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Research article

A Spatio-temporal analysis of land use land cover changes of dry tropical forest ecosystem of Chhattisgarh, India

Abstract

Land use changes have an adverse effect on biodiversity loss, rising temperatures, nutrition, ecological interruption, and economic growth, they have gained substantial attention on a global scale. Widespread human activity is a major cause of deforestation, which increases vulnerability to land deterioration and results in a major loss of native land cover. The present study was carried out in land use change detection analysis of dry tropical forest ecosystem at Barnowapara Wildlife Sanctuary, Chhattisgarh, India through the satellite remote sensing which is renowned for its diverse range of species and rich flora. This includes flora with a range of traits and significance in terms of medical usefulness. The results revealed that the LULC was classified in seven classes (164.45 km^2) over the past three decades, considerable forest and agricultural areas have been lost due to anthropogenic activities, with a significant portion of the remaining land experiencing varying degrees of degradation. The change detection during 2005-2023 in DMF (18.21%), SMF (14.39%), TF (12.92%) and WB (4.48%) was gradual decreased, whereas, OMF (33.16%), AG (6.51%) and HB in (10.33%) area was increased. In this study, forest vegetation was converted to open mixed forest, agricultural land, and habitations due to anthropogenic activities like illicit felling of forest, collection of fuel woods, medicinal plants, and NTFPs, and grazing and lopping by local peoples. The study concludes on land use changes in dry tropical forests, allowing for a deeper understanding of human and ecological dynamic and also recommended for policy and practice in managing land use in dry tropical ecosystems.

Keywords: LULCC, wildlife sanctuary, change detection matrix, remote sensing and geospatial technique

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Introduction

Land use and cover change (LULC) is a significant issue because of the growing interdependence of humans and environment.[1–3] Aldwaik and Pontius (2012) initially introduced the idea of LULC change intensity analysis, which estimates the magnitude and rate of change in land-cover classes over time intervals using cross-tabulation matrices.[4] This work uses intensity analysis to resolve methodological gaps in LULC investigations. LULC contributes in several ways to the preservation of water, prevention of erosion, and provision of sediment to coastal landforms. Loss of global biodiversity, increased soil erosion, and disruption of the hydrological cycle are among the threats posed by LULC alterations. The biogeochemical and energy balance cycles of the planet are altered by changes in LULC, which has an impact on land surface characteristics, ecosystem services, and climate.[5,6]

Land is the main natural capital used by humans for activities including social, economic, and ecological development. Human activity on Earth's surface is the most basic type of land usage. Land cover is the term used to describe the biophysical features and man-made structures of the Earth's surface, including different terrestrial ecosystems.[5,7–9] As long as there have been people, there have been changes in LULC.[10–12]

Understanding how land cover has changed over time is important for managing natural resources, sustainable development, urban planning, environmental research, and other social requirements.[13] Urbanization, industrialization, and the rising number of people relocating from rural to urban areas, especially in developing countries, have all contributed to the relevance of researching changes in land use/land cover.[14–16] In the past few years, scientists from various fields have concentrated on gaining a deeper comprehension of the reasons behind and effects of land use changes, as well as investigating the extent and future locations of land use changes.[17,18]

It has become essential to understand the consequences of the growing anthropogenic demand on ecosystems while planning development projects and developing land-use management strategies. While changes in land use are mostly caused by human activity, changes in land cover primarily relate to adjustments made to the planet's biophysical surface. The processes of land-use and land-cover changes (LULCC) are ongoing and caused by a variety of anthropogenic and natural sources.[19] Assessing the condition of natural resources, monitoring changes over time and space, and projecting future events are all made easier by the land-use and land-cover (LULC) study. Due to shifting environmental circumstances and increasing anthropogenic stresses, a global LULCC database is becoming increasingly important. The present study focuses on the land use change detection analysis of dry tropical forests in Barnowapara Wildlife Sanctuary using geospatial techniques.

Anthropogenic causes are primarily responsible for deteriorating and LULC changes in our native biodiversity and impact on structure, composition and vegetation cover in tropics, which in turn alarmingly enhance the emissions of GHGs in the atmosphere and contributing for global warming.[19,20] Carbon dioxide is one of the major culprit greenhouse gas, which dramatically increased from 280 ppm in preindustrial era to over 400 ppm levels in the present day context and predicted to further increase up to 560 ppm by 2050 (IPCC, 2018). The global warming is causing climate change by altering the temperature and rainfall patterns, which has severe impact on the structure, functioning and habitability of tropical ecosystems. Although, tropical forests are once recognized as important carbon sinks but many of these productive forest ecosystems are now becoming unproductive and acting as carbon sources due to rapid industrialization, encroachment, forest fires and habitat fragmentation.

A number of significant elements influencing LULC changes are rapid urbanization, inadequate drainage, infrastructure development, fires, logging, and demographic pressure.[2] Alterations in pastoral lands, altered wetlands, degraded soil, and forest transformations all have an effect on LULC alterations. Pre- and post-disaster scenarios are necessary in disaster-prone locations to map areas sensitive to forest degradation, buffer high-risk zones, and plan land use and loss compensation. Policies and planning can effectively incorporate measures to ensure sustainable land use, promote climate change, and foster sustainable development. Examples of international intervention frameworks that do this include the Intergovernmental Panel on Climate Change (IPCC), the Paris Agreement, and the Sustainable Development Goals (SDGs). Supporting these discussions requires assessing patterns in LULC change and future research and development planning directions.[2] One major problem that has an impact on both the global economy and human well-being is land degradation. It lowers worldwide economic output by a tenth and adversely impacts the living conditions of at least two fifths of the world's population.[21] Roughly 24% of the world's land area experienced land degradation between 1981 and 2003.[22] Land degradation gets worse as the population increases and the effects of climate change intensify.[3,12] Vegetation cover, soil condition, biological diversity, and physico-chemical characteristics of the soil are common indicators of land degradation.[22–24] The land degradation can be explored by evaluating various types of LULC, Soil health, plant diversity, SV indices using remote sensing and GIS techniques.[3,24]

Changes of forest cover or landscape fragmentation and habitat loss have currently emerged as two major ecological issue, posing a serious challenge for conservation of rapidly eroding biodiversity of tropical forest ecosystems.[25,26] Anthropogenic activities like logging, clearing, burning, along with expression of agriculture and rural settlements etc. have dramatically increased over the last couple of decades witnessed an extensive forest loss and enhanced fragmentation across the tropical landscapes.[27] Forest fragmentation is a progressive process of conversion of large sized undisturbed forests into small remnant patches which decline intact contiguous forest cover, increase forest edge and isolates remaining patches in a forested landscape.[28,29] Geospatial technology has proven to be very powerful tools to characterize and monitoring and mapping of structure, composition, species diversity and LULC pattern of the region. Proper determination, monitoring and mapping of species incidence in a respective forest region provides distributional pattern related to ecological factors and their significance.[16,30]

Material and Methods

Study area

Barnowapara Wildlife Sanctuary, a dry tropical forest environment served as the study site. The area of the Wildlife Sanctuary is 245 km2. It lies between longitudes 82°21' and 82°26' east and latitudes 21°20' and 21°28' north. There are three main seasons: rainy, winter, and summer, and the climate is tropical, dry, and humid. The study area's average annual rainfall ranges from 1200 to 1350 mm. The research area's average yearly temperature, which rises from March to May, is roughly 26.5 °C. The temperature reaches a high of over 41.8 °C in May and a low of under 12.7 °C in December. Three kinds of soils- Inceptisols, Alfisols, and Vertisols represent the wide variation in physical and chemical characteristics of the study area's soils (Soil Survey Staff 1960). The location map of the study area is depicted in Figure 1.

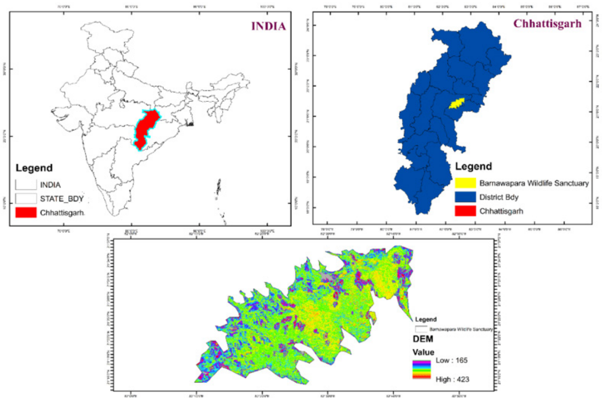

Figure 1 Layout map with elevation model of the Barnawapara wildlife sanctuary.

Data source

Landsat-5, 7, and 9 satellite images with a medium resolution were utilized between 1990 and 2023 to map the Land Use and Land Cover (LULC) and detect changes in Barnowapara Wildlife Sanctuary (Table 1). Free access to Landsat images was provided by satellite data on the USGS website (http://glovis.usgs.gov/). The acquired data's image analysis was done using ArcGIS 10.8 on a personal computer, while the Survey of India (SoI) toposheet provided the auxiliary data.

Table 1 Characteristics of the selected Satellite data

Data	Time	Resolution	Data source	Site
DEM	2023	30m	Bhuvan NRSC	https://bhuvan.nrsc.gov.in/
	1990	30m	Landsat-5 (March 1990)	(EarthExplorer - USGS)- https://earthexplorer.usgs.gov/
Land Cover	2005	30m	Landsat-7 (June 2005)	(EarthExplorer - USGS)- https://earthexplorer.usgs.gov/
	2023	10m	Landsat-9 (October 2023)	(EarthExplorer - USGS)- https://earthexplorer.usgs.gov/
Soil Properties	2022	-	-	Field Sampling
Climate Data	1990-2023	-	-	Data Access Viewer https://power.larc.nasa.gov/data-access-viewer/
Precipitation	1990-2023	-	30m	Data Access Viewer https://power.larc.nasa.gov/data-access-viewer/

Pre-processing and classification

The pre-processing methods framework is illustrated in Figure 2. With the SOI toposheets at a scale of 1:50000 eliminated geometric distortions, georeferencing the image to map registration is accomplished. The crucial method for analysing LULC change detection is followed by pre-processing chosen satellite data, which also maintains the distinctive structure needed to link the data. Using the ArcGIS 10.8 software to geo-referencing and mosaic collected data based on an area of interest (AoI). The Landsat satellite data's multiple as-sign spectral signatures were used to categorize the images according to different land uses. The following various spectral bands and mean spectral values (DN) of different LU classes are used to create LULC classes as represented in Table 3 and Figure 4, respectively. The maximum likelihood algorithm (MLA) potential process was used to classify images of LULC changes in order to create the LULCC map using geospatial data.

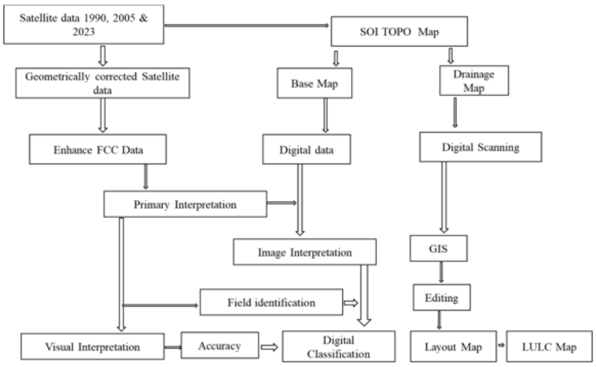

Figure 2 Methodology for the generation of thematic maps.

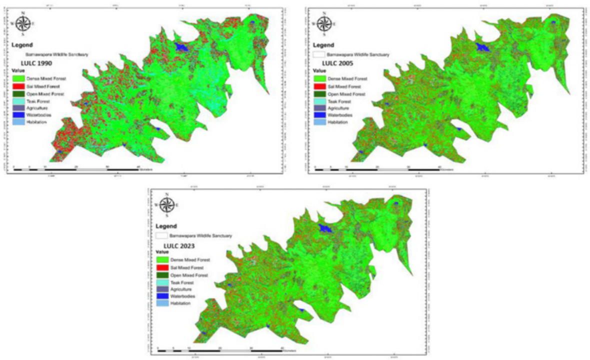

Figure 4 Classified map of 1990, 2005 & 2023 in Barnawapara wildlife Sanctuary.

Analysis of LULC and change detection

For the classified map, LULC and change detection analysis are conducted using Landsat-4, 5, 7 & 9 satellite imagery from 1990 to 2023. To generate the transformation on a pixel basis, a comparison was made with a pixel-based technique to boost the efficiency of the gains for all categories. LULCC and Change matrix analysis (1990, 2005, and 2023) determined as per methodology used by[21] and satellite images created under ArcGIS 10.8 environ.[16,31]

Results and discussion

LULC Pattern and vegetation mapping

Standard false color composite (SFCC) maps, as shown in Figure 3, were employed in the MLA and supervised classification to classify the land cover in current study. It shows decadal fluctuations in the investigated area during a 33-year period. The seven LC and vegetation classifications that were defined were water bodies (WB), agricultural (AG), habitation (HB), open mixed forest (OMF), teak forest (TF), and sal mixed forest (SMF). 164.45 km^2 make up the whole research area. The statistics on the spatial extent of the different forest types classified are shown in Table 3.

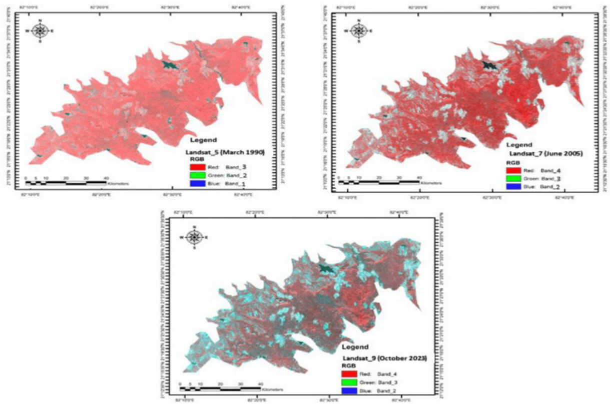

Figure 3 False colour composite (FCC) map of the study area: 1990, 2005 & 2023.

LULC pattern 1990

LULC study in 1990 was covered in different classes. The DMF was in 27.86% followed by TF 23.08%, OMF 20.21%, SMF 14.41%, AG 10.26%, HB 2.97% and WB 1.22% area. In LULC of 1990, DMF covered the highest percent of the total area, while the lowest percent was covered in WB.

LULC pattern 2005

In the year 2005 LULC pattern was observed in different classes. The DMF covered 37.25 km2, SMF covered 20.93 km2, OMF covered 40.87 km2, TF covered 34.51 km2, AG covered 19.32 km2, HB covered 9.63 km2 and WB covered in small patches 1.94 km^2.

LULC pattern 2023

The results show that the LULC pattern in 2023 was classified into different classes. The DMF, SMF, OMF, TF, AG, HB and WB in 33.67 km2 (20.47%), 18.10 km2 (11.01), 47.39 km2 (28.82%), 31.97 km2 (19.44%), 20.60 km2 (12.53%), 11.66 km2 (7.09%) and 1.06 km2 (0.64%), respectively. The greatest area covered in 2023 was OMF, which was followed by DMF, TF, AG, SMF, and HB. WB had the lowest area covered. The other land use (HB, WB) was 12.72 km2 (7.73%), and the land cover area of green vegetation (containing various forms of agricultural and forest) was 151.73 km2 (92.27%) (Table 2).

Table 2 Summary of accuracy assessment

Class Name	Accuracy (%) 1990	Accuracy (%) 2005	Accuracy (%) 2023
Dense Mixed Forest	88.32	90.2	91.25
Sal Mixed Forest	89.21	88.93	89.84
Open Mixed Forest	90.71	93.91	94.25
Teak Forest	82.21	92.79	93.23
Agriculture	92.32	89.56	95.17
Habitation	93.27	94.38	98.52
Water Bodies	98.29	98.28	100

Accuracy assessment of 1990, 2005 and 2023

The results revealed that the accuracy of different forest type was ranged 82.21-98.29%, 88.93-98.28% and 89.84-100% in years 1990, 2005 and 2023, respectively (Table 3).

Table 3 Land use land cover pattern in Barnawapara wildlife sanctuary between 1990 to 2023

Class Name	Area (km²) 1990	Area (%) 1990	Area (km²) 2005	Area (%) 2005	Area (km²) 2023	Area (%) 2023
Dense Mixed Forest	45.81	27.86	37.25	22.65	33.67	20.47
Sal Mixed Forest	23.7	14.41	20.93	12.73	18.1	11.01
Open Mixed Forest	33.23	20.21	40.87	24.85	47.39	28.82
Teak Forest	37.95	23.08	34.51	20.99	31.97	19.44
Agriculture	16.87	10.26	19.32	11.75	20.6	12.53
Habitation	4.88	2.97	9.63	5.86	11.66	7.09
Water Bodies	2.01	1.22	1.94	1.18	1.06	0.64
Total	164.45	100	164.45	100	164.45	100.00

Current study on LULCC was analyzed at Baranawapara Wildlife Sanctuary. A similar type of work in different scientists in different areas. The study was conducted in AABR, Central India by[31] results revealed that the LULC was seven land use classes were delineated and the accuracy was recorded in 81.43-100%. Examined how the land cover categories in the Brazilian tropical rainforest were categorized: primary forest, bare soil, agriculture, pastures, and forest regrowth from 1 to 23 years old.[32] The LULC investigation and estimates covered the following six classes: agriculture, coniferous, broad-leaf, mixed forest, settlement, and water. The most productive mixed woods in Turkey's Western Black Sea Region, Bartın Province, were found to have these classifications.[33]

This study examines the changes in land-use and land-cover (LULC) in the Lakshmibaur-Nalair Haor area using Landsat multispectral images between 1989 and 2019.[34] Five types of LULC were discovered by the study: towns, cultivated and rural settlements, forests, grasslands, and a small artificial pond dryland watershed of the Hirmi agro-ecosystem in Ethiopia's northern highlands.[35] A similar type of work was conducted in the southeastern part of Andhra Pradesh state and the northeastern part of the Ananthapur district.[36] In northern China, the detection accuracy was 72–83% and the overall accuracy was 84–96%.[37] The classification of accuracy for different classes ranged from 71.23 to 100% in Barnawapara Sanctuary, India.[16,25,38] The research was carried out in AABR. Eight land cover types- DMF, SMF, OMF, TP, BB, AG, HB, and WB, are distinguished based on vegetation. According to,[29] the accuracy of classification for various land use classes varied from 76.69 to 99.07 percent. Open mixed forest, degraded mixed forest, young teak plantation, dense mixed forest, teak forest, sal mixed forest, habitation, grasslands, and water bodies are the nine types of land cover that make up vegetation. The categorization accuracy ranged from 71.23% to 100% for several land-use classes in the Raipur region of Chhattisgarh, India's Barnawapara Sanctuary.[29] Using various classification techniques, multiple employees examined vegetation and land use using satellite remote sensing in a variety of scenarios.[39]

Change detection analysis

The results of change detection are illustrated in Figure 5 & 6 a, b presented in Table 4.

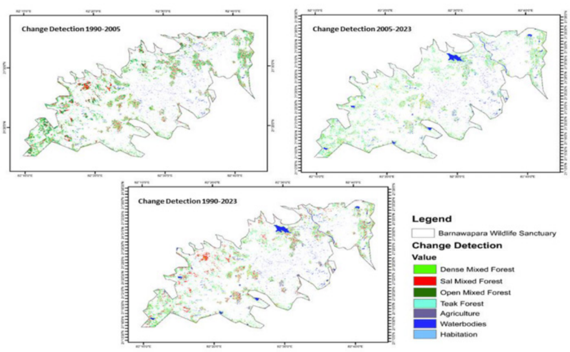

Figure 5 Change detection map of 1990, 2005, & 2023 in Barnawapara wildlife Sanctuary.

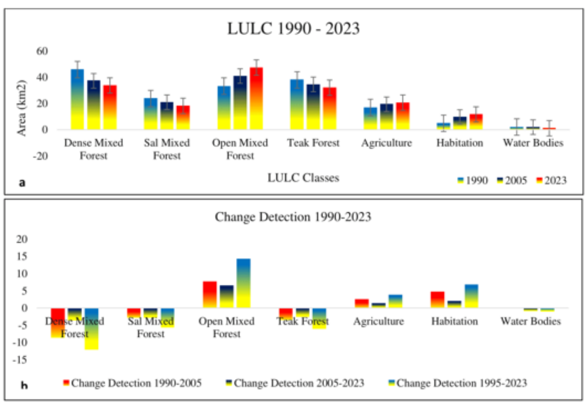

Figure 6 LULC and change detection maps of 1990 to 2023 images (a) and (b).

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Table 4 Analysis of change detection in Barnawapara wildlife sanctuary between 1990 to 2023

Class Name	Change Detection 1990 - 2005	Change Detection 2005 - 2023	Change Detection 1990 - 2023
Dense Mixed Forest	-8.56	-3.58	-12.14
Sal Mixed Forest	-2.77	-2.83	-5.6
Open Mixed Forest	7.64	6.52	14.16
Teak Forest	-3.44	-2.54	-5.98
Agriculture	2.45	1.28	3.73
Habitation	4.75	2.03	6.78
Water Bodies	-0.07	-0.88	-0.95

Change detection in 1990-2005

The change detection in the years 1990 to 2005 in DMF, SMF, TF, and WB was 8.56 km^2, 2.77 km^2, 3.44 km^2 and 0.07 km^2, respectively decreased whereas, OMF, AG, and HB in 7.64 km^2, 2.45 km^2, and 4.75km^2, respectively area was increased.

Change detection in 2005-2023

Change detection during 2005-2023, 3.58 km^2 in DMF, 2.83 km2 (3.39%) in SMF, 2.54 km^2 in TF and 0.88 km^2 in WB was a gradual decrease, whereas, 6.52 km^2 in OMF, 1.28 km^2 in AG and 2.03 km^2 in HB was increased.

Change detection in 1990-2023

Results show that the change detection during 1990-2023 in DMF was 12.14 km^2, SMF in 5.6 km2, TF in 2.54 km^2 and WB in 0.95 km^2) was gradual decreased, whereas, OMF in 14.16 km^2, AG in 3.73 km^2 (6.51%) and HB in 6.78 km^2 area was increased. The present observed in dense mixed forest, sal mixed forest, teak forest, and water bodies are converted to open mixed forest, agriculture, and habitations. A similar type of result was observed in different scientists in different areas. The similar results observed in[31] AABR in Central India. In the years 2001-2021 land use change of forest areas viz; DMF, SMF, BB and TP which was converted to OMF, AG and Habitation areas. The study was conducted in the Kathmandu district for a period of 20 years (from 1990 to 2010), and the results show that lost 9.28% of its forests, 9.80% of its agricultural land, and 77% of its water bodies.[40] Because of the fast urbanization in Guangdong province, China's south, agricultural land and forests have continued to shrink while built-up areas have risen 6.4 times between 1988 and 2015, according to a statistical analysis of LULC trends.[41] Examined the LULC change in the greater Cairo (GC) peri-urban area (PUA) using two Landsat photos from 2010 and 2018. Using TerrSet software, the spatial trends of LULC change and representations of the gains and losses in LULC were examined.[42]

Anthropogenic activities such as slash and burn, overgrazing, overexploitation of MAPs in the ground and underground vegetation, encroachment, etc., have negatively impacted the environment. Studying the LULC change in AABR from 2008 to 2018, we were able to identify significant changes that transpired over the 10-year period. These changes included the conversion of dense and sal mixed forest covers to open mixed forest and agricultural land. In addition to putting tremendous strain on biological resources, permanent structure construction, mining, urbanization, and the water crises all destroy flora and fauna habitats.[30]

In the study which examined research on land use and land cover changes (LULC) conducted between 1990 and 2023. The seven LULC classes DMF, SMF, BB, TP, WB, OMF and BB areas were among the land categories examined in the study. The findings revealed a decrease in closed forests and an increase in croplands and mixed vegetation and open forests. Significant variations in the gross change rates between the two time periods were also discovered by the various investigation globally.[43–46] The growth of croplands and mixed vegetation, as well as open forests, followed the loss of closed forests.[47–49] This pattern is in line with other research, including investigations conducted in other part of the World.[50–52] A number of causes, including waning efforts to conserve forests, quick changes in the socioeconomic landscape, and institutional alterations, are responsible for the transformation of closed canopy forests into open canopy forests. Change is primarily driven by livelihood activities like agricultural expansion and settlement.[53–54]

Conclusions

This study aims to suggest topics for future development and planning of Land Use and Land Cover Change (LULC) studies by reviewing the scientific research history and data advancements from 1990 to 2023. It emphasizes that the main focus of LULC research is remote sensing, and the main technique for addressing environmental concerns is maximum likelihood classification. The detection of land use change in the dry tropical forest environment of Barnowapara Wildlife Sanctuary is the main objective of the current investigation. Seven categories- DMF, SMF, OMF, TF, AG, HB, and WB, were used to categorize the land use and land cover pattern. Study region DMF, SMF, TF, and WB showed a progressive decline in change detection, while OMF, AG, and HB showed an increase. The research area's forest vegetation was transformed into open mixed forest, agricultural land, and habitations as a result of anthropologic activities such as illicit forest logging, fuel wood collecting, NTFPs, medicinal plant collection, grazing, and lopping. According to the current finding suggestions may stop environmental degradation by supporting policies related to climate change, conservation, and afforestation. Addressing land use cover change in dry tropical forests of Barnowpara Wildlife Sanctuary, Raipur Forest Division requires a multifaceted approach that considers ecological, social, and economic factors. By implementing sustainable practices and effective conservation strategies, it is possible to mitigate the adverse effects of land use change and preserve these vital ecosystems for future generations.

Acknowledgments

Credit authorship contribution statement: DKP: contributed to data collection, methodology and software provisioning. JL: contributed to data collection, methodology and formal analysis and editing. TKT: contributed to conceptualization, supervision, and writing (preparing original draft, reviewing, and editing). All authors have read and agreed to the final version of the manuscript.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in the present paper.

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