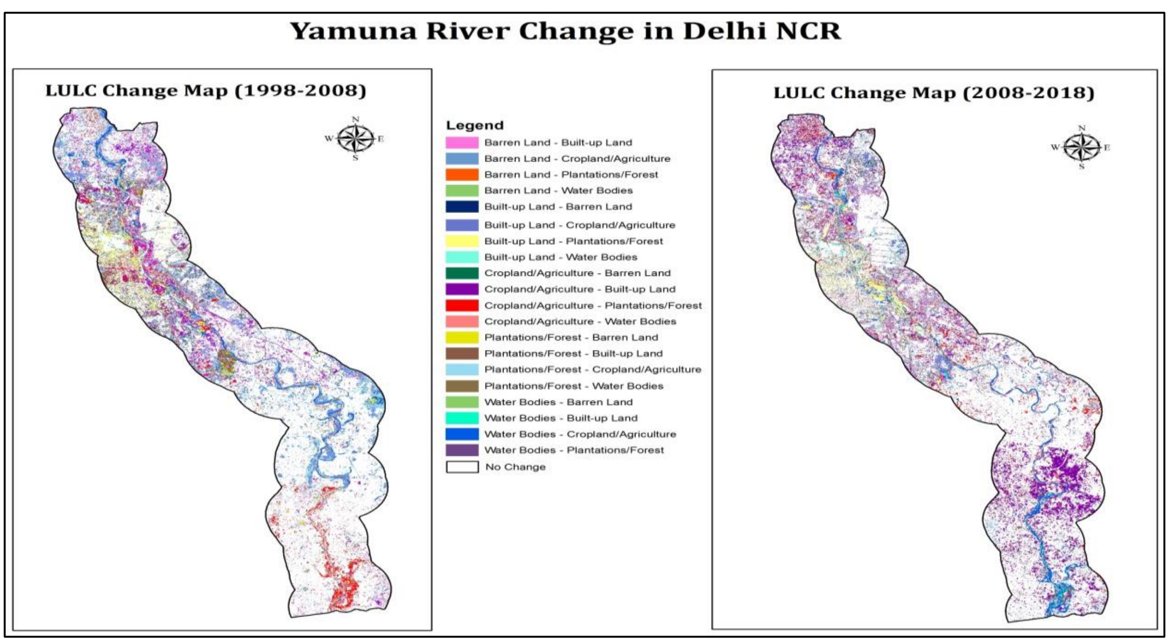


Figure 6 LULC change map: 1998-2008 and 2008-2018

Table 5 Five LULC class change year wise

S. No.	LULC class change (1998-2008)	Area change km^2 (1998-2008)	Area change km^2(2008-2018)
1	Barren Land - Built-up Land	14.36	18.79
2	Barren Land - Cropland/Agriculture	39.98	12.38
3	Barren Land - Plantations/Forest	2.85	2.17
4	Barren Land - Water Bodies	1.6	0.43
5	Built-up Land - Barren Land	16.32	0.91
6	Built-up Land - Cropland/Agriculture	49.59	63.56
7	Built-up Land - Plantations/Forest	17.99	22.23
8	Built-up Land - Water Bodies	8.24	3.08
9	Cropland/Agriculture - Barren Land	9.43	2.97
10	Cropland/Agriculture - Built-up Land	60.62	135.08
11	Cropland/Agriculture - Plantations/Forest	33.29	30.14
12	Cropland/Agriculture - Water Bodies	7.38	5.17
13	Plantations/Forest - Barren Land	5.59	0.12
14	Plantations/Forest - Built-up Land	32.34	24.32
15	Plantations/Forest - Cropland/Agriculture	56.61	28.29
16	Plantations/Forest - Water Bodies	3.03	3.9
17	Water Bodies - Barren Land	0.75	0.05
18	Water Bodies - Built-up Land	5.88	9.51
19	Water Bodies - Cropland/Agriculture	8.05	10.51
20	Water Bodies - Plantations/Forest	7.02	3.66

5.Discussion

India has witnessed a remarkable surge in urbanization over the few decades before, particularly following the implementation of economic reforms in 1991[37, 38]. The findings indicate a substantial transformation in the LULC pattern of Delhi NCR over the research period. The most prominent change was observed in the expansion of built-up areas, followed by alterations in cropland/agriculture and barren land. Previous research has consistently shown that peri-urban areas experience LULC changes primarily characterized by the expansion of built-up areas, which often come at the expense of cropland/agriculture, plantations/forest, and barren lands [39]. The LULC transformation in Yamuna River has been particularly striking, particularly in the urban areas including neighboring area like, Gurgaon, Noida, and others. The built-up areas in these area have experienced a significant and exponential increase [17, 30]. Furthermore, we are engaging in an in-depth discussion regarding the changes in each LULC class during the two decades, from 1998-2008 and 2008-2018. The following statements outline the observed trends:

Barren land

It is seen from the *Figure 7* and *Table 4* that the total barren land around the Yamuna River has been shrinking over the two decades of study period. During the first ten years (1998-2008) the shrinkage was 44% whereas during the next decade (2008-2018) the decadal shrinkage was 88%. Thus, we see that, not only has the shrinkage of barren land occurred astride Yamuna River, but this shrinkage has been drastically accelerating as the time progressed, over the research period, bringing out the stress levels on the flood plains/ wetlands astride Yamuna. At the end of 2018, the barren patch of land reduced to a mere 4% (4.1) of its original area (60.53) in 1998. Detailed discussion on activities to analyze the reduction of barren land in the backdrop of ever increased population, migration, and human intervention through agricultural and construction activities, have been done in subsequent paragraphs.

Plantations/forest

In the first decade, there is a sudden drop in area under forest, nearly one third of 111.33 km^2 has been reduced (32.7%). However, between next decade, Forest cover has increased marginally (from 74.9 to 76.5) which indicates the successful government intervention to check this malady. The above analysis also indicates that the loss of barren land in last decade is not attributable to forests, instead the other three factors or water, agricultural area and built-up need to be analyzed for the same.

Water bodies

Data shows that water bodies themselves have been subjected to severe stress over the decades. The area covered by water flow decreased marginally in first decade of study (1998-2008) by about 4.4%. During the next decade of (2008-2018), water flow area in Yamuna drastically. More than one third of area under flowing water has been reduced (34.96%). The reasons for the above reduction will be analyzed subsequently after correlating to the data obtained from built-up and agriculture pixels.

Cropland/agriculture

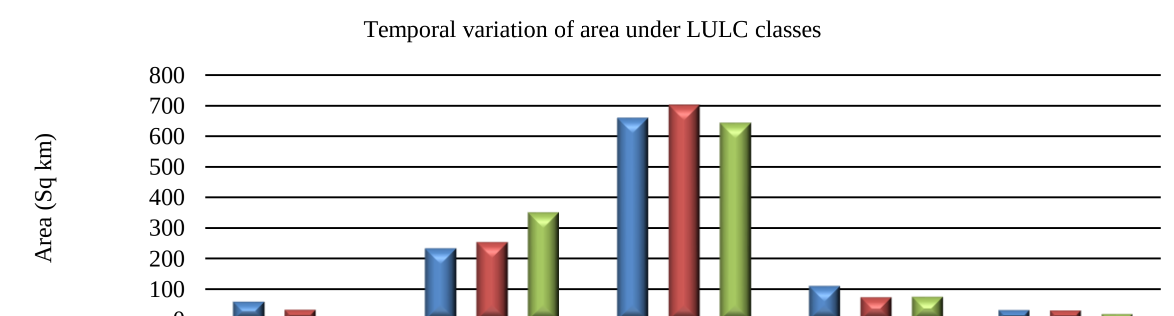
Area under agriculture has slightly increased in the decade 1998-2008 by 6.6%, from 659.56 km^2 to 703.1 km^2. However, in the subsequent decade of 2008-2018, this area has taken the reverse trend, and decreased substantially by 8.3% from 703.1 to 644.45 km^2. This data will further be correlated to a corresponding increase in built up area.

Built-up land

Built-up land has slightly improved in the decade 1998-2008 by 9%, from 233.88 km^2 to 254.93 km^2. However, in the subsequent decade of 2008-2018, this area has made a substantial hike of 38.41% from 254.94 to 352.88 km^2. If we correlate this buildup factor to decreasing level of water in Yamuna, it can be safely concluded that settlements around Yamuna are having a much bigger adverse impact on water levels, than the agriculture itself.

Natural growth and immigration have virtually equally and constantly contributed to population growth in the Delhi NCR, particularly in the developed districts of the Delhi NCR, such as G. B. Nagar (Noida and Greater Noida), Ghaziabad, Faridabad, and Gurgaon. Metropolitan areas like Delhi, Noida, Ghaziabad, Gurugram, and Faridabad have seen a huge growth in population as a result of the relocation of a large labour force. After the economic reforms of 1991, the expansion of the financial and industrial companies as well as the creation of Special-Economic-Zones (SEZ) like Gurgaon and Noida drew a sizable number of workers to the Delhi NCR [40]. During the past decades, the LULC pattern of Delhi NCR has been profoundly reshaped as a result of two key factors: population growth and the development of large financial and industrial firms.

The reduction of barren land, forests, and water bodies has led to a decline in the ecosystem's resilience, with negative effects on the local population's livelihoods, particularly farmers and fishermen. The increase in built-up area has also contributed to the decline in water levels in the Yamuna River, which has affected the quality of life of the local population, including their access to clean drinking water and the impact on the river's biodiversity. The study's findings can provide insight into the need for sustainable land use practices, balancing urban development with conservation efforts and the importance of maintaining ecological integrity. The study's implications can be useful for policymakers, urban planners, and researchers working towards sustainable development in the Yamuna River area.



	Barren Land	Built-up Land	Cropland/Agriculture	Plantations/Forest	Water Bodies
LULC (1998)	60.53	233.88	659.56	111.33	33.35
LULC (2008)	33.82	254.94	703.1	74.9	31.89
LULC (2018)	4.1	352.88	644.45	76.48	20.74

Figure 7 Area under LULC classes has a temporal trend in 5 Km buffer zone of Yamuna River in Delhi NCR

5.1Limitations

While there are limitations to consider, several significant research projects have focused on utilizing RS data for regular wetland monitoring. To address the challenges associated with wetland ecosystem monitoring, estimation, and mapping, it is important to leverage publicly accessible sensors such as Landsat data, which offer high temporal revisit rates, broad coverage, and improved resolutions. However, there are specific limitations that need to be acknowledged. Firstly, the calculation of unit values from a single region for a specific item assumed that the ES vegetation (ESV) within all LULC categories was homogeneous. In practice, this assumption may not hold true, as ESV characteristics can vary within different areas [41]. This generalization may lead to potential inaccuracies.

Secondly, the study encountered a limitation in terms of the availability of studies on ESV in the Yamuna River portion. Therefore, the context and analysis were based on ESV indices that had been adapted to suit regional ecological conditions, using worldwide data. This adaptation may introduce some uncertainties and limitations in applying the findings specifically to the Yamuna River area. Despite these limitations, the study still provides valuable data for local decision-making processes and serves as a foundation for further research in similar freshwater ecosystems across the country.

A complete list of abbreviations is shown in *Appendix I*.

6.Conclusion and future work

1998-2008: this decade saw encroachment of barren land and forest land. Trends indicate that built up area would come up on barren areas, whereas forest land was converted to agricultural land. Area under river water reduced, but this effect was much smaller as compared to subsequent decade. 2008-2018. this decade saw stabilization of forest land. Alongside, a sharp increase in built-up Area around Yamuna was witnessed along with decrease in water level of the river and a similar decrease in barren land. Net cultivated land also decreased. On the whole, these trends suggest that agricultural land and barren land astride Yamuna were converted to built-up areas in this decade.

This led to 38% new settlement areas, and a consequent rising population around Yamuna. This further led to an increased demand for water consumption for human settlements, which was the main factor for reduction of 35% water levels in Yamuna River. This comprehensive study investigates the spatial and temporal patterns of LULC changes in Delhi NCR, an inter-state policy territory that has had strong economic growth and population expansion in the last twenty years with two decade i.e. 1998 to 2008 and 2008 to 2018. The change matrix was computed after the LULC maps were created using Landsat 8 (OLI/TIRS) and Landsat 5 (TM) satellite data. The findings demonstrate that the Delhi NCR LULC pattern has changed dramatically over the research period. The built-up area had the most substantial modifications, which expanded by around 119 km^2, from 1998 to 2018. At the same period, the area of cropland/agriculture, plantations/forest, barren land, and water bodies has decreased by 15.11 km^2, 34.85 km^2, 56.43 km^2 and 12.61 km^2, respectively, whereas the size of the ridge has decreased just a little. The result also demonstrates that cropland/agriculture, plantations/forest and barren land are the key sponsors to the growth of the urbanization land, as the settlement land has frequently developed across these land usage groups, while greenery cover has also played a substantial role in the growth of the built-up area. As opposed to that, the connection between overall migration and built-up circulation was poor in 1998, but it has since improved and is now moderately encouraging in 2008 and very encouraging in 2018. This indicates that while growing relocation of settlement is a key indicator of built-up growth, built-up development and LUC are not entirely determined by rising migration. The authors suggest that future studies of LULC change in such economically and administratively significant locations incorporate information on economic development and industrial expansion (such as the sum of industries).

Using a combination of RS and GIS, we explored the methods of land-use dynamics and the influence of socio-economic and physical driving armies on LULC in Delhi NCR, India. The findings suggest that the land-use outline in Delhi NCR has changed histrionically, with varying rates of net gain or reduction. During the years 1998-2018, built-up land increased 119 km^2 and for plantations/forest barren land the highest reduction in the area was 34.85 km^2 and 56.43 km^2 respectively.

The conversion of plantations/forest for economic development accounted for the majority of the rise in built-up land. The combined impacts of socio-economic and physical elements on LUC were dominating in the land structure, whereas yearly temperature, particularly annual rainfall, was less relevant to LULC. The most important criteria for three primary categories of LULC were population, industry proportion, and agricultural gross output value. The current research can help with planning and policy implementation in the study region to improve ecology and the environment. It can also aid in the improvement of the region's land use system. As a result, the authors recommend that comparable methodologies be used at the national level in future studies. Studies on ES change have been conducted at all levels in India and other developing nations, including local, regional, and national levels. At the same time, just a few studies at the local level have been conducted in India. As a result, similar studies are required in India at both the local and national levels. Finally, the suggested approach has been applied to various high and medium resolution of satellite with good results, in addition to the test images used in the trials illustrated here. When dealing with high spatial resolution images that contain urban area patterns or a significant number of structures, the approach must take into account additional features in addition to spectral ones in order to improve performance.

The following are some recommendations made by this study to help people use land resources more effectively.

1. Considering the unchecked urban expansion that has permeated the research region and its potential impact on land cover, offering comprehensive planning strategies, encompassing both short- and long-term perspectives, can assist local planners in improving urban planning efforts.
2. It is essential for the government to take the lead in developing a master plan for the research sector, particularly due to the decreasing agricultural land availability. Prioritizing the expansion of green spaces over rapid urbanization is highly desirable for the region's sustainable development.
3. Effective policies need to be implemented to foster sustainable land use practices, including measures to minimize deforestation, encourage reforestation, promote sustainable agriculture, and enhance water management practices.
4. There should be efforts to raise public awareness of the impacts of LUC and the importance of sustainable land use practices.
5. There is a need for further research to delve into the economic and industrial factors that drive LUC and explore effective strategies for managing them to foster sustainable development.
6. The approach used in this study, combining RS and GIS techniques, can be applied to other regions to gain a better understanding of land use dynamics and inform land use planning and management.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Raghvendra Singh: Analysis of RS and GIS, data collection, writing – original draft, writing – review and editing. **Varun Narayan Mishra**: Supervision, review and editing. **Sudhakar Shukla**: Study conception, design, supervision, **Kewal Krishan Kakkar:** Writing – review and editing, analysis of RS and GIS, study conception and draft manuscript preparation.

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Appendix I

S. No.	Abbreviation	Description
1	ED	Environmental Disservices
2	ES	Ecosystem Services
3	ESV	Ecosystem Services Vegetation
4	FCC	False-Color-Composite
5	GIS	Geographical Information System
6	GPS	Global Positioning System
7	ISODATA	Iterative Self-Organizing Data Analysis Technique
8	LUC	Land Use Change
9	LULC	Land Use Land Cover
10	MSS	Multi-spectral Scanner
11	NCR	National Capital Region
12	NRSC	National Remote Sensing Centre
13	OLI	Operational Land Imager
14	RS	Remote Sensing
15	SOI	Survey of India
16	KM^2	Square Kilometer
17	TIRS	Thermal Infrared Sensor
18	TM	Thematic Mapper
19	USGS	United States Geological Survey
20	UTM	Universal Transverse Mercator Projection
21	WYC	Western Yamuna Canal