Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 44 No. 12
December 2023

Evaluating Dynamics of Land Use and Land Cover Changes in the Coastal Regions of the IB-Watershed of the Mahanadi River using Multi-Temporal Landsat-8 Data

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Abstract

This study analyzes IB watershed land use changes from 1991 to 2021 using Landsat-8 datasets. Supervised classification techniques are employed to assess alterations in various land use and land cover categories. Results reveal reduced cropland due to urban expansion and increased barren land, signaling widespread degradation. Statistical analysis links these changes to urbanization, population growth, and agriculture. The study involves satellite image preprocessing, maximum likelihood classification, and change detection analysis. The insights generated from this investigation emphasize the pressing need for sustainable land management practices to mitigate further degradation within the IB watershed. These findings hold substantial implications for policymakers and land management authorities, providing crucial guidance for formulating effective conservation strategies and optimizing land resource management strategies within the region.

Keywords: *Land use and Land cover; Change detection analysis; Landsat data; supervised classification; accuracy assessment; IB-watershed; Mahanadi basin-India*

1. Introduction:

Land use and land cover (LULC) changes, witnessed globally at an unprecedented pace, entail the transformation of natural landscapes—such as forests and wetlands—into human-dominated territories encompassing agriculture and urban areas (Zang et al., 2011). These alterations bear significant environmental and societal impacts, including loss of biodiversity, diminished ecosystem services, and escalated carbon emissions (Kanianska, 2012). The intricate interplay of socio-economic, political, and environmental factors, such as population growth, urbanization, agricultural expansion, and resource extraction, fuels these changes (Melese, 2016).

Deforestation, a direct consequence of LULC changes, contributes to climate change by hindering carbon sequestration (Matono et al., 2019). Concurrently, soil erosion compromises fertility and heightens the risk of landslides and floods (Kanianska, 2012). Loss of biodiversity truncates crucial ecosystem services like pollination and water purification, impacting human well-being. Socially and economically, these changes disrupt livelihoods, displace communities, and incite conflicts over resources, leading to loss of traditional knowledge and cultural practices (Parven et al., 2022).

Addressing LULC challenges demands a collaborative approach encompassing governmental policies, community engagement, and innovative technologies (Coleman et al., 2017). Effective policies might include sustainable land use incentives and land management planning.

Community involvement can empower local resource management initiatives (Melese, 2016), while technological innovations like remote sensing and GIS offer crucial data for planning and monitoring (Quarder W.M. et al., 2016).

India, undergoing substantial LULC shifts driven by population surge, urbanization, and agricultural expansion (Roy et al., 2015), confronts challenges such as urban encroachment into rural areas, leading to habitat loss and ecosystem fragmentation (Bhattacharjee et al., 2017). The Green Revolution's agricultural gains, while boosting productivity, also spurred deforestation and overuse of groundwater (Behera et al., 2018). Recent shifts towards high-value crops further impact water use and biodiversity (salman et al., 2017).

These LULC changes have profound implications for India, affecting ecosystem services, climate change, and human welfare (Li et al., 2021). Deforestation and wetland loss contribute to carbon emissions (Loukika et al., 2019) while reducing water availability, and soil degradation hampers agricultural productivity, exacerbating food security concerns (Das and Das, 2019).

Effective management strategies in India necessitate policy interventions favoring sustainable practices like agro-forestry (Kordi F et al., 2022) and conservation agriculture (Behera et al., 2018). Urban planning emphasizing green spaces and eco-friendly transport can mitigate urbanization's impacts (Chen, 2007). Leveraging technologies like remote sensing aids evidence-based decision-making (Quarder W.M. et al., 2016). The Mahanadi River Basin in eastern India has experienced significant LULC transformations due to population growth, agricultural expansion, and industrialization (S Suresh et al., 2016). Spanning Chhattisgarh and Odisha, the Mahanadi River sustains diverse ecosystems and livelihoods. This study aims to analyze LULC changes in the IB-watershed of the Mahanadi basin from 1980 to 2020, utilizing multi-temporal satellite data (S Suresh et al., 2016). Additionally, it seeks to identify the drivers of these changes, filling research gaps concerning hydrological models and water balance components in the IB river basin. By utilizing three decades of satellite data, this study sheds light on the spatial and temporal aspects of LULC changes in ungauged watersheds.

2. Study Area:-

The study focuses on the land use and land cover changes within the IB River watershed, located in the Mahanadi River basin. Spanning 5893.15 km2 from 22°08′ N to 23°20′ N latitude and 83°30′ E to 84°16′ E longitude (Figure 1), it ranges in elevation from 201 m to 1167 m. Originating in Chhattisgarh's Jashpur district, the IB River flows southward into the Hirakud dam. This watershed forms part of the southeastern segment of the NW-SE oriented Mahanadi Master Basin, characterized by a half-graben syncline dipping in a NW direction. The geological composition, reported by the Central Ground Water Board in 2012, includes various features like banded gneissic complex, basalt, laterite, khondalite, granite, schist, and alluvium aquifer systems. The region experiences an average annual rainfall of 1352.7 mm, with dry days reaching a maximum temperature of 46.11 °C and wet days dropping to 10 °C. The southwest monsoon contributes significantly to the area's rainfall.

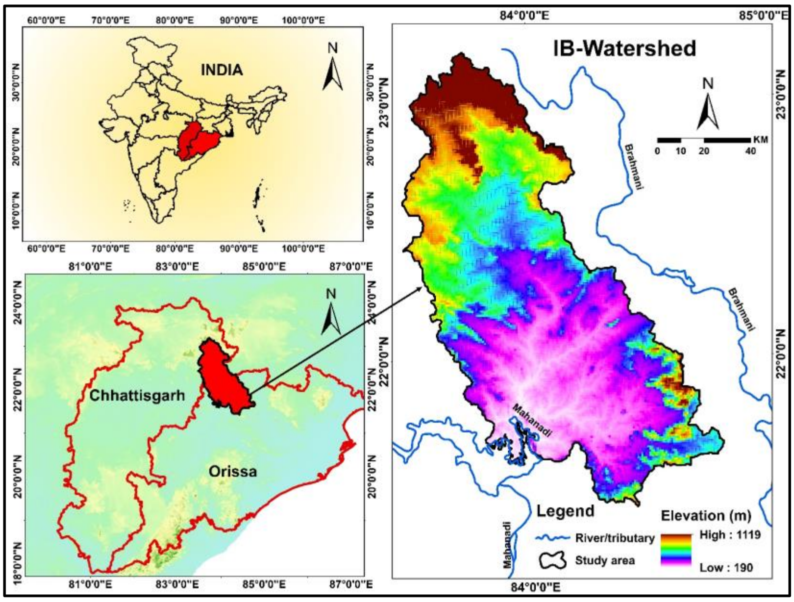

Figure 1. Location of the study area.

3. Data sets and Methodology

3.1 Data sets used in the study:-

The study utilized multi-temporal Landsat satellite imagery covering the period from 1990 to 2021 to examine land use and land cover changes within the IB watershed (Ahmed et al., 2022; Rawat et al., 2023; Imdad et al., 2022). These datasets were sourced from the United States Geological Survey (USGS) Earth Explorer platform, comprising Landsat 5, 7, and 8 images with a spatial resolution of 30 meters. Additionally, digital elevation models (DEMs) from the Shuttle Radar Topography Mission (SRTM) were acquired to access elevation data. Existing land use and land cover maps, along with census data from the Indian government, supplemented the analysis. Cloud-free Landsat imagery for each year was selected, resulting in a collection of 10 images for the study area.

3.2 Methodology:-

The methodology employed for analyzing land use and cover change in the IB watershed included several key steps:

- Pre-processing: Landsat images underwent pre-processing to ensure data consistency, involving atmospheric, radiometric, and geometric correction.
- Land use and cover classification: The supervised maximum likelihood algorithm classified images into five types: forest, agriculture, water bodies, urban, and barren land.
- Accuracy assessment: 100 sample points were randomly selected to compare classified images with high-resolution Google Earth images, evaluating classification accuracy.
- Change detection analysis: A post-classification comparison method identified changes in land use and cover types across different periods.
- Statistical analysis: Utilizing census data and land use policy information, statistical analysis elucidated drivers such as population growth, urbanization, and agricultural practices.

The study examined land use and cover changes in the IB watershed from 1990 to 2021. Classification revealed major cover types: forest, agriculture, water bodies, urban, and barren land. Results indicated a significant decrease in forest cover due to agricultural expansion and urbanization, alongside an increase in barren land indicating regional land degradation. Statistical analysis pinpointed population growth, urbanization, and agricultural practices as primary drivers. Further details on the methodology are illustrated in Figure 2.

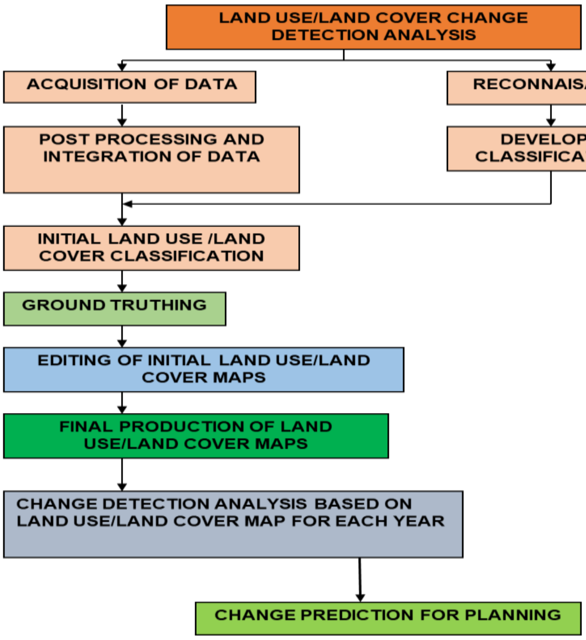

Figure 2. Methodology Flow chart

3.3 Accuracy assessment: -

Accuracy assessment in land use and land cover (LULC) classification ensures the reliability of the classified map. The Kappa coefficient, a commonly used metric, gauges agreement between the classified map and ground truth data, with values ranging from -1 to 1. A Kappa coefficient near 1 signifies high agreement, while 0 implies chance-level agreement, and negative values indicate less agreement than chance.

This assessment involves collecting reference data representing true land cover types in the study area, comparing it with the classified map using the same area, and computing the Kappa coefficient. A confusion matrix, illustrating correctly classified (diagonal cells) and misclassified (off-diagonal cells) pixels for each land cover class, aids in this evaluation.

The Kappa coefficient's formula involves N (total observations), ai (pixels correctly classified in class i), and bi (pixels in reference data for class

$$\mathbf{Kappa = (N \times \sum(ai \times bi) - \sum ai \times \sum bi) / (N^2 - \sum ai \times \sum bi)}$$

This coefficient quantitatively assesses LULC classification accuracy, widely employed in remote sensing studies. It facilitates comparison among classification algorithms, evaluation of training data impact, and identification of areas requiring additional data for improved accuracy.

4. Results:

Land use and land cover (LULC) change analysis is crucial to comprehend the evolving earth's surface and evaluate human activities' environmental impact. Monitoring these changes offers pivotal insights for land use planning, resource management, and policy formulation. Especially vital in swiftly urbanizing areas with burgeoning populations and expanding agriculture, such analysis illuminates how resource demands and alterations affect ecosystems and biodiversity. Additionally, these changes significantly influence hydrology, climate, and soil properties, altering water availability, carbon storage, and ecosystem services. Detecting LULC changes helps identify key areas and drivers, empowering policymakers and land managers to make informed decisions regarding planning, conservation, and restoration. Leveraging high-resolution satellite data allows for regional and global-scale analysis, providing crucial insights into the dynamics of land use changes essential for sustainable resource and ecosystem management.

4.1 LULC in 1991:-

The LULC of the IB-Watershed in 1990 was mapped on the Landsat TM images with a spatial resolution of 30 m. The results show that, Cropland is the most dominant LULC class with an area of 7789 square kilometers, representing 62.57% of the total area (Figure 3).

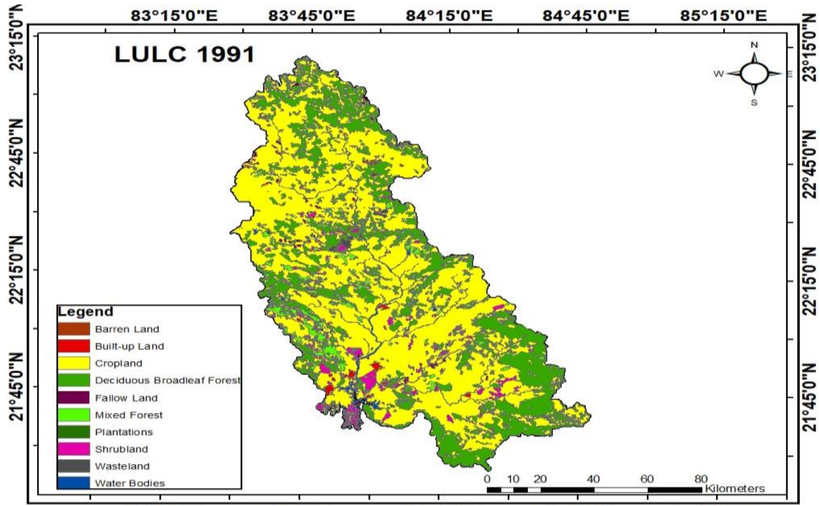

Figure 3. LULC map of IB-watershed in 1991

The Deciduous Broadleaf Forest is the second most dominant class, spanning 3463 square kilometers, making up 27.82% of the total area. Water Bodies encompass the smallest area among all classes, with only 209 square kilometers, representing 1.68% of the total area. Scrub land covers 393 square kilometers, accounting for 3.16% of the total area. Fallow Land, Mixed Forest, Built-up Land, Wasteland, Barren Land, and Plantations cover areas each constituting less than 1% of the total area. Refer to Supplementary Table 2 for a detailed breakdown of each land use class, their respective areas, and percentages.

4.2. LULC in 2001:-

The LULC area of the study area in 2001 was mapped using Landsat-TM imagery. Supplementary Table 3 illustrates that Cropland emerged as the dominant class, encompassing 8051 square kilometers, constituting 64.68% of the total area. Following this, the Deciduous Broadleaf Forest ranked as the second most dominant class, spanning 3314 square kilometers and accounting for 26.62% of the total area.

Water Bodies encompass a modest area of 210 square kilometers, constituting 1.69% of the total area. Following this, Scrub land spans 295 square kilometers, covering 2.37% of the total area. Fallow Land extends over 74 square kilometers, representing 0.59% of the total area. Meanwhile, Mixed Forest, Built-up Land, Barren Land, Wasteland, and Plantations each cover areas accounting for less than 1% of the total area, as illustrated in Figure 4.

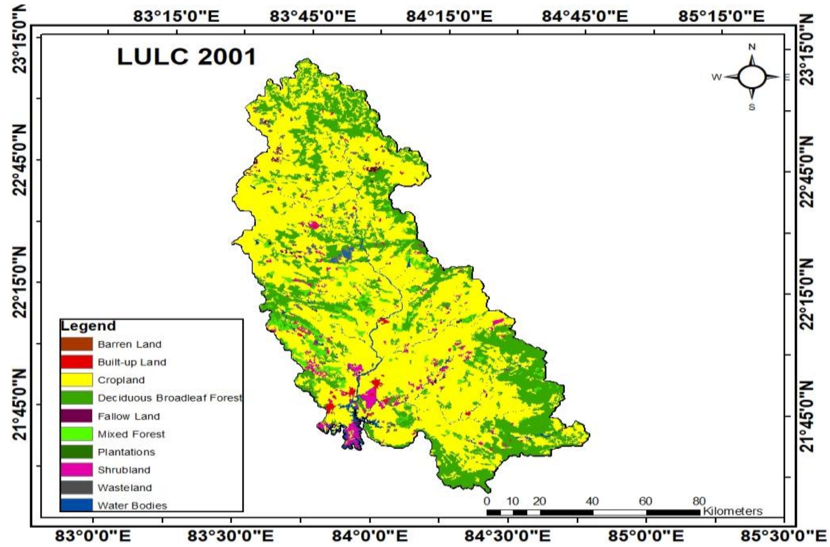

Figure 4. LULC map of IB-watershed in 2001

4.3. LULC during 2011:-

The LULC map of the IB-watershed was derived using Landsat-ETM imagery. The tabulated data offers a comprehensive representation of the land use and land cover (LULC) classes within a specific region in 2011. These classes are categorized by their covered areas, presented in square kilometers and percentages, facilitating an understanding of the relative dominance of each class.

Cropland prevails as the largest LULC class in the area, encompassing 7493 square kilometers, making up 60.19% of the total area. Following this, Deciduous Broadleaf Forest ranks as the second-largest class, covering 3606 square kilometers, representing 28.97% of the total area. Water Bodies occupy a limited space, accounting for only 1.71% of the total area, while Scrub land covers 3.92%, and Fallow Land encompasses 0.57% of the total area. Meanwhile, Mixed Forest, Built-up Land, Barren Land, Wasteland, and Plantations are less prominent, each covering less than 1% of the total area. Refer to Figure 5 for the LULC map of the study area in 2011.

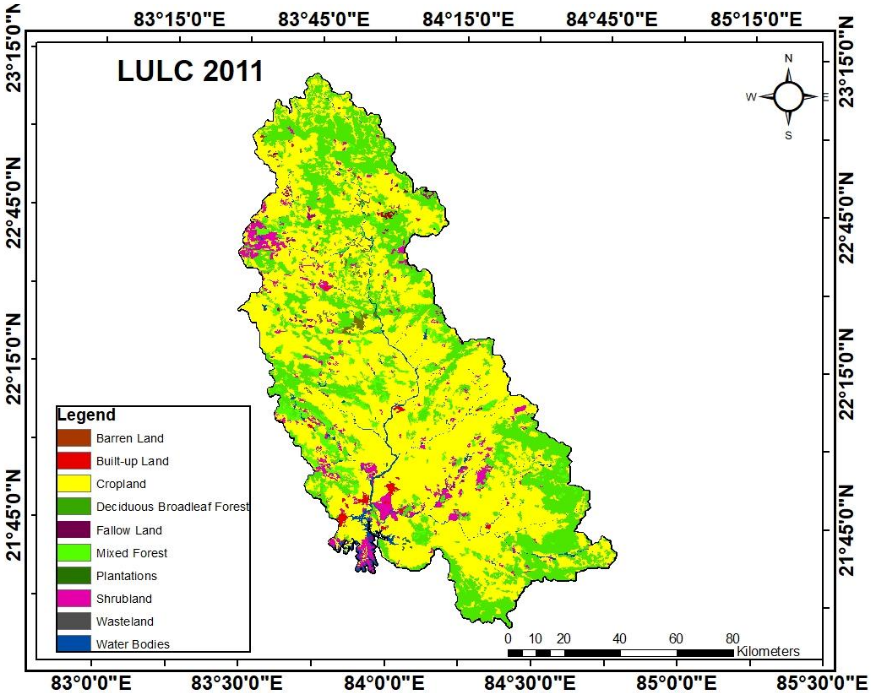

Figure 5. LULC map of the study area in 2011.

4.4. LULC during 2021:-

The 2021 LULC map of the study region was derived from Landsat-8 OLI imagery with a 30-meter spatial resolution. Table 5 offers a detailed breakdown of LULC classes observed in the area for that year, presenting coverage in square kilometers and percentages, revealing their dominance.

Cropland spans 5932 square kilometers, accounting for 47.65% of the total area, while Deciduous Broadleaf Forest covers 2119 square kilometers, representing 17.02% (Figure 6).

Water Bodies encompass 6.22% of the area, with Scrub land and Fallow Land covering 11.95% and 4.59%, respectively. Mixed Forest occupies 11.39%. Additionally, Built-up Land, Barren Land, Wasteland, and Plantations each cover less than 1%..

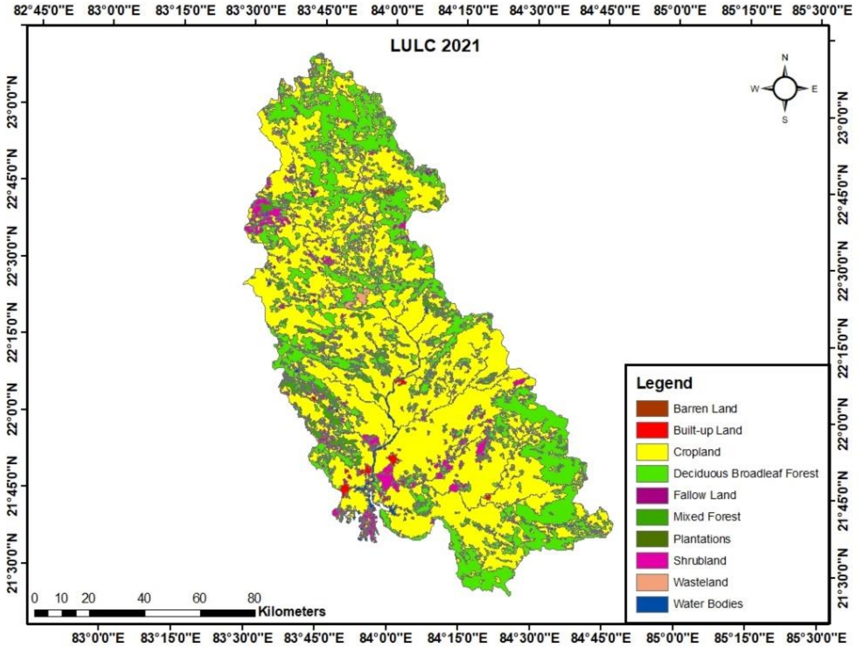

Figure 6. LULC map of the study area in 2021.

4.4. LULC change detection analysis (1991 to 2021):-

The multi-temporal Landsat analysis of LULC change in the IB watershed reveals substantial landscape alterations from 1991 to 2021. Table 6 delineates these changes across 10 distinct land use classes over three decades, presenting areas in square kilometers and their respective percentages. Additionally, it highlights the area variations (in square kilometers and percentages) for each class between 1991 and 2021.

In 1991, cropland dominated the region, covering 62.57% of the total area. However, by 2021, it decreased by 14.92%, witnessing shifts towards deciduous broadleaf forest and scrub land. Notably, nearly every class, excluding wasteland and plantations, experienced changes. Deciduous broadleaf forest and mixed forest expanded, while water bodies and barren land diminished.

The LULC classification's accuracy, assessed via the Kappa coefficient, demonstrated an overall accuracy of 91.2% and a Kappa coefficient of 0.86, indicating high precision.

These findings align with studies in other Indian regions, highlighting agriculture and urban expansion as pivotal drivers of LULC change. Forest depletion bears implications for vital ecosystem services like water regulation, carbon storage, and biodiversity conservation.

5. Causes of LULC change in the region:-

The region under study undergoes diverse drivers of land use and land cover (LULC) change, mirroring common global trends. Key factors include:

- Population Growth: Increasing population demands more land for housing and infrastructure, leading to reduced forest cover and agricultural land due to conversion for residential and commercial purposes.
- Agricultural Expansion: Growing food demand drives farmers to expand agricultural activities, converting forested areas and natural habitats into arable land.
- Urbanization: The transformation of rural spaces into urban centers leads to the conversion of farmlands, forests, and natural habitats into urban areas, contributing to declining forest cover and agricultural lands.
- Industrialization: The expanding industrial sector necessitates land for factories and infrastructure, resulting in the conversion of agricultural and forested lands into industrial areas.

- Climate Change: Altered temperature and rainfall patterns drive shifts in vegetation, impacting the distribution of forests and grasslands.

These drivers present a complex interplay of human-induced activities and population growth, agricultural and industrial expansions, urbanization and natural influences like climate change. Understanding these multifaceted causes is crucial for formulating strategies to manage and mitigate the repercussions of LULC changes on both the environment and human well-being.

1. Discussion

Land use and land cover change (LULC) profoundly impacts ecosystems and human well-being. The observed changes in the region stem from various factors, notably population growth and urbanization. A rising population has spurred the demand for residential, commercial, and industrial spaces, leading to considerable conversions of natural areas like forests, croplands, and wetlands into built-up land. This urban expansion has fragmented habitats, culminating in diminished biodiversity and ecosystem services. The escalating need for infrastructure has further propelled LULC changes, converting natural areas into transportation networks like roads and highways.

The data and analysis underscore significant LULC alterations in the IB watershed over the past three decades. The most conspicuous change is the decline in cropland area from 7789 sq. km in 1991 to 5932 sq. km in 2021, a 14.92% reduction. Factors contributing to this decline likely include urbanization, population growth, and shifts in agricultural practices.

The rise in deciduous broadleaf forest area from 3463 sq. km in 1991 to 2119 sq. km in 2021 reflects positive strides, possibly stemming from reforestation initiatives and conservation endeavors by governmental and non-governmental entities. Conversely, the increase in mixed forest area from 387 sq. km in 1991 to 1418 sq. km in 2021 may signal commercial forestry expansion rather than a positive trend.

The augmentation of water bodies from 209 sq. km in 1991 to 774 sq. km in 2021 may result from dam construction, reservoirs, and irrigation systems, alongside natural processes like precipitation and snow melt. However, this increase may pose adverse effects, including terrestrial habitat loss and human displacement.

The surge in scrub land area from 393 sq. km in 1991 to 1488 sq. km in 2021 likely stems from agricultural land abandonment, overgrazing, and altered fire management practices. Similarly, the escalation in fallow land area from 42 sq. km in 1991 to 571 sq. km in 2021 may reflect changes in agricultural practices, like crop rotation and fallowing.

The modest rise in built-up land area from 73 sq. km in 1991 to 76 sq. km in 2021 signifies ongoing urbanization and industrialization in the region. Such developments could profoundly impact the environment and human populations, potentially escalating pollution, biodiversity loss, and altering land use patternsThe increase in wasteland area from 67 sq. km in 1991 to 18 sq. km in 2021 is puzzling and warrants further investigation. Similarly, the decrease in barren land area from 18 sq. km in 1991 to 45 sq. km in 2021 is also unclear and requires more research. In conclusion, the LULC changes in the IB watershed over the past three decades have been significant and complex. While some changes, such as the increase in deciduous broadleaf forest area, are positive, others, such as the decrease in cropland area and the increase in water bodies, may have negative impacts on the environment and human populations. Further research and monitoring are needed to fully understand the causes and implications of these changes and to develop effective strategies for managing and conserving the region's natural resources.

LULC Class	Area in 1991 (Km^2)	Percentage (%)	Area in 2001 (Km^2)	Percentage (%)	Area in 2011 (Km^2)	Percentage (%)	Area in 2021 (Km^2)	Percentage (%)	Change in area from 1991 -2021 (km2)	Change in area (%)
Cropland	7789	62.57	8051	64.6770566	7493	60.19	5932	47.65	1857	14.92
Deciduous Broad leaf Forest	3463	27.82	3314	26.6227506	3606	28.97	2119	17.02	1344	10.80
Water Bodies	209	1.68	210	1.68701799	213	1.71	774	6.22	-565	-4.54
Scrub land	393	3.16	295	2.36985861	488	3.92	1488	11.95	-1095	-8.80
Fallow Land	42	0.34	74	0.59447301	71	0.57	571	4.59	-529	37.41
Mixed Forest	387	3.11	366	3.10089974	431	3.46	1416	11.39	-1031	-8.28
Built-up Land	73	0.59	74	0.41773779	76	0.61	78	0.61	-3	-0.02
Wasteland	67	0.54	18	0.14460154	18	0.14	18	0.14	49	0.39
Barren Land	18	0.14	41	0.32937018	45	0.36	45	0.36	-27	-0.22
Plantations	6	0.05	6	0.04820051	6	0.05	6	0.05	0	0.00
Total	12447	100	12447	100	12447	100	12447	100		

Table 6. Area and Percentage change of different LULC classes in IB-Watershed from 1991 to 2021.

2. Conclusion

The study revealed that the study area has witnessed substantial changes in land use and cover between 1991 and 2021. While cropland and deciduous broadleaf forests remained dominant, their proportional area slightly diminished. Water bodies, scrub and fallow lands notably decreased, and mixed forests also saw a reduction, while built-up land remained stable. Wasteland and barren land areas decreased, and plantations remained unchanged. Urbanization, industrialization, agricultural expansion, and deforestation played pivotal roles in these changes, impacting biodiversity, water resources, soil quality, and climate. Thus, vigilant monitoring and management are imperative for sustainable development and conservation of natural resources, calling for well-crafted policies, sustainable land practices, and the utilization of advanced technologies like remote sensing and GIS..

Data availability: The data sets that supports the results of this study are present with in the article.

Conflict of Interest: There is no conflict of interest in this paper regarding publication.

Funding: Not applicable.

Ethical Approval: All the ethical standards were taken care of during this study.

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