Assessing Urban Expansion and Land Use Transformation in Dehradun Using Geospatial Techniques

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Abstract: Rapid urbanization has emerged as a defining feature of contemporary development, significantly transforming land use and land cover (LULC) patterns, particularly in ecologically sensitive regions. Dehradun, located in the fragile Himalayan foothills, has witnessed accelerated urban growth over the past two decades, raising concerns about environmental sustainability, loss of green cover, and pressure on natural resources. Against this backdrop, the present study aims to analyze the spatio-temporal dynamics of urban expansion and LULC transformation in the Dehradun Planning Area from 2001 to 2026, with a particular focus on understanding the magnitude and direction of recent changes. The study is based on multi-temporal satellite data acquired from Landsat missions (2001, 2010, 2018, and 2026) with 30-meter spatial resolution. Standard geospatial techniques, including image preprocessing, supervised classification using the Maximum Likelihood Algorithm, and post-classification change detection, were employed to map and quantify LULC transitions. Accuracy assessment was conducted using error matrices and Kappa statistics to ensure reliability of the classification results. The findings reveal a significant transformation of the landscape, characterized by rapid expansion of built-up areas and a corresponding decline in agricultural land and vegetation. Between 2018 and 2026, built-up area increased by 17.88%, becoming the dominant land use (53.07%), while cropland and vegetation declined by 14.03% and 7.38%, respectively. Water bodies remained relatively stable, whereas barren and transitional land showed a noticeable increase. These changes indicate an unbalanced and unsustainable pattern of urban growth driven by population pressure and infrastructural development. The study concludes that Dehradun is experiencing a critical phase of urban transition, necessitating urgent interventions in land use planning, conservation of green spaces, and adoption of sustainable urban development strategies to ensure long-term ecological resilience and balanced regional growth.

Keywords: Urbanisation, LULC transformation, geospatial techniques, sustainable urban development and Accuracy assessment

INTRODUCTION

Throughout human history, urban areas have played a significant role in transforming society. They have been the scene and setting of major social, economic and political change. Urbanization has been an important social and economic phenomenon taking place at an unprecedented scale and rate all over the world (Batty et al., 1999). Although urban areas cover a very small fraction of the world's land surface, their rapid expansion has significantly altered the natural landscape and created enormous environmental, ecosystem, and social impacts (Bhat et al., 2017; Farooq & Ahmad, 2008). Globally, urban areas are growing at an alarming rate and this era is better known as the era of urbanization. The percentage of the global population residing in urban areas has increased from 32% in 1955 to 38% in 1975 and 45% in 1995 (World Health Organisation, 1998) and is predicted to grow up to approximately 69% by 2050 (United Nations, 2022).

In India also situation is not any more different, and the demographic shift has likewise led to an increasing proportion of Indians living in cities. The urban share of the Indian population jumped from 18% in 1961 to 31.16% in 2011 (Census of India, 2011). This urban population is mostly concentrated in class I towns (towns having a population more than 1 lakh). As per the Census 2011, there are 468 class I towns having a population of 264.9 million persons, constituting 70% of the total urban population. Land use and land cover (LULC) dynamics are rapid and significant processes primarily driven by human activities, which in turn influence environmental conditions and human well-being (Agarwal et al. 2002). These changes alter the availability of key biophysical resources such as soil, water, and vegetation, leading to reduced ecosystem services and environmental degradation (Delgado & Marín, 2020). Land use refers to the functional utilization of land for activities such as agriculture, settlement, and industry, whereas land cover represents the physical characteristics of the Earth's surface (Chaudhary et al., 2008). The study of LULC change is essential for understanding land transformation and managing environmental pressures. It plays a crucial role in sustainable urban planning and monitoring urban growth. Tools such as Remote Sensing and GIS enable efficient detection and analysis of spatial changes, while change detection techniques using multi-temporal satellite data help trace the evolution of urban areas (Pandey & Prashanth, 2025). This study has the analysis of LULC transition from 2001 to 2010, from 2010 to 2018 and from 2018 to 2026. The transitions in all the LULC classes have been studied. The main study of this study is "To study the urban growth dynamics (Land use and land cover change) of Dehradun Planning Area for the year 2001 and 2026.

Research Problem

India is experiencing rapid urban growth, with the urban population increasing from 286 million (21%) in 2001 to 377 million (31%) in 2011, and it is projected to reach 50% by 2050 (Census of India, 2011; United Nations, 2014). Urbanisation presents a dual reality: while cities act as centres of economic growth and opportunity, they also pose serious environmental and social challenges, including the loss of green spaces and deterioration of environmental quality. This has created a strong need for predictive urban growth models to assist planners and policymakers in monitoring and forecasting future urban expansion (Jat et al., 2010).

Dehradun has witnessed rapid urban expansion, significantly impacting biodiversity, the natural environment, and the local climate. Situated in the fragile Himalayan foothills near the Main Boundary Thrust (MBT), the city is highly vulnerable to natural hazards, and unplanned urbanization further increases this risk (Ahmad et al., 2024). Urban growth simulation models are increasingly used to support sustainable management of urban resources and to minimise environmental impacts (Liu et al., 2024). Given the limited availability of resources, effective city planning is essential to ensure sustainable development (Mell & Sturzaker 2014). This study focuses on simulating land cover change in Dehradun for the years 2001, 2010, 2018, and 2026, generating various scenarios to support sustainable urban planning.

Study Area

The study area has been the Master Plan zone covered in the Amended Master Plan for Dehradun prepared by the Town and Country Planning Department for the year 2005-2025 (Rahul, 2025). The latitudinal and longitudinal extent of the study area lies between 30°20'52.68 "N to 30°18'23.75 "N and 78°0'43.34 "E to 78°3'57.63 "E. According to the 2011 census, the study area has a population of 9,37,597 and a population density of 2,604 persons per sq. km (Census of India, 2011). The area has been divided into nine zones in the Zonal Development Plan prepared by the Mussoorie Dehradun Development Authority (MDDA).

METHODOLOGY

The present study aims to analyze the urban growth dynamics through Land Use and Land Cover (LULC) changes in the Dehradun Planning Area for the period 2001-2026. The methodology integrates geospatial techniques, field observations, and statistical analysis to assess LULC transitions across three time periods: 2001-2010, 2010-2018, and 2018-2026.

Database and Data Sources

Both primary and secondary data have been used. Primary data were collected through field surveys and interviews with government and non-government agencies. Secondary data include Census records, district statistical reports, socio-economic reviews, Survey of India (SOI) toposheets, and multi-temporal satellite imagery. Landsat data for the years 2001, 2010, 2018 and 2026 were acquired from the United States Geological Survey. The datasets include Landsat 5 TM (2001), Landsat 7 TM (2010), and Landsat 8 OLI/TIRS (2018 and 2026) with 30 m spatial resolution. Images were selected from the winter season (January–February) to minimise cloud cover and seasonal variations.

Table 1: Satellite Data Used for LULC Analysis

S. No.	Satellite	Sensor	Date	Spatial Resolution
1	Landsat 5	TM	20 January 2001	30 m
2	Landsat 7	TM	16 January 2010	30 m
3	Landsat 8	OLI/TIRS	1 February 2018	30 m
4	Landsat 8	OLI/TIRS	11 March 2026	30 m

Source: Prepared by the researcher based on USGS data

Data Processing and LULC Classification

Satellite images were pre-processed (georeferencing, atmospheric correction, and layer stacking) using GIS and remote sensing software. Supervised classification was carried out using the Maximum Likelihood Classification (MLC) technique, which is based on the Bayes theorem (Kumar & Singh, 2014). Training samples were selected for major LULC classes such as vegetation, agriculture, built-up area, water bodies, and barren land (John et al., 2020). The classified outputs were validated using ground truth data and accuracy assessment methods (Mas et al., 2004).

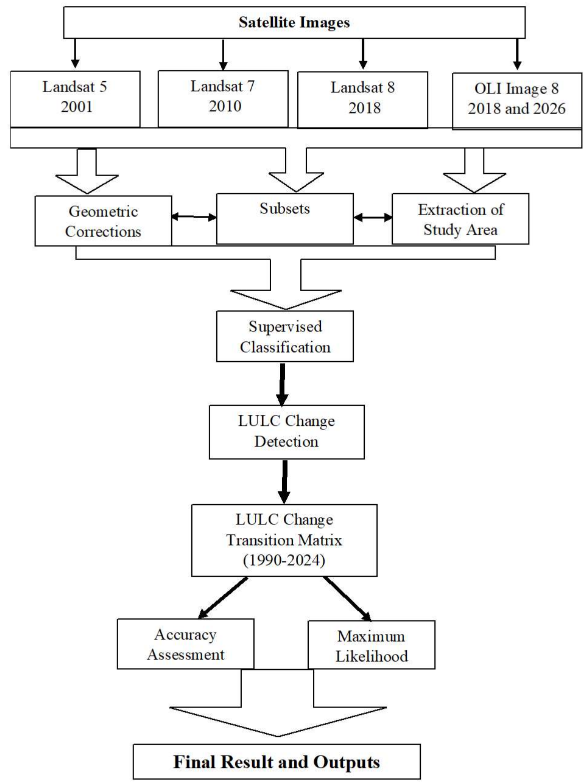


Figure 1: Flow chart of Research Methodology

The backbone of any kind of research is data. The data required for the study comprised of topographical maps, satellite images and secondary data. In order to study the change in LULC, LANDSAT data (2001-2026) were used to generate different layers of maps. Spatial-temporal information on the LULC and its changes were determined by GIS and RS techniques (Figure 1).

LULC Change Detection and Transition Analysis

Post-classification comparison was used to detect LULC changes for the periods 2001–2010, 2010- 2018, and 2018 to 2026. Transition matrices were generated to quantify the conversion of land from one class to another. For the period 2018-2026, predictive modelling and simulation techniques were applied to estimate future land cover scenarios. This helped in understanding the direction and magnitude of urban expansion.

RESULT AND DISCUSSION

The extent of urbanization or its growth is one such phenomenon that drives the changes in land use patterns. These urban sprawl changes are characterised by a haphazard patchwork of development, which leads to disorganised development in any city. At the same time, these megacities are getting slums and are not able to provide adequate shelter, drinking water and electricity (Kundu et al., 1999). The rapid growth of urban population exerts huge pressure on land within cities and its surroundings. The rapid urban growth is responsible for the alarming rate of Land Use/Land Cover (LULC) changes, where built-up areas are increasing rapidly at the cost of agricultural land, vegetation and open spaces. These LULC changes have detrimental ecological and environmental effects which affect at local and regional levels, especially the urban heat island (Gallo and Owen, 1998; Streutker, 2003; Ahmed et al., 2013). There is a large-scale incidence of urban poverty and slums in cities of developing countries. This has resulted in a mismatch among infrastructure, resources and population, leading to degraded and unsustainable urban environments that poses threat to human health and wellbeing (Ghani et al., 2021).

Land Use and Land Cover Classification

Land is a dynamic and essential natural resource, and its sustainable management is crucial for human well-being. Land use and land cover (LULC) reflect the interaction between natural environmental conditions and human activities, making their analysis important for effective planning and resource management (Wolf et al., 2023). Remote sensing has emerged as a widely accepted tool for acquiring spatial and temporal information on land dynamics, supported by various classification techniques ranging from conventional parametric to advanced algorithms (Lu and Weng, 2007).

In the present study, supervised classification using the Maximum Likelihood method was applied to Landsat satellite imagery. Due to the 30 m spatial resolution, five major LULC classes were identified: built-up area (impervious surfaces), water bodies (rivers and streams), cropland (agricultural land), vegetation (forests and green cover), and others (barren and rocky land). These classes were delineated based on their spectral signatures observed in False Colour Composite (FCC) images, where vegetation appears in red tones and built-up areas in cyan.

Land Use Land Cover Change Detection Analysis

The change detection analysis is described as changes over the surface with the passing of time. The land use and land cover change detection analysis resulting from Landsat images that is accurate and authentic description of the research area. The Landsat Enhanced Thematic Mapper (ETM) spatial data provided the source of base maps, which were collected with the help of the United States Geological Survey (Killeen et al., 2015). The spatio-temporal pattern of Land Use and Land Cover has been studied from 2001 to 2026 with respect to three time periods, i.e. Land Use and Land Cover of 2001, Land Use and Land Cover of 2010, Land Use and Land Cover of 2018 and 2026. In this section, the land use and land cover for each year has been discussed.

Land Use and Land Cover, 2001

The land use and land cover of Dehradun city and its surroundings for the year 2001 has been studied using the Landsat 5 TM data. Five major land use and land cover classes have been identified in the study area in 2001 (Table 2 and Figure 2). Around 18112.10 hectares of land area, which is 50.31 per cent of the study area, has been under the class vegetation. It included forests as well as other forms of vegetation.

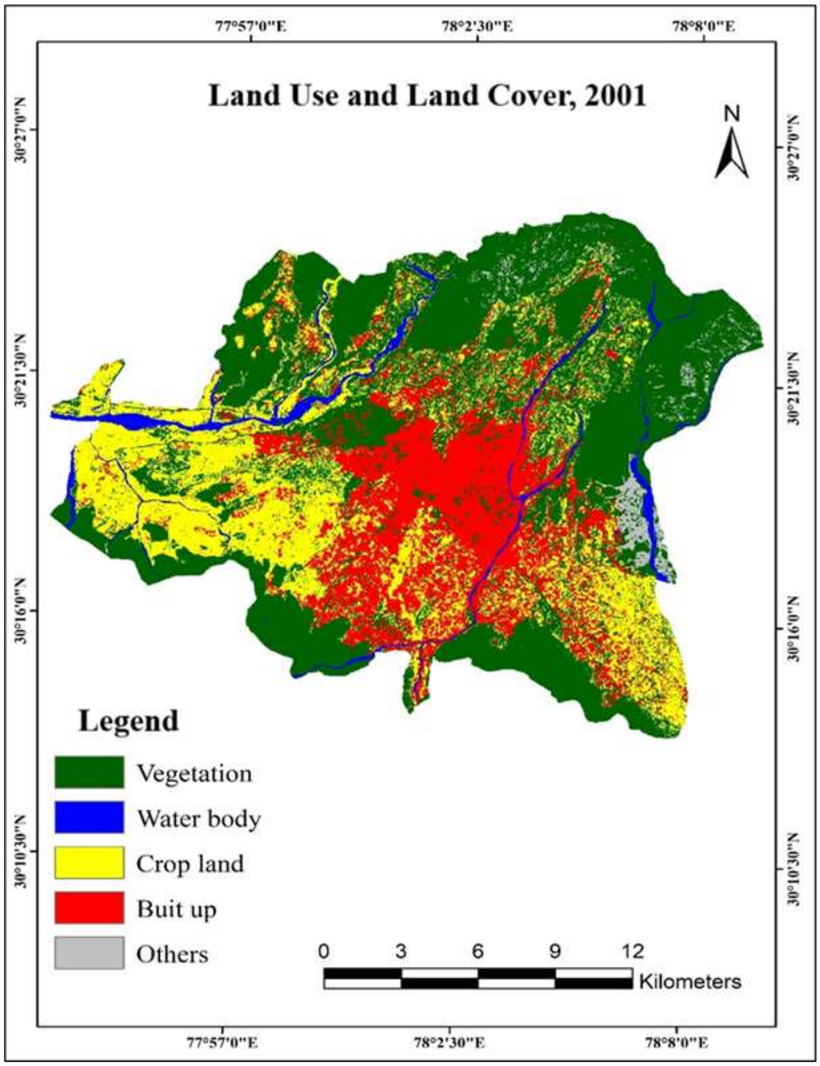
Table 2: Land Use and Land Cover - 2001

LULC Classes	Area in hectares	Area in Percentage
Crop land	9005.51	25.01
Built up	7069.80	19.64
Water body	1150.48	3.20
Vegetation	18112.10	50.31
Others	664.11	1.84
Total	36002.00	100.00

Source: Prepared by the researcher based on Landsat 5 data

The Land Use and Land Cover (LULC) distribution for the year 2001 in the Dehradun Planning Area reveals a landscape predominantly characterised by natural and agricultural land uses. Vegetation constitutes the largest share, covering 50.31% (18,112.10 hectares) of the total area. This indicates that more than half of the region was under forest cover and natural vegetation, reflecting a relatively healthy ecological condition at the beginning of the study period. Cropland is the second dominant category, accounting for 25.01% (9,005.51 hectares). This highlights the significance of agriculture as a major land use, supporting livelihoods and the local economy. Built-up areas cover 19.64% (7,069.80 hectares), suggesting a moderate level of urban development in 2001. Although urbanization was present, it had not yet dominated the landscape.

Water bodies occupy 3.20% (1,150.48 hectares), representing rivers and streams that contribute to the hydrological system of the region. The “Others” category, including barren land and rocky surfaces, comprises only 1.84% (664.11 hectares), indicating limited unused or degraded land. The table reflects that in 2001, the study area was largely dominated by vegetation and agriculture, with comparatively lower urban expansion. This baseline distribution is crucial for understanding subsequent land transformation and urban growth patterns in later years.



Source: Prepared by the researcher based on Landsat 5 data

Figure 2: Land Use and Land Cover, 2001

Figure 2 illustrates the spatial distribution of Land Use and Land Cover (LULC) classes in the Dehradun Planning Area for the year 2001, derived from Landsat 5 satellite data. The map clearly shows that vegetation dominates the landscape, occupying the largest proportion of the area, mainly concentrated in the peripheral and hilly regions. The figure highlights a landscape largely dominated by natural vegetation and agricultural land, with limited urban expansion in 2001. This spatial pattern serves as a baseline for assessing subsequent urban growth and land transformation in later years.

Land Use and Land Cover, 2010

The land use and land cover of Dehradun city and its surroundings for the year 2010 has been studied using the Landsat 5 TM data. Five major land use and land cover classes have been identified in the study area in 2011 (Table 3 and Figure 3).

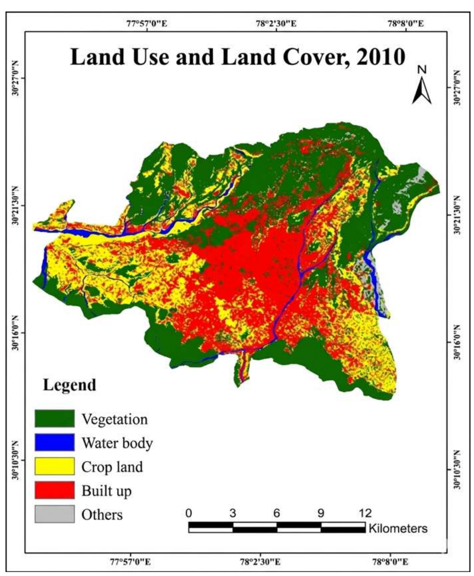
Table 3: Land Use and Land Cover, 2010

LULC Classes	Area in hectares	Area in percentage
Crop land	8213.45	22.81
Built up	11076.10	30.77
Water body	1041.20	2.89
Vegetation	15179.20	42.16
Others	492.05	1.37
Total	36002.00	100.00

Source: Prepared by the researcher based on Landsat 5 data

The Land Use and Land Cover (LULC) pattern for 2010 in the Dehradun Planning Area indicates significant changes compared to 2001, particularly reflecting rapid urban expansion. Built-up area has emerged as the most prominent change, increasing to 30.77% (11,076.10 hectares). This sharp rise indicates accelerated urban growth and expansion of residential, commercial, and infrastructural developments during the decade.

Vegetation, although still substantial, has declined to 42.16% (15,179.20 hectares) from its earlier dominance. This reduction suggests the conversion of forest and green areas into built-up and other land uses, raising concerns about environmental sustainability. Cropland has also decreased to 22.81% (8,213.45 hectares), indicating pressure on agricultural land due to urban encroachment and land transformation. Water bodies show a slight decline to 2.89% (1,041.20 hectares), which may be attributed to land reclamation or environmental degradation. The "others" category (barren and rocky land) has been reduced to 1.37% (492.05 hectares), reflecting limited availability of unused land. The 2010 LULC pattern highlights a clear shift from natural and agricultural land uses towards urban development, marking a critical phase of urbanization in the study area.



Source: Prepared by the researcher based on Landsat 5 data

Figure 3: Land Use and Land Cover, 2010

Figure 3 represents the spatial distribution of Land Use and Land Cover (LULC) in the Dehradun Planning Area for the year 2010, derived from Landsat satellite data. The map highlights significant urban expansion compared to 2001. Built-up areas (shown in red) have expanded considerably, forming a dense and continuous cluster in the central and southern parts of the city, indicating rapid urbanization. This expansion is largely concentrated along transportation corridors and plains.

Vegetation (green) is mainly confined to the northern and peripheral hilly regions, showing a noticeable reduction in comparison to earlier years. Cropland (yellow) is distributed in the surrounding plains but appears fragmented due to increasing urban encroachment. Water bodies (blue), including rivers and streams, are linearly distributed across the region, maintaining their natural course but with slight spatial reduction. The “others” category (grey), representing barren or rocky land, is minimal and scattered. The figure clearly demonstrates a transition from a vegetation- and agriculture-dominated landscape towards a more urbanized pattern by 2010, reflecting increasing developmental pressure on natural land resources.

Land Use and Land Cover, 2018

The land use and land cover of Dehradun city and its surroundings for year 2018 has been studied using the Landsat 8 OIL/TIRS data (Table 4 and Figure 4).

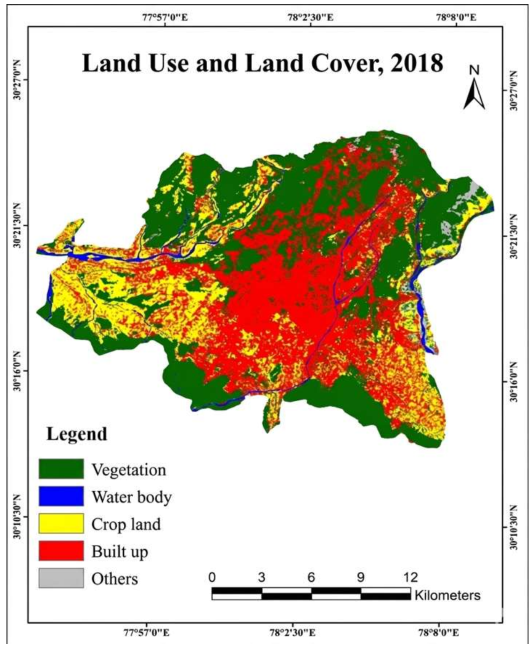
Table 4: Land Use and Land Cover, 2018

LULC Classes	Area in hectares	Area in Percentage
Crop land	7158.70	19.88
Built up	12670.30	35.19
Water body	893.91	2.48
Vegetation	14837.20	41.21
Others	441.89	1.23
Total	36002.00	100.00

Source: Prepared by the researcher based on Landsat 8 data

The Land Use and Land Cover (LULC) pattern for 2018 in the Dehradun Planning Area indicates a continued trend of rapid urban expansion and transformation of natural land. Built-up area has further increased to 35.19% (12,670.30 hectares), making it the dominant land use class. This reflects accelerated urban growth, infrastructure development, and population pressure during the period 2010-2018.

Vegetation, though still significant, has declined to 41.21% (14,837.20 hectares), indicating ongoing conversion of forest and green areas into urban and other uses. This reduction raises concerns regarding ecological balance and environmental sustainability. Cropland has decreased to 19.88% (7,158.70 hectares), showing a continuous decline due to urban encroachment and land use transformation. Water bodies have been slightly reduced to 2.48% (893.91 hectares), suggesting possible environmental stress or land modification affecting natural drainage systems. The “others” category (barren and rocky land) accounts for 1.23% (441.89 hectares), indicating minimal unused land. The 2018 LULC distribution highlights a clear shift towards urban dominance, with a substantial reduction in vegetation and agricultural land. This trend emphasises increasing pressure on natural resources and the need for sustainable urban planning.



Source: Prepared by the researcher based on Landsat 8 data

Figure 4: Land Use and Land Cover, 2018

Figure 4 illustrates the spatial distribution of Land Use and Land Cover (LULC) in the Dehradun Planning Area for the year 2018, derived from Landsat 8 data. The map clearly highlights a significant expansion of built-up areas compared to earlier years. Built-up areas (red) dominate the central and southern parts of the region, forming a dense and extensive urban core. The expansion is also visible along major transport corridors and towards peripheral zones, indicating rapid and outward urban growth.

Vegetation (green) is largely confined to the northern and hilly regions, though fragmented patches are also visible within the urban matrix, showing a decline and fragmentation of green cover. Cropland (yellow) appears scattered and reduced, especially in areas surrounding the expanding urban core, reflecting conversion into built-up land. Water bodies (blue) maintain their linear pattern along river channels, though their spatial extent appears slightly reduced. The "others" category (grey) remains minimal and sparsely distributed.

The comparison clearly indicates a transition from a vegetation- and agriculture-dominated landscape (2001) to a rapidly urbanizing landscape (2018). The period 2001–2010 marks the beginning of accelerated urban growth, while 2010-2018 represents an intense phase of urban expansion and land transformation. This trend highlights increasing environmental stress, loss of green cover, and pressure on natural resources, emphasising the urgent need for sustainable urban planning and land management strategies in Dehradun.

Land Use and Land Cover, 2026

The 2026 Land Use Land Cover (LULC) pattern shows a mostly urban environment, suggesting a substantial change in land use over time. With 19,105.99 hectares (53.07%) of the overall geographical area, the built-up area stands out as the most significant category, reflecting increased human activity and fast urban growth. This significant increase demonstrates the mounting pressure from economic activity, infrastructural expansion, and population growth that has resulted in the widespread conversion of productive and natural regions into urban areas (Table 5).

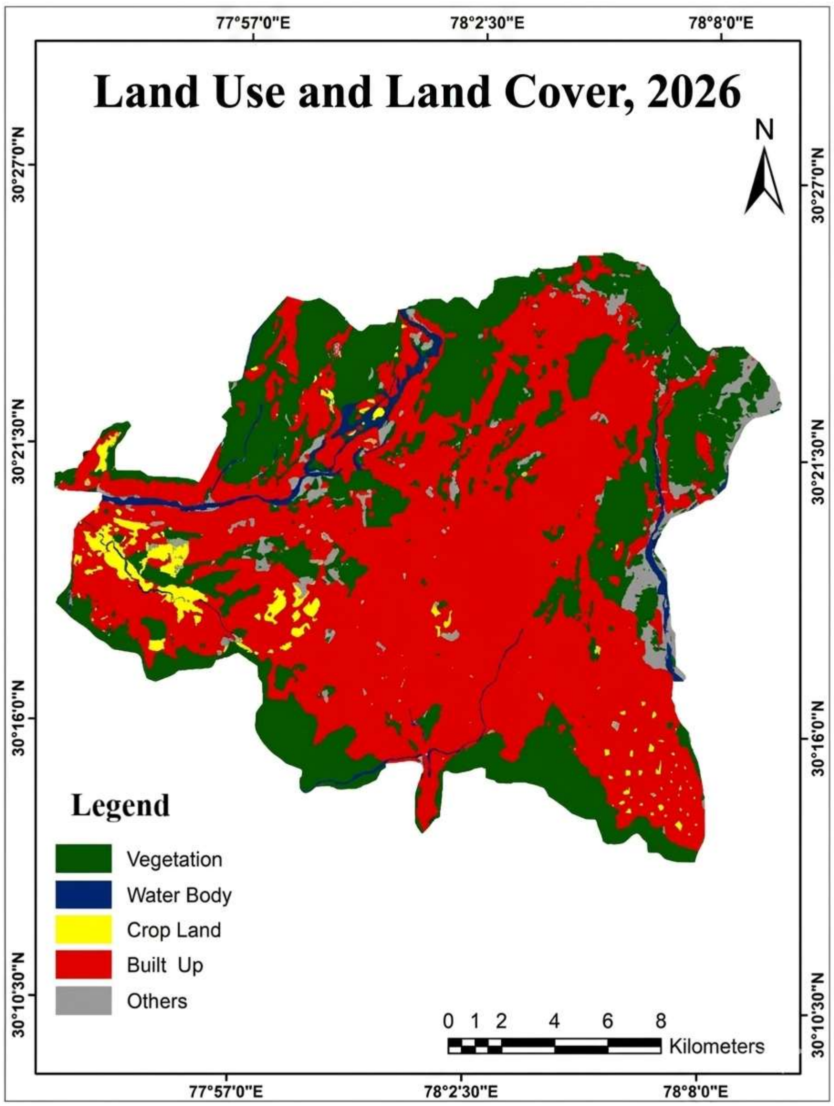
Table 5: Land Use and Land Cover, 2026

LULC Classes	Area in hectares	Area in Percentage
Crop land	2107.637	5.85

Built up	19105.996	53.07
Water body	897.027	2.49
Vegetation	12178.9	33.83
Others	1712.94	4.76
Total	36002.5	100.00

Source: Prepared by the researcher based on Landsat 8 data

On the other hand, agricultural land has sharply decreased to 2,107.64 hectares (5.85%), indicating a significant decrease in farmland and indicating extensive land conversion, which raises grave worries for rural sustainability and food security. The total area of vegetation cover in 2026 is 12,178.9 hectares (33.83%), indicating a significant decrease and the deterioration of green areas as a result of ongoing urban encroachment.



Source: Prepared by the researcher based on Landsat 8 data

Figure 5: Land Use and Land Cover, 2026

Due to its direct impact on biodiversity, ecological balance, and rising land surface temperatures, this vegetation loss is crucial. Although the area of water bodies, which make up 897.03 hectares (2.49%), is still comparatively steady, their seasonal variability and quality may still be subject to growing urban stress (Table 5). The "Others" category has grown to 1,712.94 hectares (4.76%), showing an increase in transitional, degraded, or barren land that may be related to building projects, land degradation, or vacant areas waiting for development. The 2026 LULC scenario reflects an unsustainable trajectory of urban growth characterized by the dominance of built-up land at the expense of agricultural and vegetative landscapes. This pattern underscores the urgent need for integrated land use planning, conservation of green spaces, and sustainable development strategies to mitigate environmental degradation and ensure long-term ecological resilience.

Accuracy Assessment of Land Use and Land Cover Classification

In order to evaluate the accuracy of the land use land cover classification, accuracy assessment (Table 6, Table 7, Table 8 and Table 9) has been carried out for land use and land cover maps for the years 2001, 2010, 2018, and 2026. Table 6 presents the accuracy assessment of the Land Use and Land Cover (LULC) classification for 2001 in the Dehradun Planning Area using an error matrix. The overall classification accuracy is 90.40%, indicating a high level of reliability of the classified data. Among the classes, built-up shows the highest user accuracy (97.44%), followed by others (95.00%) and water bodies (91.84%), reflecting strong classification performance. Vegetation (83.33%) and cropland (82.35%) exhibit relatively lower accuracies due to spectral similarities between these classes.

Table 6: Classification Accuracy, 2001

Classified Data ↓ / Reference Data →	***Water Body***	***Vegetation***	***Others***	***Cropland***	***Built-up***	***Row Total***	***User's Accuracy (%)***
Water Body	*45*	*0*	*1*	*2*	*1*	*49*	*91.84*
Vegetation	*1*	*30*	*2*	*1*	*2*	*36*	*83.33*
Others	*2*	*0*	*38*	*0*	*0*	*40*	*95.00*
Cropland	*1*	*1*	*0*	*28*	*4*	*34*	*82.35*
Built-up	*0*	*0*	*0*	*1*	*38*	*39*	*97.44*
Column Total	*49*	*31*	*41*	*32*	*45*	*198*	—
Producer's Accuracy (%)	*91.84*	*96.77*	*92.68*	*87.50*	*84.44*	—	***Overall Accuracy = 90.40%***

Source: Prepared by the researcher based on Landsat 5 data

In terms of producer's accuracy, vegetation (96.77%) and others (92.68%) perform well, while cropland (87.50%) and built-up (84.44%) show comparatively lower values. Overall, the classification is sufficiently accurate for further LULC change analysis, with minor errors mainly occurring between vegetation and cropland or cropland and built-up areas.

Table 7 shows the classification accuracy assessment for 2010 in the Dehradun Planning Area, which shows an overall accuracy of 89.05%, indicating a reliable but slightly lower accuracy compared to 2001. Built-up areas exhibit high user accuracy (95.00%), followed by cropland (93.33%), suggesting good classification of urban and agricultural areas. Water bodies (86.54%), vegetation (85.71%), and others (86.36%) show moderate accuracy levels.

Table 7: Classification Accuracy Matrix (2010)

Classified Data ↓ / Reference Data →	Water Body	Vegetation	Others	Cropland	Built-up	Row Total	User's Accuracy (%)
Water Body	45	0	1	1	5	52	86.54
Vegetation	0	30	0	5	0	35	85.71
Others	1	0	38	0	5	44	86.36
Cropland	0	1	0	28	1	30	93.33
Built-up	1	0	1	0	38	40	95.00
Column Total	47	31	40	34	49	201	—
Producer's Accuracy (%)	95.74	96.77	95.00	82.35	77.55	—	**Overall Accuracy = 89.05%**

Source: Prepared by the researcher based on Landsat 5 data

In terms of producer's accuracy, vegetation (96.77%), water bodies (95.74%), and others (95.00%) perform well, while cropland (82.35%) and especially built-up (77.55%) show relatively lower accuracy, indicating some misclassification. The major confusion occurs between built-up and other classes, as well as between vegetation and cropland. Overall, the classification is sufficiently accurate for LULC change analysis, though minor classification errors are present due to spectral similarities and increasing urban complexity.

The following table (Table 8) represents the classification accuracy assessment for 2018 in the Dehradun Planning Area, showing a high overall accuracy of 95.25%, indicating a significant improvement compared to previous years. Built-up areas exhibit the highest user accuracy (98.44%), followed by vegetation (97.10%), reflecting excellent classification performance. Water bodies (95.65%) and others (95.52%) also show high accuracy, while cropland (90.80%) has slightly lower accuracy due to spectral mixing.

Table 8: Classification Accuracy Matrix (2018)

Classified Data ↓ / Reference Data →	Water Body	Vegetation	Others	Cropland	Built-up	Row Total	User's Accuracy (%)
Water Body	88	0	0	2	2	92	95.65

Vegetation	0	67	0	1	1	69	97.10
Others	2	0	64	0	1	67	95.52
Cropland	2	2	4	79	0	87	90.80
Built-up	0	0	0	1	63	64	98.44
Column Total	92	69	68	83	67	379	—
Producer's Accuracy (%)	95.65	97.10	94.12	95.18	94.03	—	**Overall Accuracy = 95.25%**

Source: Prepared by the researcher based on Landsat 8 data

Producer's accuracy is consistently high across all classes, with vegetation (97.10%) and cropland (95.18%) performing particularly well. Minor misclassification is observed between cropland and other classes. Overall, the results demonstrate highly reliable classification, likely due to improved sensor quality (Landsat 8) and better data processing techniques, making it suitable for detailed LULC change and urban growth analysis.

The classification accuracy assessment for 2026 in the Dehradun Planning Area shows an overall accuracy of 91.46%, indicating a high and reliable level of classification suitable for LULC analysis. Among the classes, built-up areas exhibit a high user's accuracy (94.74%), reflecting strong identification of urban features despite increasing spatial complexity. Water bodies also show high accuracy (92.86%), indicating clear spectral distinction. The other class (90.16%) maintains good classification reliability. However, vegetation (87.88%) and cropland (87.50%) show comparatively lower user's accuracy, mainly due to spectral similarity and mixed pixel effects, especially in transitional zones (Table 9).

Table 9: Classification Accuracy Matrix (2018)

Classified Data ↓ / Reference Data →	**Water Body**	**Vegetation**	**Others**	**Cropland**	**Built-up**	**Row Total**	**User's Accuracy (%)**
Water Body	78	1	1	2	2	84	92.86
Vegetation	1	58	2	3	2	66	87.88
Others	2	1	55	1	2	61	90.16
Cropland	1	3	2	70	4	80	87.50
Built-up	0	1	1	2	72	76	94.74
Column Total	82	64	61	78	82	367	—

Producer's Accuracy (%)	95.12	90.63	90.16	89.74	87.80	—	**Overall Accuracy = 91.46%**

Source: Prepared by the researcher based on Landsat 8 data

In terms of producer's accuracy, water bodies (95.12%) perform best, followed by vegetation (90.63%) and others (90.16%), indicating that most reference features are correctly classified. Cropland (89.74%) and built-up (87.80%) show slightly lower producer's accuracy, suggesting some omission errors. The confusion matrix indicates that most misclassification occurs between cropland, vegetation, and built-up areas, which is common in rapidly urbanizing regions where land use patterns become fragmented and intermixed. The classification demonstrates strong agreement and robustness, making it reliable for analysing urban growth dynamics and LULC transitions in Dehradun.

Table 10 shows the overall classification accuracy and Kappa coefficient values, indicating a consistently high level of reliability in LULC classification for the Dehradun Planning Area across all years. The overall accuracy improved from 90.40% in 2001 to 95.25% in 2018, reflecting advancements in satellite data quality and classification techniques. The highest Kappa coefficient (0.94) in 2018 indicates excellent agreement between classified and reference data. In 2010, although the overall accuracy slightly decreased to 89.05%, the Kappa value (0.86) still indicates strong agreement. For 2026, the overall accuracy is 91.46% with a Kappa coefficient of 0.89, suggesting a slight decline compared to 2018 but still maintaining strong classification reliability.

Table 10: Overall Accuracy for Land Use Land Cover Classification

Year	**Overall Accuracy (%)**	**Kappa Coefficient (κ)**
2001	90.40	0.82
2010	89.05	0.86
2018	95.25	0.94
2026	91.46	0.89

Source: Calculated by the researcher

This minor reduction may be attributed to increasing urban complexity, mixed land use patterns, and spectral confusion among classes such as vegetation, cropland, and built-up areas. Overall, the results confirm that the classification across all years is robust and suitable for analysing LULC changes and urban growth dynamics. It could be observed that the overall accuracy of the classification, as well as the Kappa coefficient, is acceptable for the three time periods. The three accuracies i.e. Producer's Accuracy, User's Accuracy, and Overall Accuracy, along with Kappa Coefficient, have been calculated for the classification. The Anderson (1971) rule of minimum 85 per cent accuracy and Anderson et al. (1976) have been followed as acceptable and accurate for any image classification.

Land Use and Land Cover Change Detection, 2001-2018

Spatio-temporal Change Detection 2001-2010

Change detection has been done to study the impact of urban growth on land use and land cover. The study has revealed the transformation of the various land use and land cover classes from 2001 to 2010. However, the change has not been equal in every land use and land cover class.

All the classes analyzed in the classification have undergone negative change with the exception of built-up area (Table 11). The built-up areas have registered rapid increase in percentage from 2001 to 2010, it has recorded growth of 56.67 per cent. Whereas, all other classes have shown decrease, others (25.91 per cent), vegetation (116.19 per cent), water body (9.50 per cent) and cropland (8.80 per cent).

Table 11: Land Use and Land Cover Change 2001-2011

LULC Change in 2001 to 2011
LULC Classes
Crop land
Built up
Water body
Vegetation
Others

Source: Prepared by the researcher based on Landsat 5 data

The 56.67 per cent tremendous increase in the built area could be attributed to the fact that Uttarakhand was declared a separate state with Dehradun as its capital during this time period, which accelerated the urbanization process. To meet the demands of the process of urbanization the pervious surfaces have been converted to impervious surfaces.

6.8.2 Spatio-temporal Change Detection 2010-2018

From 2010 to 2018, all the classes analysed in the classification have undergone negative change with the exception of the built-up area (Table 12). The built-up areas have again increased in percentage from 2010 to 2018, it has recorded growth of 14.39 per cent. Whereas, all other classes have shown a decrease, others (10.19 per cent), vegetation (2.25 per cent), water body (14.15 per cent) and cropland (12.84 per cent).

Table 12: Land Use and Land Cover Change 2010-2018

LULC Change in 2010 to 2018
LULC Classes
Crop land
Built up
Water body
Vegetation
Others

Source: Prepared by the researcher based on Landsat data

The built-up area has increased, but not at the same percentage as it has been from 2001 to 2018 but data depicts lower percentage growth from 2010 to 2018. But it could be due to the fact that satellite data is only able to capture horizontal growth not vertical, which is more common in Dehradun these days.

Spatio-temporal Change Detection 2018-2026

The analysis of LULC change from 2018 to 2026 reveals a significant shift in the dynamics of land use, mostly due to fast urban growth. With a rise of 6,435.69 hectares (17.88%), the built-up area has seen the most growth.

This clearly shows increased urbanization, infrastructural development, and population pressure. Cropland has drastically decreased by 5,051.06 hectares (-14.03%), indicating a significant transfer of productive land into urban uses, and this expansion has mostly come at the expense of agricultural land (Table 13). Serious questions about food security, the loss of rural livelihoods, and shifting socioeconomic systems are raised by such a reduction.

Table 13: Land Use and Land Cover Change 2018-2026

LULC Change in 2018 to 2026
LULC Classes
Crop land
Built up
Water body
Vegetation
Others

Source: Prepared by the researcher based on Landsat data

Additionally, there has been a significant decline in vegetation cover of 2,658.3 hectares (-7.38%), indicating that ongoing urban expansion and land transformation processes are causing green space degradation. The loss of biodiversity, ecological imbalance, and rising land surface temperatures are all consequences of this vegetation decline. The LULC change pattern between 2018 and 2026 shows an unsustainable trend marked by the loss of natural and agricultural landscapes and the domination of urban areas. To maintain long-term environmental sustainability and balanced regional development, this pattern highlights the critical necessity for sustainable land use planning, vegetation protection, and urban expansion restriction.

CONCLUSION

The study highlights that by 2026, Dehradun has undergone rapid and largely unplanned urban expansion, with built-up area becoming the dominant land use (53.07%). This growth has occurred mainly at the cost of cropland (-14.03%) and vegetation (-7.38%), indicating serious ecological degradation and pressure on agricultural resources. While water bodies remain almost unchanged, the increase in barren and transitional land reflects ongoing land transformation and development activities. Overall, the findings reveal an unsustainable pattern of urban growth that threatens environmental stability and long-term resilience. To address these challenges, the study suggests promoting compact and planned urban development, protecting agricultural land and green spaces, and integrating green infrastructure into city planning. Additionally, the use of geospatial technologies for continuous monitoring and stricter policy implementation is essential to ensure sustainable and balanced urban growth in the future.

Author Contributions

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