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Dynamic Change Analysis of Landuse Landcover in Darrang, Assam (India) Using Remote Sensing and Geospatial Techniques

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ABSTRACT

In today's world, the mapping of landuse and landcover (LULC) and its change analysis are considered a critical research area. LULC study of an area shows the relationship between human activities and natural processes influencing the ecological balance and socio-economic development. Assam, a state in North-Eastern India, is showing landscape alteration due to multiple developmental processes. The present study is first carried out mapping of LULC using multi-temporal Landsat Satellite Earth Observation datasets from 1995–2025, followed by change analyses of influencing factors that altered LULC in Darrang district of Assam. Geospatial tools like ERDAS Imagine and ArcGIS 10.8 software were applied for image processing and supervised classification using the maximum likelihood algorithm. The overall classification accuracy ranged from 83.85% to 91.43%, indicating a very good to excellent agreement. Categories are considered for the present analysis. In this connection, six major LULC classes are generated, and dynamic changes are interpreted and analysed for three decades. The result of this study reveals several changing aspects, including decline in vegetation cover from 13.85% in 1995 to 11.74% in 2015 and a slight increase of 0.63% in 2025. In addition, a decrease in agricultural land from 57.84% in 1995 to 43.35% in 2025 and

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an increase in built-up area from 5.05% in 1995 to 12.31% in 2025 are also evident. A notable rise of about 8.28% also seen in the area under barren land from 1995 to 2025. The study of LULC change mapping are necessary for future environmental protection and sustainable development.
Keywords: Landuse and Landcover; Dynamic Changes; Driving Factors; Landsat Imagery; Darrang; Assam

1. Introduction

One of the remarkable factors for determining the relationship between the natural environment and human activities is the change in the dynamics of land use and land cover (LULC) of an area. The land surface emerges as an essential natural resource that delivers several services to humankind [1], including those crucial for agriculture, industry, and infrastructure. Over the past decades, the LULC of the earth's surface has witnessed ongoing variations due to both natural [2], and anthropogenic processes [3–6]. Comprehensive analysis and understanding of such spatial-temporal changes [7,8] are important for sustainable LULC practices and their regional development planning.

From a geographical perspective, the concepts of LULC are distinct from each other [1]. Land use refers to the changes made by humans on land for their own welfare, including agro-based activities, built-up expansion, or commercial activities [8]. According to National Remote Sensing Centre (NRSC) of the Indian Space Research Organization (ISRO), Landuse refers to the human utilization of land for different purposes such as cropping, grazing, forestry, and settlement [9]. It showcases both the financial and social functions that are linked to a specific area. Landuse shows how people use the landscape- whether for development, conservation, or mixed uses. On the other hand, the natural features that form the topography, such as forests, water bodies, grassland, barren land, and deserts, can be termed as land cover. According to Weng (2002) [10], Landcover refers to the surface characteristics of the earth, both natural and artificial, which can be derived from remote sensing imagery and GIS techniques. Spatial and temporal analysis of any selective region using modern GIS and remote sensing technology with earth observation datasets has helped to track the various LULC changes of the area over the decades [11–13].

Darrang, a district in Assam, is known for its historical and cultural richness. The region is situated at the core of the state, comprising a total area of 1587.66 km^2. The land utilization and surface cover arrangement of Darrang district have undergone significant changes the district has witnessed several LULC transformations over the decades. Earlier, the district was governed by large tracts of agricultural land (AGL) and forest vegetated areas (V), which led to rural economic development and conservation of local biodiversity. But with the increasing involvement of anthropogenic activities due to population growth in Mangaldai and surrounding villages, several tracts of AGL and V have been transformed into built-up land (BUL) areas. Several anthropogenic factors are responsible for the change of LULC pattern in the district, which include population growth and urbanization [14], agricultural expansion, industrial and infrastructure development, floods and river valley change assessment [15–17], erosion [18], and several other human activities [19]. This has ultimately helped the government and policy makers to understand and analyze the past and present situation and to take necessary measures for protecting and sustainably developing the region.

Through this research, an initiative has been formulated to identify the land utilization and surface cover changes that are prevalent in the Darrang district of Assam and their driving influencing factors that significantly impact the environment. Various methods of Remote Sensing and GIS (Geographic Information System) are employed to identify these changes from 1995 to 2025 by splitting the multi-temporal satellite images into three decades, such as 1995–2005, 2005–2015, and 2015–2025, which are utilized to complete the study. These analyses have been carried out to get a clear, precise picture of the problems that are associated with the land utilization and surface cover transformations in the district. The LULC transformations over the decades have promptly impacted the local environment, which needs to be addressed immediately to reduce the percentage of loss of vegetation, natural cover, and quality of human life.

1.1. Problem Statement and Research Gap

The Darrang district of Assam has highlighted the change of LULC in an extensive way over the past few decades. On one hand, these changes are fruitful towards economic development and infrastructural development for humankind. But, on the other hand, it is creating a threatening situation for the environment and the biodiversity of the area. These changes in LULC in the district are visible in the transformation of agricultural land into urban settlements, loss of vegetation to support industrial and commercial activities, and the consequence of shifts in climate pattern on wetlands and biodiversity. The ecological balance of the district has been significantly affected due to an increase in anthropogenic activities. One of the most urgent issues that comes along with LULC changes is the decline in the proportion of natural spread, which has resulted in climate change, loss of habitat and an uplift for carbon emissions.

Darrang district's LULC shows both positive and negative consequences on various fields of the region, such as its environment, economy, and society. While some variations are beneficial in the path of development, others turn out as a threatening factor towards the environment, with an increase in risk of environmental degradation and disaster risk. By analysing the LULC changes of three decades (1995–2025), the present study aims to address the above-mentioned gaps and show the number of changes that took place in the district over the years and how it has influenced the environment on a large scale.

1.2. Conceptual Framework of LULC Change

This study reveals a conceptual framework where it is clear that there is a direct linkage among the root causes of land transformation, the processes involved, and the consequences to the environment. In Darrang district, the primary causes include demographic growth, urbanization, growth in agriculture, infrastructural development, and flood–erosion changes that take place every year, impacting the LULC changes in the region. These root causes function with the processes of land transformation, which include transitioning of agricultural land into built-up land, the reduction of forest areas, changes in river channels, and intensifying of sandbars [20–23]. Due to these LULC changes, there is a direct impact on the environment, including increasing intensity of floods, loss of forested areas, degradation of soil quality, loss of wetlands, and ecological imbalance. By incorporating the LULC maps that are produced with the help of remote sensing, along with the analysis of primary root causes and impacts, this conceptual framework provides an in-depth understanding of human–environment relations in the study area.

2. Materials and Methods

2.1. Study Area

The name Darrang is derived from the Assamese word "Doar," which means "door," because of the alluvial floodplains in eastern and northeastern India that have acted as a route for the traders and travelers coming from the Himalayan region. The Darrang district of Assam comprises an overall extent of 1587.66 km^2 and is situated between longitudes of 20°09′ N to 26°95′ N latitudes and 91°45′ E to 92°22′ E longitude (**Figure 1**). The region is bounded by Udalguri district in the North, Sonitpur district in the East, and Kamrup district in the West, along with the mighty Brahmaputra River (BR) to the South. Mangaldai is considered the district headquarters of the region. The different physiographic characteristics of the region comprise mostly plain areas, elevated spaces, flood-vulnerable regions, and marshy lands. The tributaries of BR that run through the district are Barnadi, Nanoi, Mangaldai, Nowanodi, Saktola, and Dhansiri.

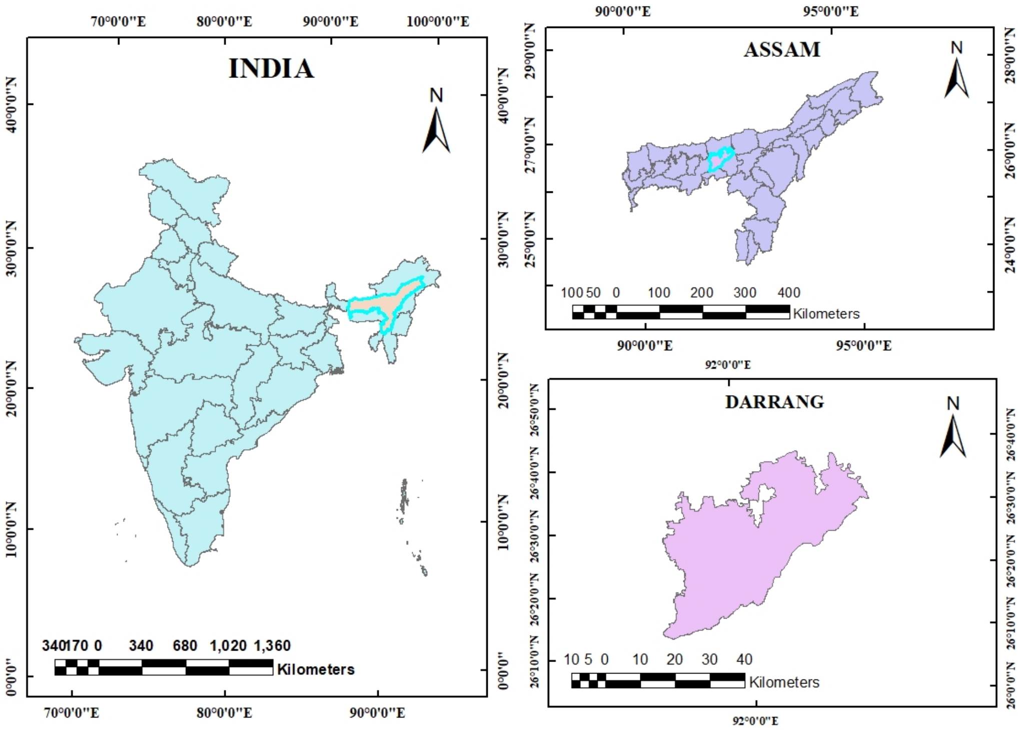


Figure 1. Location of the Study Area.

2.2. Data Sets Used

The information that has been used to complete the present study was acquired solely from secondary sources of data, which include various research papers, journals, articles, dissertations, the internet etc. Space-based images were utilized to prepare the maps for change detection analysis. Multiple software is being employed, including ArcGIS 10.8 and ERDAS Imagine 10. In the preparation of Land utilization/surface cover maps, Landsat multispectral images of three decades (1995–2025) with a time interval of 10 years (i.e., 1995–2005, 2005–2015, and 2015–2025) of Darrang district, Assam have been downloaded from the United States Geological Survey (USGS) Earth Explorer archive (available at: https://earthexplorer.usgs.gov/). The details of the satellite data used in this study are shown in **Table 1**. In addition, the Digital Elevation Model (DEM), Geomorphological, Geological and Soil maps were considered for showing the geo-environmental background of the district, which have been downloaded from the official data repositories of Bhukosh and FAO GeoNetwork (https://geonetwork.fao.org/geonetwork/).

Table 1. Data Used in the Present Study.

Date of Acquisition	Satellite and Sensor	Spatial Resolution	Path/Row	Band Used
04/04/1995	Landsat-5 TM	30 m	136/042	1,2,3,4,5,7
14/03/2005	Landsat-5 TM	30 m	136/042	1,2,3,4,5,7
21/11/2015	Landsat-8 OLI	30 m	136/042	1,2,3,4,5,6,7
30/12/2015	Landsat-8 OLI	30 m	137/042	1,2,3,4,5,6,7
16/01/2025	Landsat-8 OLI	30 m	136/042	1,2,3,4,5,6,7

Source: USGS (https://earthexplorer.usgs.gov/).

2.3. Methodology

The area of interest is the Darrang district of Assam. Through this study, the emphasis is placed on detecting LULC changes over three decades using maximum likelihood algorithms and their impact on the environment. For this, firstly, a related literature review was done from the previous works of various authors, including research papers, journals, articles, and dissertations, from which different kinds of information have been acquired regarding the past LULC changes and their impact on the environment. Satellite images of Landsat-5 TM and Landsat-8 OLI were acquired from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) for the years 1995, 2005, 2015, and 2025. These maps were further extracted and made composite using ERDAS Imagine 10 software. Furthermore, these maps are classified using the supervised classification method [19] in ERDAS Imagine 10 software. Thereafter, accuracy assessment classification maps of each year have been done in ArcGIS 10.8 software. In addition, areas of the maps are calculated which have helped to identify and detect the changes over a specific period. Lastly, results were obtained from the prepared maps, and their impact on the environment has been detected. In this way, a conclusion has been made, providing several recommendations for future utilization. Additionally, Microsoft Excel was utilized for the graphical representation (such as Bar charts) of the calculated LULC datasets [20]. The methodological outlines are shown in the following **Figure 2**, and the detailed methodological steps are outlines in the following subsections from 2.3.1 to 2.3.3.

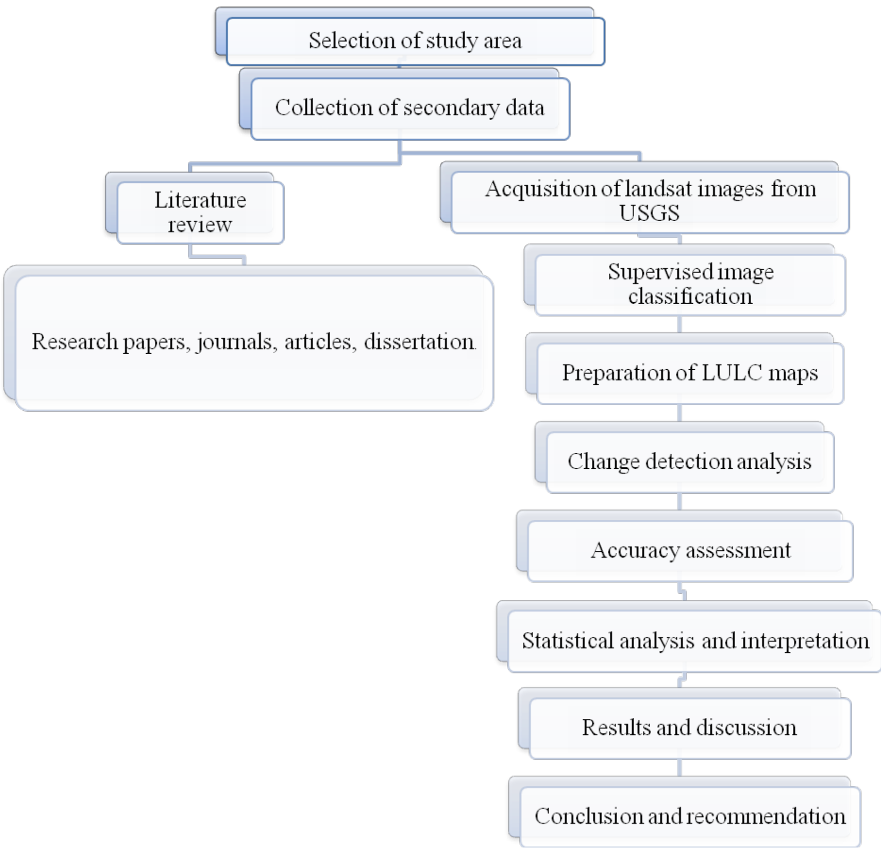


Figure 2. Methodological Flowchart used in this study.

2.3.1. Training Sample Selection

In this study, training samples for supervised classification of LULC maps of Darrang district for three decades were chosen with the help of visual interpretation of false color composite (FCC) images, along with high-resolution Google Earth Pro images and local terrain information. In order to capture the spectral dynamics of different land cover types over different time periods, multiple representative training polygons were accumulated for each LULC class.

2.3.2. Image Classification Procedure

In this study, image classification was done through supervised classification with the help of the Maximum Likelihood Classification (MLC) algorithm. This method considers a standard distribution of spectral values for each LULC class. Before the process of classification, all satellite images acquired through remote sensing and GIS were radiometrically refined and projected to a common coordinate system.

2.3.3. Accuracy Assessment and Validation

Accuracy assessment was carried out with the help of independent validation samples that were obtained from Google Earth Pro imagery and reference points. Confusion matrices were created to compute overall accuracy, producer's accuracy, user's accuracy, and Kappa statistics for the Darrang district for each of the four years.

3. Results

3.1. LULC Mapping from 1995–2025

The study of LULC changes reveals the dynamic pattern of a region to understand its various natural and human-induced activities. For analyzing the patterns of Darrang district in Assam, Landsat multi-temporal satellite images from four different times (i.e., 1995, 2005, 2015, and 2025) have been utilized and classified using a supervised classification method. The maps for the four years are generated (**Figure 3**) to showcase the differences that are present in the region over the decades.

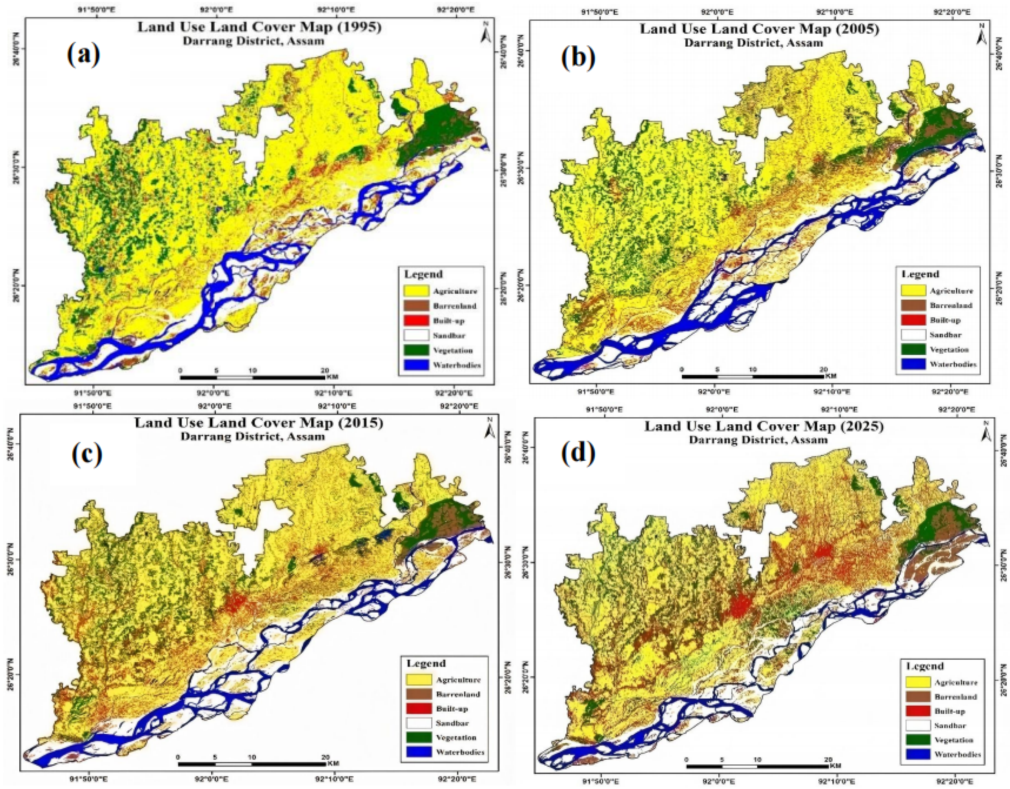


Figure 3. LULC of Darrang district (Assam) in: (**a**) 1995; (**b**) 2005; (**c**) 2015; (**d**) 2025.

Figure 3 highlights the area covered by six categories of LULC, including water bodies (WB), sandbar (SB), barren land (BL), V, AGL and BUL, during the years 1995, 2005, 2015, and 2025 in Darrang district covering a total area of 1587.66 km^2. In each sub-figure, WB are represented by blue color, SB are white, BL is brown, V is dark green, AGL is yellow, and BUL are represented by red color. In 1995, out of the total area, WB covers about 131.09 km^2 (8.25%), SB covers about 177.59 km^2 (11.18%), BL covers about 60.38 km^2 (3.80%), V about 219.93 km^2 (13.85%), AGL about 918.46 km^2 (57.84%), and lastly, BUL occupies the region for about 80.28 km^2 (5.05%) (**Table 1** and **Figure 3a**). In 2005, WB covers 159.53 km^2 (10.04%), SB covers about 187.75 km^2 (11.82%), BUL areas cover 97.53 km^2 (6.14%), V covers 201.15 km^2 (12.66%), and BL is about 96.55 km^2 (6.08%), and lastly, AGL holds an area of about 845.23 km^2 (53.23%) out of the total area (**Table 1** and **Fig-**

ure 3b). This shows the early expansion of urban areas and increasing erosional activities resulting in productive land transformation. Whereas, during 2015, WB cover 128.13 km^2 (8.07 %), SB cover 186.54 km^2 (11.74%), V about 186.42 km^2 (11.74%), BUL covers for 136.05 km^2 (8.56%), AGL covers about 783.95 km^2 (49.37%), and lastly, BL occupied an area for about 166.65 km^2 (10.49%) (**Table 1** and **Figure 3c**). Finally, in 2025, the district has WB covers an area of about 97.36 km^2 (6.13%), SB is 184.74 km^2 (11.63%), BL is 191.88 km^2 (12.08%), V is 229.90 km^2 (14.48%), BUL is about 195.45 km^2 (12.31%), and lastly AGL covers about 688.33 km^2 (43.35%) (**Table 1** and **Figure 3d**).

3.2. Comparative Analysis of LULC

For detecting the changes, six major classes of land use are employed, having different percentages of area coverage (**Table 2** and **Figure 4**). The details of graphical presentation of LULC Change Comparison of Darrang district from 1995 to 2025 and net change in percentage (%) are shown in **Figures 4** and **5**, respectively.

Table 2. Comparative Assessment of LULC Percentage Change and Net Change Areas of Darrang District.

LULC Categories	1995		2005		2015		2025		Net Change Areas (in %)		
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	1995–2005	2005–2015	2015–2025
AGL	918.46	57.85	845.23	53.23	783.95	49.37	688.40	43.35	−4.61	−3.86	−6.02
BL	60.38	3.80	96.55	6.08	166.65	10.49	191.89	12.08	2.28	4.41	1.59
BUL	80.28	5.06	97.53	6.14	136.05	8.56	195.45	12.31	1.09	2.42	3.75
SB	177.60	11.18	187.75	11.82	186.54	11.74	184.74	11.63	0.64	−0.08	−0.11
V	219.93	13.85	201.15	12.66	186.42	11.74	229.90	14.48	−1.19	−0.92	2.74
WB	131.09	8.26	159.53	10.04	128.13	8.07	97.36	6.13	1.79	−1.97	−1.94
Total	1587.74	100	1587.74	100	1587.74	100	1587.74	100			

Sources: Landsat-5 TM Satellite Image of 4th April 1995, Landsat-5 TM Satellite Image of 14th March 2005, Landsat-8 OLI Satellite Image of 21st November & 30th December 2015, and Landsat-8 OLI Satellite Images of 16th January 2025.

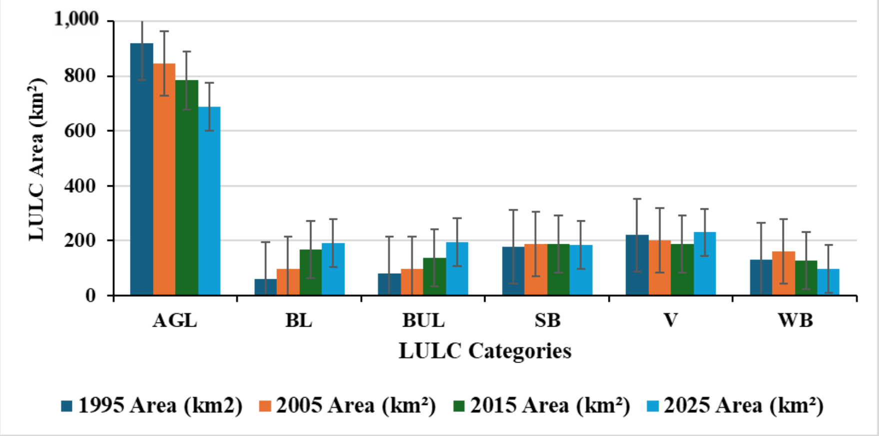


Figure 4. LULC Change Comparison of Darrang district from 1995 to 2025.

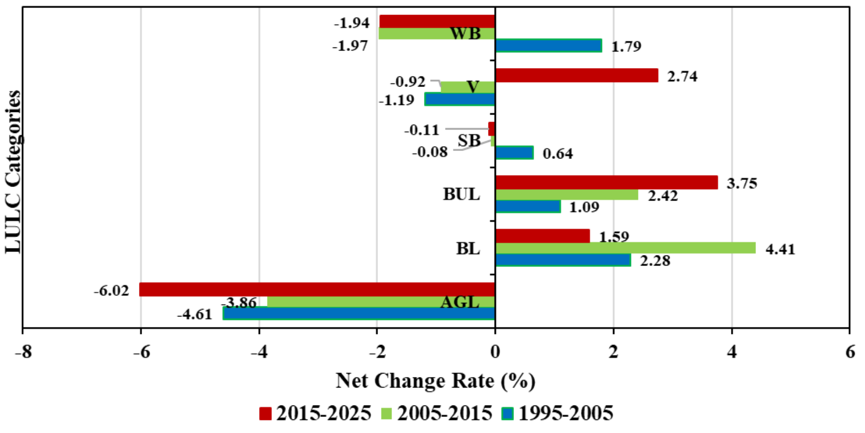


Figure 5. LULC Net Change Rate of Darrang District from 1995 to 2025.

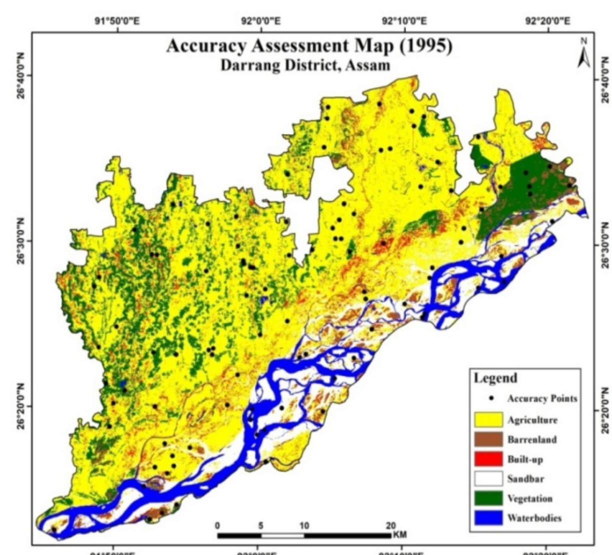
From **Table 2**, it is evident that there is a fluctuation of change in LULC categories (**Figure 4**) in both positive and negative ways. The AGL of the area has shown a negative growth rate from 1995 to 2025. The net change seemed to be −4.61% from 1995 to 2005, −3.86% from 2005 to 2015, and −6.02% from 2015 to 2025 (**Figure 5**). Simultaneously, there is a growth of area under BL within three decades, along with a net change of 2.28% to 1.59% from 1995 to 2025 (**Figure 5**). Also, there is a fast increase in the built-up area for an expanse of thirty years, from 80.28 sq. km in 1995, which accounts for 5.05 % of the total area, to 195.45 sq. km in 2025, which accounts for 12.31% (**Table 2**). Therefore, it explains that there is 1.09% of net change during 1995–2005, 2.42% during 2005–2015, and 3.75% during 2015–2025 (**Figure 5**). It can be assumed that it is due to factors like population growth, rural-urban migration and an increase in birth rate.

Furthermore, there is a fluctuating growth of the area under SB and WB. One of the major reasons for fluctuation is that the district falls under major flood-prone areas of Assam due to the presence of the BR and its various tributaries, and as a result, the erosional and depositional processes are very active in the region. In 2005, the data shows the extreme growth of total area under SB and WB, which are 187.75 km^2 and 159.53 km^2, respectively, because of heavy flood cases being reported in that year in this region. Moreover, the area under V was 219.93 km^2 in 1995, 201.15 km^2 in 2005, 186.42 km^2 in 2015, and 229.90 km^2 in 2025 (**Figure 4**). From 1995 to 2015, there is a decline in the area under V because of factors like AGL expansion in areas like Mangaldai, Dalgaon, and Kharupetia areas, along with riverbank erosion in Besimari and Sialmari char region near Sipajhar subdivision and Northern bank of the BR, respectively.

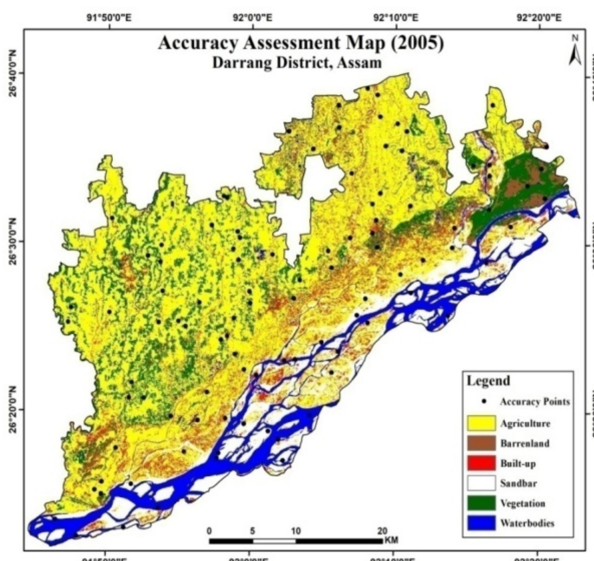
3.3. Accuracy Assessment

Accuracy assessment examines the amount of reliability of the various categories of LULC with the real-world scenario. For the completion of the study, a supervised classification method was utilized and further its accuracy has been assessed with the help of ground truth data along with high resolution images of the region taken from Google Earth Pro (GEP).

The accuracy assessment was done for the respective years, i.e., 1995, 2005, 2015, and 2025 (**Figure 6**) and (**Tables 3–6**) to assess the data found in the LULC map with the real world. The overall accuracy has been found to be 91.43% (**Table 3**), and 86.73% (**Table 4**) in 1995 and 2005, respectively, whereas in 2015 the overall accuracy is 83.85% (**Table 5**), and in 2025 it is 90.50% (**Table 6**).

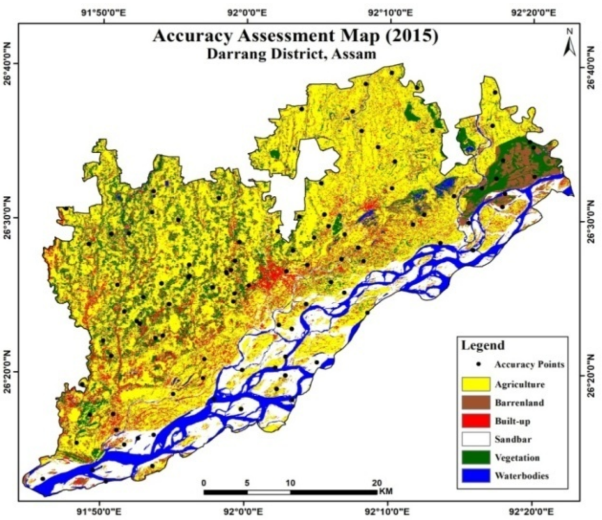


(**a**) Accuracy Assessment Map, 1995.

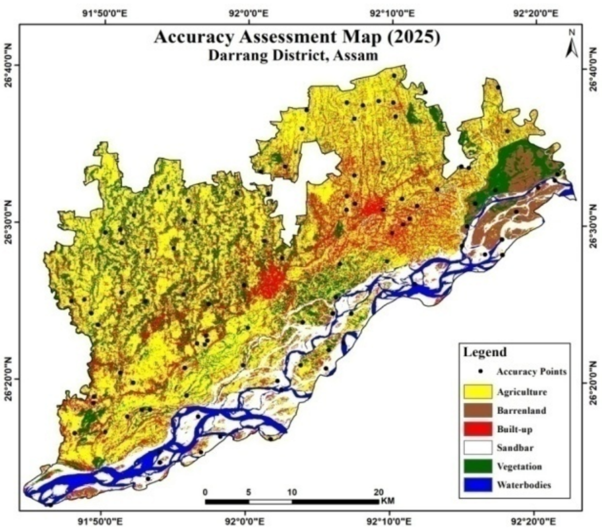


(**b**) Accuracy Assessment Map, 2005.

Figure 6. *Cont.*



(**c**) Accuracy Assessment Map, 2015.



(**d**) Accuracy Assessment Map, 2025.

Figure 6. Accuracy Assessment Map of Darrang District, 1995–2025.

Table 3. An Error Matrix of LULC Classification in Darrang District (1995).

OID (Object Identifier)	Class Value	AGL	BL	BUL	SB	V	WB	Total	User Accuracy	Kappa
0	AGL	60	0	0	0	0	0	60	1	0
1	BL	0	6	0	0	0	0	6	1	0
2	BUL	3	0	2	1	0	0	6	0.33	0
3	SB	0	0	0	10	0	0	10	1	0
4	V	0	0	0	0	11	0	11	1	0
5	WB	1	0	0	0	0	6	7	0.85	0
6	Total	64	6	2	11	11	6	100	0	0
7	Producer Accuracy	0.93	1	1	0.90	1	1	0	0.95	0
8	Kappa	0	0	0	0	0	0	0	0	0.91

Table 4. An Error Matrix of LULC Classification in Darrang (2005).

OID (Object Identifier)	Class Value	AGL	BL	BUL	SB	V	WB	Total	User Accuracy	Kappa
0	AGL	49	0	2	0	1	0	52	0.94	0
1	BL	0	8	0	0	0	0	8	1	0
2	BUL	2	1	5	1	0	0	9	0.55	0
3	SB	1	0	0	10	0	0	11	0.90	0
4	V	1	0	0	0	10	0	11	0.90	0
5	WB	0	0	0	0	0	9	9	1	0
6	Total	53	9	7	11	11	9	100	0	0
7	Producer Accuracy	0.92	0.88	0.71	0.90	0.90	1	0	0.91	0
8	Kappa	0	0	0	0	0	0	0	0	0.86

Table 5. An Error Matrix of LULC Classification in Darrang (2015).

OID (Object Identifier)	Class Value	AGL	BL	BUL	SB	V	WB	Total	User Accuracy	Kappa
0	AGL	47	0	3	0	2	0	52	0.90	0
1	BL	1	6	0	0	0	0	7	0.85	0
2	BUL	0	1	3	1	0	1	6	0.5	0
3	SB	0	0	0	13	0	0	13	1	0
4	V	2	0	0	0	15	0	17	0.8	0
5	WB	0	0	0	0	0	5	5	1	0
6	Total	50	7	6	14	17	6	100	0	0
7	Producer Accuracy	0.94	0.85	0.5	0.92	0.88	0.83	0	0.89	0
8	Kappa	0	0	0	0	0	0	0	0	0.83

Table 6. An Error Matrix of LULC Classification in Darrang (2025).

OID (Object Identifier)	Class Value	AGL	BL	BUL	SB	V	WB	Total	User Accuracy	Kappa
0	AGL	42	0	0	0	0	1	43	0.97	0
1	BL	1	8	0	0	0	0	9	0.88	0
2	BUL	2	0	9	0	0	0	11	0.81	0
3	SB	0	0	0	15	0	0	15	1	0
4	V	1	2	0	0	12	0	15	0.8	0
5	WB	0	0	0	0	0	7	7	1	0
6	Total	46	10	9	15	12	8	100	0	0
7	Producer Accuracy	0.91	0.8	1	1	1	0.87	0	0.93	0
8	Kappa	0	0	0	0	0	0	0	0	0.90

Limitations and Uncertainty

Even though the range of overall accuracy is high, ranging from 83.85% to 91.43%, there are still some uncertainties remaining due to similarity in spectral signatures between agricultural land, barren land and sandbars in post- flood situations where soil and sediment surfaces have similar reflectance characteristics. Some other factors like seasonal differences, medium spatial resolution and the availability of field-based data, are limited and may have influence the accuracy of LULC categories to some extent. Despite these constraints, the accuracy achieved is acceptable for LULC change dynamics analysis and has provided a reliable understanding of the changes that took place over the years in the district.

4. Discussion

4.1. LULC Impact Analyses on Environment

4.1.1. Factors Contributing to LULC Changes

There are several factors that significantly contribute to the changing LULC pattern of an area. The Darrang district also experiences such factors that influence changes in its LULC from the past to the present. Multiple contributing factors are involved in making these changes, such as population and urban growth, decrease in agricultural areas, losses of vegetation cover, infrastructure development, and governmental frameworks and landholding issues.

Demographic Expansion and Urban Growth

Over the years, Darrang district has experienced a growth rate in terms of its population composition. This has enhanced the pressure on the resources of the district and, as a result, leads to its transformation. This transformation can be seen in the new BUL urban spaces. The rising number of inhabitants has led to the growth of BUL and agricultural production in the district. Darrang district has gone through rapid urbanization, which is evident in towns like Mangaldai, Kharupetia and Patharighat. These urban spaces have expanded into the nearby AGL and low-lying areas, leading to the expansion of BUL.

Decrease in AGL Areas

The LULC changes in the district can be evident from the decrease in the percentage of AGL. From 1995 to 2025, there are several factors which are responsible for this change, such as the agricultural land has seen a significant decline in its area due to factors like riverbank erosion, frequent flooding and land degradation. These have gradually degraded the soil, making it unfit for agricultural activities. In addition, the AGL has also been converted to BUL areas due to population growth and urbanization in the district, such as Mangaldoi, Sipajhar, and Kharupetia, which have significantly expanded.

Loss of V Areas

The LULC maps of Darrang district of three decades (1995–2025) showcases a decline in the rate of forest V cover from 1995–2015 and a gradual increase of 14.48% in the year 2025. This is due to the clearance of forests areas like Rowta and Kalaigaon illegally, which is marked as the involvement of anthropogenic activities. Also, the population in rural areas uses forest products such as wood and timber as fuel for their daily needs [21]. Since the population in rural areas has seen a growth over the decades. There has been a greater number of utilization of forests resources, leading to a reduction in the percentage of forest V cover. Despite the decrease in V cover, the government has taken several measures to revive the lost forest resources, which can be evident from the increase in forest cover in 2025.

Expansion of Infrastructure

Over the decades, the district has shown a significant increase in the infrastructural development of the region, including building of embankments, roads, highways and the construction of public properties such as schools and institutional buildings. This growth has resulted in a further reduction in forest V cover of the semi urban areas of the region.

Governmental Frameworks and Landholding Issues

Government policies related to the distribution of land among the people who are excluded from owning land are taking place in the region. To fulfill these policies, the government is transforming the forest V covers into BUL areas and distributing it among the landless population of the district. As a result, the increase in areas of settlement (BUL) at the cost of green V covers is hampering the environmental condition in this district. In addition, the weak governmental framework and inadequate implementation of land-use regulations have resulted in land degradation and Environmental deterioration in the region.

4.1.2. Consequences of LULC Changes in the Environment

Depletion of Forest Area and Biodiversity Loss

Due to the changes in LULC patterns in the district between 1995 and 2025, there is a considerable depletion in forest V cover, leading to loss of habitat and declination of plant, bird, and wildlife species. The expansion of population and transformation of Forest V areas for residential and agricultural purposes have escalated biodiversity loss. This decrease in cover of V has caused ecological imbalance and intensified vulnerability to climate-related impacts, soil degradation and ecological imbalance, which needs to be addressed with a better action plan.

Soil Quality Depletion

Soil degradation has intensified in locations like Sipajhar and Dalgaon due to unsustainable agricultural practices and frequent flooding by the Brahmaputra River (BR). Soil fertility and agricultural productivity have declined due to erosion and large-scale sand deposition. Another major region for soil degradation is the occurrence of floods in the district due to the presence of the mighty BR, which causes erosion and sand deposition at a greater scale [22]. Over time, this depletion has adversely disturbed the quality of the environment and the socio-economic conditions of local communities.

Degradation of Aquatic Resources

Another major consequence of LULC changes in the environment is related to the degradation of wetlands and WB in the region. The expansion of population in the district from 1995–2025 has shown a significant transformation of wetlands into BUL and AGL, which is evident in Bhairab Pukhuri, a wetland in the district. Also, the groundwater level of the region is deteriorating due to LULC pattern changes done by anthropogenic activities [19]. With the loss of wetlands, various species of fish are also on the verge of extinction. Water pollution also emerges as another reason for the degradation of aquatic resources.

Urban Growth and Expansion of Constructed Spaces

Due to rapid urbanization, areas such as Mangaldai and Kharupetia are going through a massive land change from AGL to BUL areas. It can be related to the expansion of the population in the region, as people are more concentrated on building housing infrastructures. Growth of urban spaces has also led to waste generation, which is becoming unmanageable and is creating a situation of pollution in the district. The increase in the rate of pollution has significantly impacted on the climate of the region. Moreover, these dynamics have added to the rise of local temperatures and worsening environmental conditions, highlighting the need for conservative urban planning and sustainable urban development by the authorities [23].

Long-Term and Short-Term Climatic Variations

Due to an increase in population percentage and a rise in urbanization in Darrang district within these three decades (1995–2025), the pattern of LULC is changing at an alarming rate. This has resulted in adverse climatic conditions, including a rise in temperature in both the summer and winter seasons. Also, rainfall patterns have been changing with the change of vegetation patterns. Rapid transformations in LULC have contributed to noticeable changes in local climate patterns, including rising temperatures and irregular rainfall. Decline of vegetation cover and growth of settlement areas have intensified heat stress and transformed seasonal weather conditions. These climatic changes have further worsened issues such as health risks, degradation of soil, and reduction of water resources.

4.2. LULC Change Interpreparation and Analyses

4.2.1. Rapid Growth of Settlement Areas

From the prepared LULC maps, it is evident that the BUL area of the district rapidly expanded from 1995 to 2025. In 1995, the total area under BUL was about 80.28 sq. km, which got expanded to a high rate of about 195.45 sq. Km, which results in 12.31 % of the overall area. Rapid growth of settlement is seen in the region, mostly in Mangaldai and various other semi-urban areas in the district. This is mostly due to the contribution of rural-urban migration, high birth rates and low death rates due to the introduction of modern science and technology.

4.2.2. Decreasing Nature of AGL

The AGL in the region is seen to be decreasing over the years from 1995 to 2025. It was 57.84% in 1995, 53.23% in 2005, 49.37% in 2015 and 43.35% in 2025. Within three decades, the percentage of AGL is seen to be decreasing, especially in central and southern Darrang, as the population growth, as well as areas under fallow land, is increasing at a steady rate, ultimately decreasing the percentage of AGL.

4.2.3. Depletion of Forest V areas

The forest V areas of the region showcase a negative downfall over the years from 1995 to 2015 and a gradual increase in the year 2025. In 1995, the percentage of forests V cover was seen to be 13.85%, which gradually decreases to 11.74% in 2015, further significantly increases to 14.48% in 2025. This gradual decrease in the amount of forest V cover is related to deforestation and an increase in BUL. This is mostly due to rapid urbanization and industrialization in the district from 1995 to 2015. This issue has led to the introduction of various challenges, including biodiversity loss, ecological imbalance, depletion of wetlands and many more.

4.2.4. Dynamic Shifting of WB

The BR is a unique dynamic river in the world with intense braiding and critical bank erosion [23]. BR and its tributaries are seen to be shifting their courses in an excessive way over the years from 1995 to 2025. In 1995, it was seen to be 8.25%, followed by 10.04% in 2005, 8.07% in 2015 and 6.13% in 2025. This fluctuation reflects the seasonal floods that occur every year in the region. During the flood season, the river changes its course due to the accumulation of excessive water and siltation in the riverbeds. These changes collectively indicate the district's increasing urbanization, environmental pressures, and hydrological shifts over three decades. Moreover, these shifts have been clear due to anthropogenic activities like building unplanned embankments in various parts of the region.

4.3. Planning and Policy Relevance

The results of this study are significant for land-use planning and management of the environment in Darrang district. The increase in intensity of built-up areas and decline in agricultural land and vegetation show that there is a necessity for regulated spatial planning, especially in regions prone to floods and erosion. The LULC maps that are being created in this study can be useful to facilitate planners and local authorities in recognizing hazard-prone areas, strengthening sustainable development, sustaining agricultural land, and fortifying flood risk management strategies.

5. Conclusions

The present study analyzes the LULC changes over three decades in the Darrang district using remote sensing and GIS techniques. The study of LULC change detection in Darrang district of Assam over the time span of 1995 to 2025 shows major changes in the LULC pattern. It is due to both natural and human causes. Remote sensing and GIS techniques are significantly employed for measuring the changes in LULC patterns and mapped it effectively.

Six major classes have been taken to see the changes over time, including WB, SB, AGL, V, BL, and BUL. With the help of a supervised classification technique, Landsat images have been classified, which shows a significant number of changes in the LULC pattern over the area. This has largely impacted on the environment and surroundings as well. In 1995, there was a dense forest cover surrounding the district, which had been transformed into several agricultural and settlement areas in 2025. This has led to the depletion of the forest cover, impacting on the environment. The major changes over the period have resulted in active fluctuations in the environmental patterns, including deforestation and biodiversity loss, ecosystem imbalance, depletion of agricultural land, wetlands and waterbodies, subsequent flooding, and riverbank erosion, etc.

The findings that are generated through this highlight the need for sustainable change and environmental protection planning [8]. This may be implemented through the introduction of several government schemes and policies. To have balanced development, government and policy makers, and urban planners should include monitoring of LULC patterns over time in regional planning, which will further help to eradicate the negative impact on the environment in the area. Decision making and environmental management are also an essential part of sustainably developing the region.

The findings that are generated through this highlight the need for sustainable change and environmental protection planning. The result shows that the area has shown significant changes over the years due to both natural and human-induced processes. The gradual increase in the transformation of forest and agricultural land into built up areas has induced certain land use pressure on the region it has shown a shift in agrarian-dominated landscapes in 1995 to increased built-up areas in 2025. Due to these changes, there are several environmental consequences that came into being, including deforestation and biodiversity loss, ecosystem imbalance, depletion of agricultural land, wetlands and waterbodies, increase in frequent flood events and erosion risks. This has made the district vulnerable to several environmental challenges. From a planning framework, this study highlights the significance of frequent LULC monitoring in regional planning and environmental management strategies. In this regard, Remote Sensing and GIS play a crucial role in tracking changes in land use patterns, identifying vulnerable areas and enhancing decisions and planning processes. Collectively, this study provides valuable insights to further support land use planning in a sustainable manner and help areas with similar environmental and developmental challenges to incorporate sustainable strategies in their planning processes.

Author Contributions

Conceptualization, S.D.; P.B.; S.A.; methodology, S.D.; P.B.; software, S.D.; P.B.; validation, B.P., B.N. and S.A.; formal analysis, S.D. and P.B.; investigation, S.D. and P.B.; resources, S.A.; data curation, S.D. and P.B.; writing—original draft preparation, S.D. and P.B.; writing—review & editing, B.N.; visualization, B.N., S.A. and B.P.; supervision, S.A.; project administration, S.A. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

This study uses USGS Earth Explorer satellite images which are available to freely download. However, authors are ready to provide the prepared LULC maps upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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