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Analyzing the Impact of Urban Expansion on Land Use, Land Cover, and Surface Water: A Case Study of Pal Bichala Lake

Rohini Yadawar[1], Dr. Kh. Moirangleima[2]

[1]Research Scholar, Department of Geography, School of Earth Sciences, Banasthali Vidyapith Rajasthan-304022, India
Corresponding Author Email: rs.rohini27@gmail.com
[2.]Assistant Professor, Department of Geography, School of Earth Sciences, Banasthali Vidyapith Rajasthan-304022, India
Email: moirangleima@gmail.com

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Abstract

Over the past few decades, changes in land use and land cover have presented considerable ecological challenges around the world, affecting significantly important ecosystem services. This research analyzes the patterns of changes in land use and land cover (LULC) around the Pal Bichala Lake located in Ajmer district of Rajasthan. The lake is of paramount importance as it serves as a water source to the locals. Unfortunately, the lake's ecological balance is under serious threat due to excessive human activities in the nearby areas. The paper seeks to evaluate the LULC alterations and the impact of urban development on the condition of Pal Bichala Lake. The multi-temporal satellite imagery from Landsat 4, 5 (1991, 2001, and 2011 Years) and Landsat 8 (2023 Years) are used to prepare the LULC maps using a maximum likelihood algorithm. The analysis comprises the characterization of five classes, Agricultural land, Water Bodies, Barren Land, Built-Up, and Vegetation. The findings indicate that Agricultural land, Water Bodies specially Pal Bichala Lake, and Vegetation have all experienced a decrease in extent, shifting from 231.362 Ha to 165.616 Ha, 2.72 Ha to 1.33 Ha, and 28.2975 Ha to 10.8641 Ha, respectively, over the period from 1991 to 2023.A noteworthy increase in Built Up areas from 92.2981 Ha in 1991 to 165.529 Ha in 2023 underscores urbanization trends and infrastructural development. The transformation of Bare Ground from 5.9895 Ha in 1991 to 17.6984 Ha could indicate alterations in land degradation patterns.

Our analysis shows that the expansion of built-up areas has significantly contributed to the deterioration of Pal Bhichala Lake's ecological condition. As urbanization and the development of infrastructure continued in the surrounding areas, the Lake is now polluted by solid waste. This study may help in strategic planning and policy formation targeted at reducing pollution, protecting water quality, and safeguarding the natural balance of the lake.

Key Words: LULC, Urban Sprawl, Landsat, Surface Water Bodies, Pal Bichala Lake.

1.1 Introduction

The United Nations' World Population Report reveals a growing trend of population growth being concentrated in developing nations, underscoring the importance of addressing disparities and fostering a fair shift toward a sustainable paradigm. The World Bank states that over 50% of the global population now resides in urban areas, which are marked by population expansion and the continual growth of built-up regions. Over the last quarter-century, the most substantial population growth has taken place in developing countries, primarily in Oceania and Asia, which collectively house approximately 1.2 billion individuals. Africa, with a population of 700 million, has also experienced significant growth during this period. As per the United Nations' estimates published on their website, the global population surpassed the 8 billion milestone on November 15, 2022.

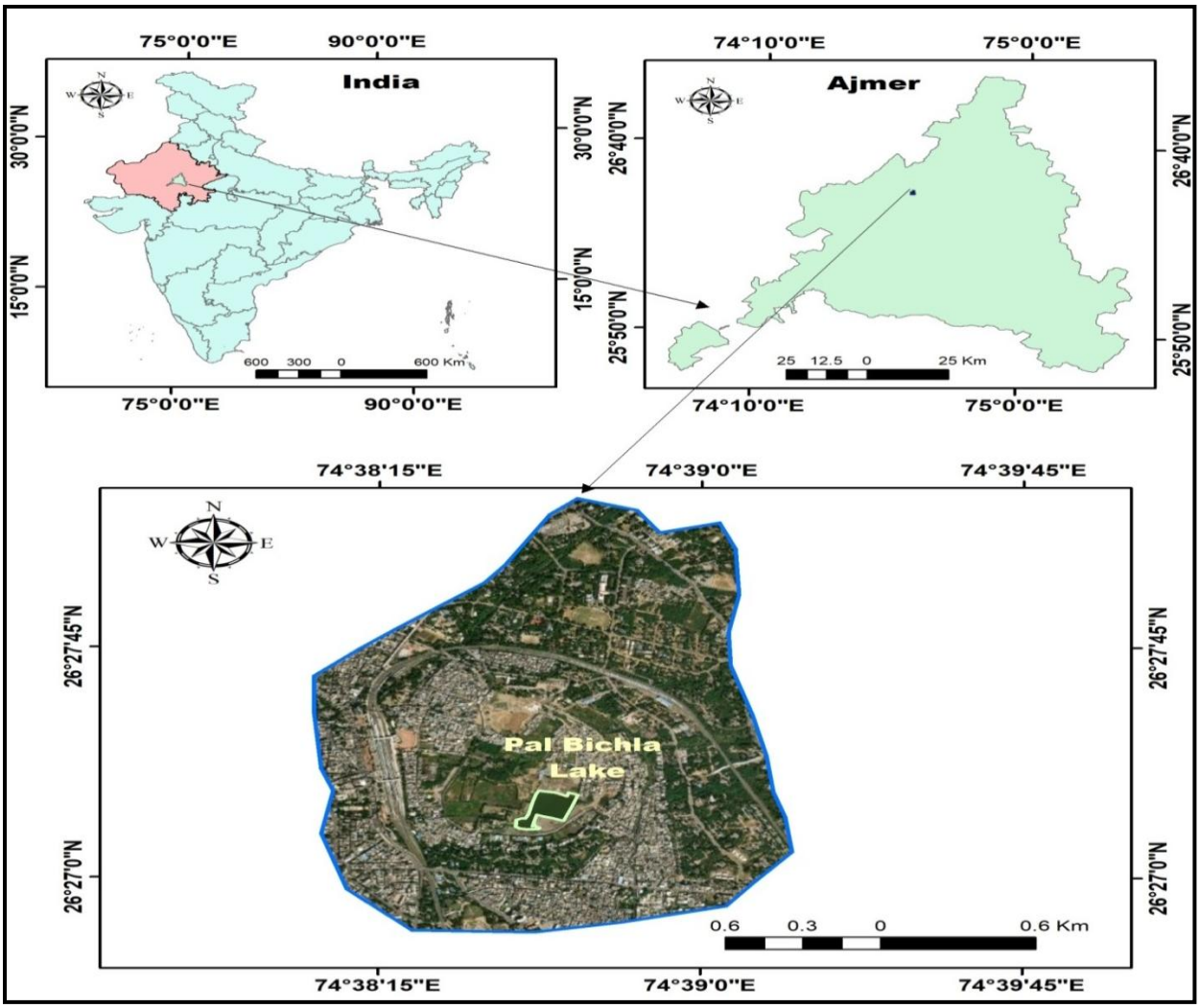
In the past 25 years, the world's population has increased by 2.1 billion people, accounting for roughly one-third of the total growth. It is projected to expand by approximately one-fifth, reaching an estimated 10 billion by 2050.In context to this when we use the term Urban sprawling it indicates to the extensive expansion of metropolitan areas, mostly characterized by the growth of built-up spaces over low-density regions. It entails the haphazard and uncontrolled development of fragmented residential and commercial structures, lacking proper planning and management. Based on the 2011 Census, India currently has an urban population of approximately 32 percent. However, the process of urbanization has not been similar across the different states of the country. Some states, such as Maharashtra, Tamil Nadu, and Gujarat, have experienced rapid urban growth rates, while the northern states have undergone a slower transition towards urbanization. Among these states, Goa stands out as the most urbanized one.The Economic Review of Rajasthan 2019-20 reveals a gradual rise in the percentage of urban population in the state, which has grown from 16.28 percent in 1961 to 23.29 percent in 1971, and further to 24.87 percent in 2011. In terms of the urbanized population in 2011, males accounted for 52.25 percent, while females represented 47.74 percent.

As per the Census 2011, the Ajmer Municipal Corporation (AMC) ranks as the fifth most populous in Rajasthan. In the district of Ajmer, the rural population accounted for 59.9%, while the urban population constituted 40.1%. In contrast, Rajasthan as a whole had a rural population percentage of 75.1% and an urban population percentage of 24.9%. Between 1991 and 2000, Ajmer city experienced a significant mean decadal growth rate of 20.5%, which decreased to 13.4% between 2001 and 2011. It is worth noting that the substantial growth between 1991 and 2001 was primarily due to the expansion of the municipal boundaries of the Ajmer Municipal Corporation. In 2013, the Town Planning Department conducted a land use survey, revealing a total urban area of 75,752 hectares, which is projected to increase to 217,888 hectares by the year 2033.

1.2 Study Area

The present study is specifically focused on surface water body of Ajmer city named as Pal Bichala. The construction of the pond was attributed to King Vigraharaj, also known as Bisaldev, who was the son of King Arnoraj, the founder of Ajmer. Situated in the middle of the pond was a temple dedicated to Lord Shiva. Ruler Jahangir also made efforts to repair its boundaries. In the past, this pond served as a supply of water for until the time of Independence. However, since 1990, the government has neglected its maintenance, leading to rampant encroachment by land mafias. The surrounding land has been used as a dumping site for solid waste, resulting in the shrinking of the overall pond area. Surprisingly, the city's master plan does not include any protection or conservation policies for the preservation of this important water body.

Map 01: Showing Location of Study Area



Source: Map created using Google Earth. (2022). Location Map of Pal Bichala Lake, Ajmer, Rajasthan, India. Google LLC. Retrieved from https://earth.google.com

1.3 OBJECTIVES

- To detect and quantify the LULC of Pal Bichla Lake using satellite imagery.
- To identified LULC change during 1991 to 2023.
- To acquire statistical data on land and evaluate changes in the water body area.
- To analyses the driving forces of land use and land cover change and urban expansion.

1.4 METHODS AND PROCEDURE

Methodology is conceptual analysis of the methods used in a subject of study. It is the theoretical experiment of a set of procedures and ideas associated to a field of information. LULC changes in study area was calculated using LULC image classification technique to identify the transformation of area and classify it into different classes to determine different land-use. Present situation was studied carefully by field visits and accordingly Land-use and Land-cover classification was created.

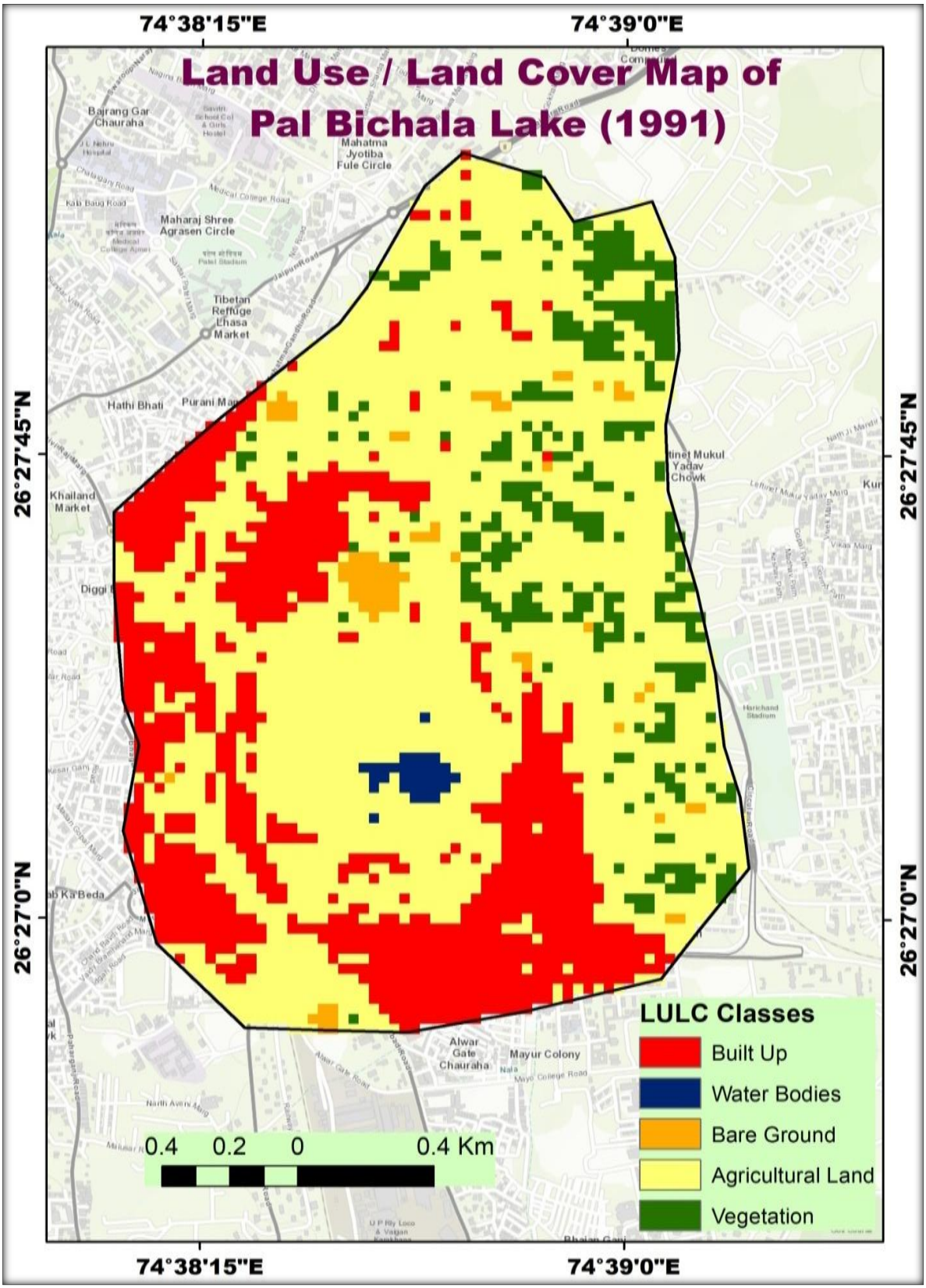
Land use land cover is very important for land surface change analysis. The Landsat data has been used for preparing land use land cover map. First image preprocessing steps that were applied were radiometric correction that included conversion of image digital number to at sensor radiance of conversion of sensor radiance value to top of atmospheric reflection and haze reduction.

The Landsat data was taken from the USGS earth explorer, after that layering of data was done, then subsets were prepared on the data based on area of interest, and performed the supervised classification assessment of the data and made several categories namely vegetation, water body, Agriculture, Bare land, Built-up. Then the area was calculated of all categories using raster calculate in ArcGIS software.

1.5 RESULTS AND DISSCUSSION

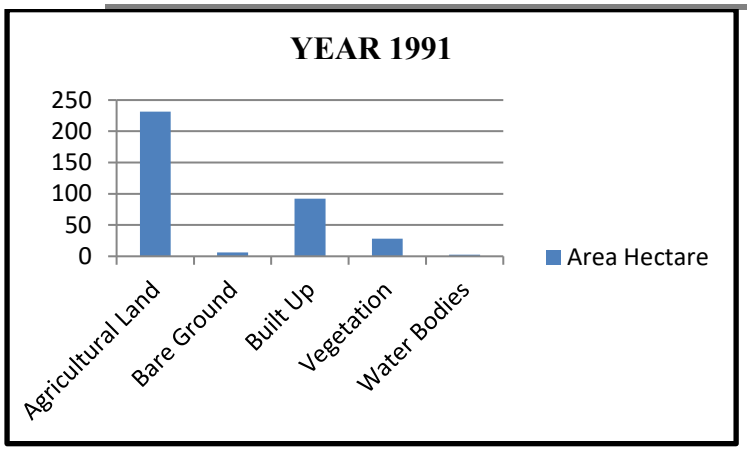
This research successfully shows the usefulness of change detection methods to land use and land cover change using remote sensing data. The study demonstrates that Pal Bichala Lake is an area of the largest change. The analysis also identifies certain changes in the vegetation, built-up areas, and water bodies. The study's overall accuracy, which was 90%, is satisfactory and the Kappa coefficient is closer to one. The change detection analysis is advantageous to describe changes observed over each land use category. There have been significant changes in built-up areas with vegetation and agricultural land over the past decade. A ground truth traverse and supervised categorization of Landsat pictures have produced an overall accuracy of the image interpretation classes. The normalized difference vegetation index method with various threshold values has been used to extract features. A useful tool for describing the changes seen in each land use category is the change detection analysis. There were significant changes in both the built-up and agricultural land throughout the course of a decade.

Map 02: LULC Map of Pal Bichala Lake (1991)



Source: LULC Map of Pal Bichala Lake (1991) created using ArcGIS Desktop, version 10.8 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA), with data sourced from the United States Geological Survey (USGS, 1991).

Graph 1 and Table 1 showing the classification of land use and land cover area per hectare for year 1991



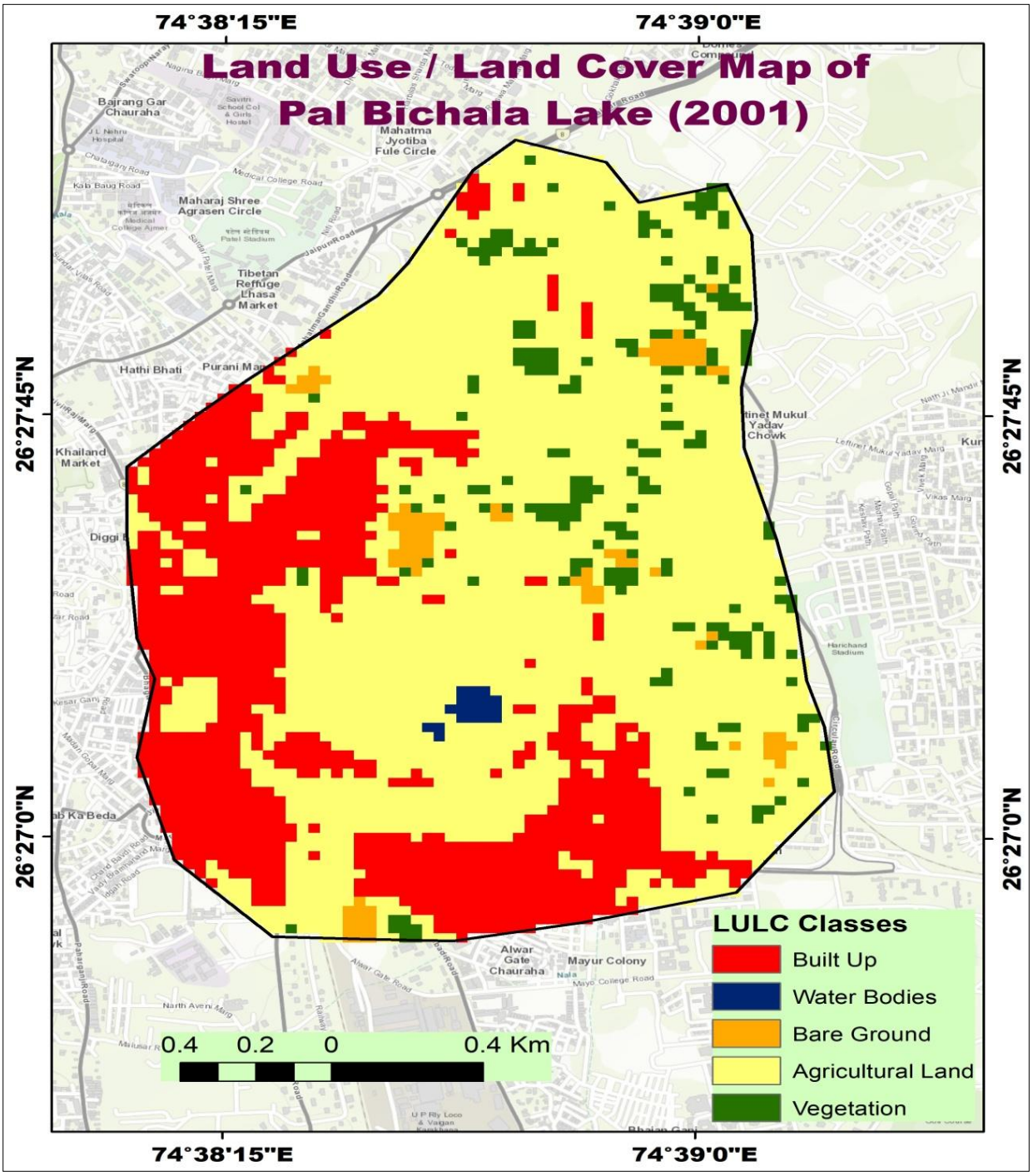
1991	
Class name	**Area Hectare**
Agricultural Land	231.362
Bare Ground	5.9895
Built Up	92.2981
Vegetation	28.2975
Water Bodies	2.72471
Total	360.67181

Source: Research Work Analysis

In 1991, the land use around Pal Bichala Lake, covering 360.67 hectares, was primarily agricultural, with 64% of the area (231.36 hectares) used for farming. This highlights the importance of the lake for irrigation. Bare ground accounted for 1.66% (5.99 hectares), indicating open land that could be susceptible to erosion or development. Built-up areas made up 25.6% (92.30 hectares), reflecting growing urbanization around the lake, which could impact the local ecosystem and water quality. Vegetation covered 7.85% (28.30 hectares), showing limited green cover and the need for conservation. The lake itself, along with other water bodies, occupied just 0.75% (2.72 hectares), pointing to its small size in relation to surrounding land uses. Overall, the map reflects a shift towards agriculture and urbanization, with a need for careful management to protect the lake and its environment.

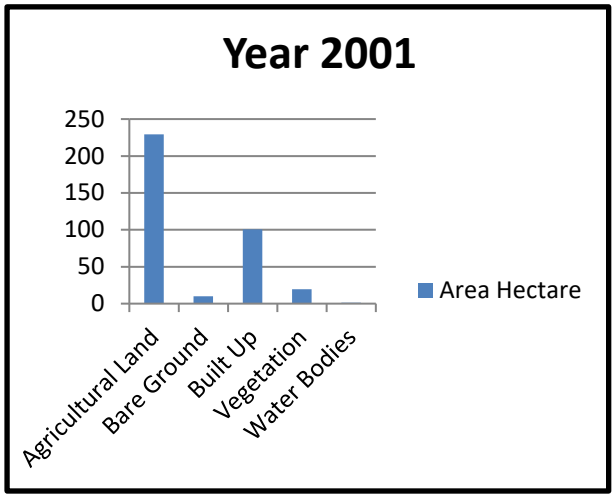
In 2001, the land use around Pal Bichala Lake, covering a total of 360.67 hectares, continued to be dominated by agriculture, though it slightly decreased to 229.50 hectares (63.7%) from the previous year. This still emphasizes the lake's role in supporting agricultural activities. Bare ground increased to 9.87 hectares (2.7%), suggesting more open or unused land that could be prone to erosion or future development. Built-up areas grew to 100.34 hectares (27.8%), showing further urban expansion around the lake, which could contribute to environmental stress and affect the surrounding ecosystem. Vegetation, covering 19.43 hectares (5.4%), showed a slight increase, yet it still represents a relatively small portion of the area, indicating that natural green cover remains limited. Water bodies, including the lake, shrank to 1.51 hectares (0.4%), highlighting a further reduction in the lake's size. Overall, the 2001 map reflects continued agricultural use, growing urbanization, and a slight decrease in the lake's water body area, signaling the need for more effective management to balance development and conservation around the lake.

Map 03: LULC Map of Pal Bichala Lake (2001)



Source: LULC Map of Pal Bichala Lake (2001) created using ArcGIS Desktop, version 10.8 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA), with data sourced from the United States Geological Survey (USGS)

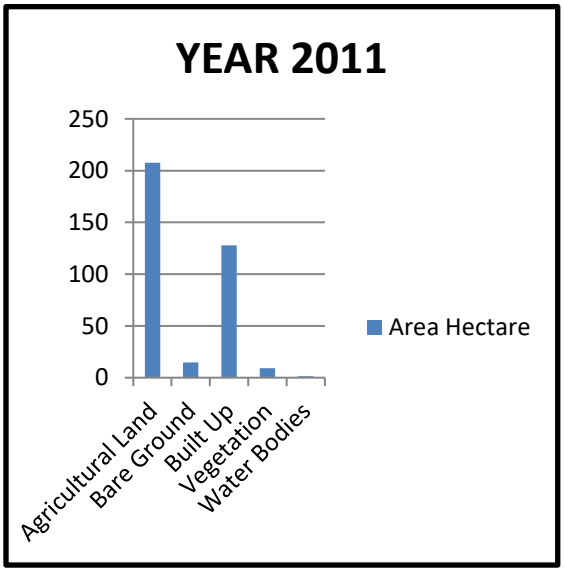
Graph 2 and Table 2 showing the classification of land use and land cover area per hectare for year 2001



2001	
Class name	**Area Hectare**
Agricultural Land	229.503
Bare Ground	9.87021
Built Up	100.341
Vegetation	19.4317
Water Bodies	1.50503
Total	360.6718

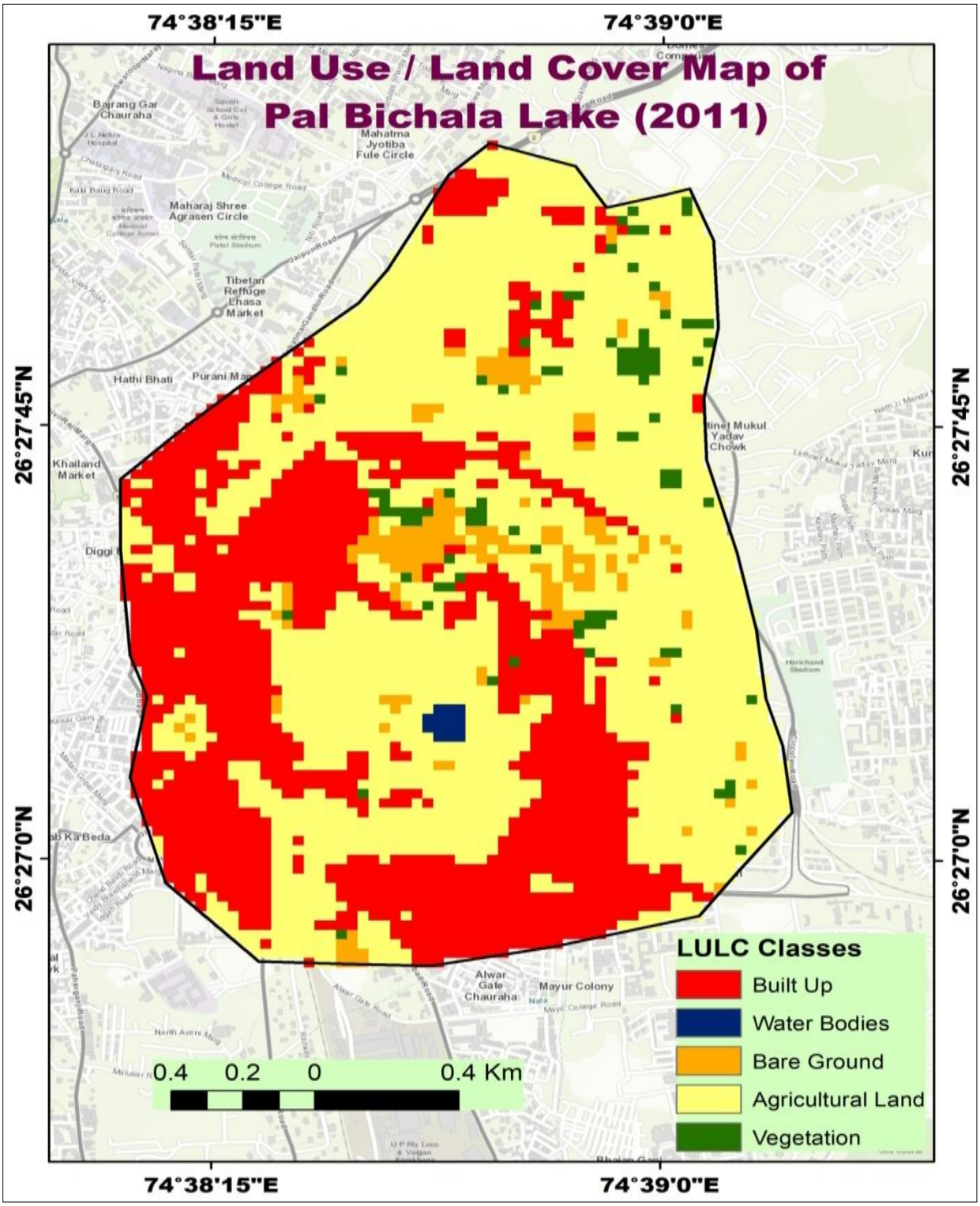
significant shifts in (57.6%), remains water for farming. built-up areas now occupying 127.76 hectares (35.4%), putting additional pressure on the environment and water quality. Bare ground has grown to 14.73 hectares (4.1%), likely due to land development or fallow areas. Vegetation has sharply decreased to 9.02 hectares (2.5%), signaling a worrying loss of green cover, which could harm local biodiversity. Water bodies, including the lake, have reduced to just 1.41 hectares (0.4%), potentially due to encroachment and sedimentation. These changes emphasize the increasing stress on the region's ecological balance and the need for sustainable management.

Graph 3 and Table 3 showing the classification of land use and land cover area per hectare for year 2011



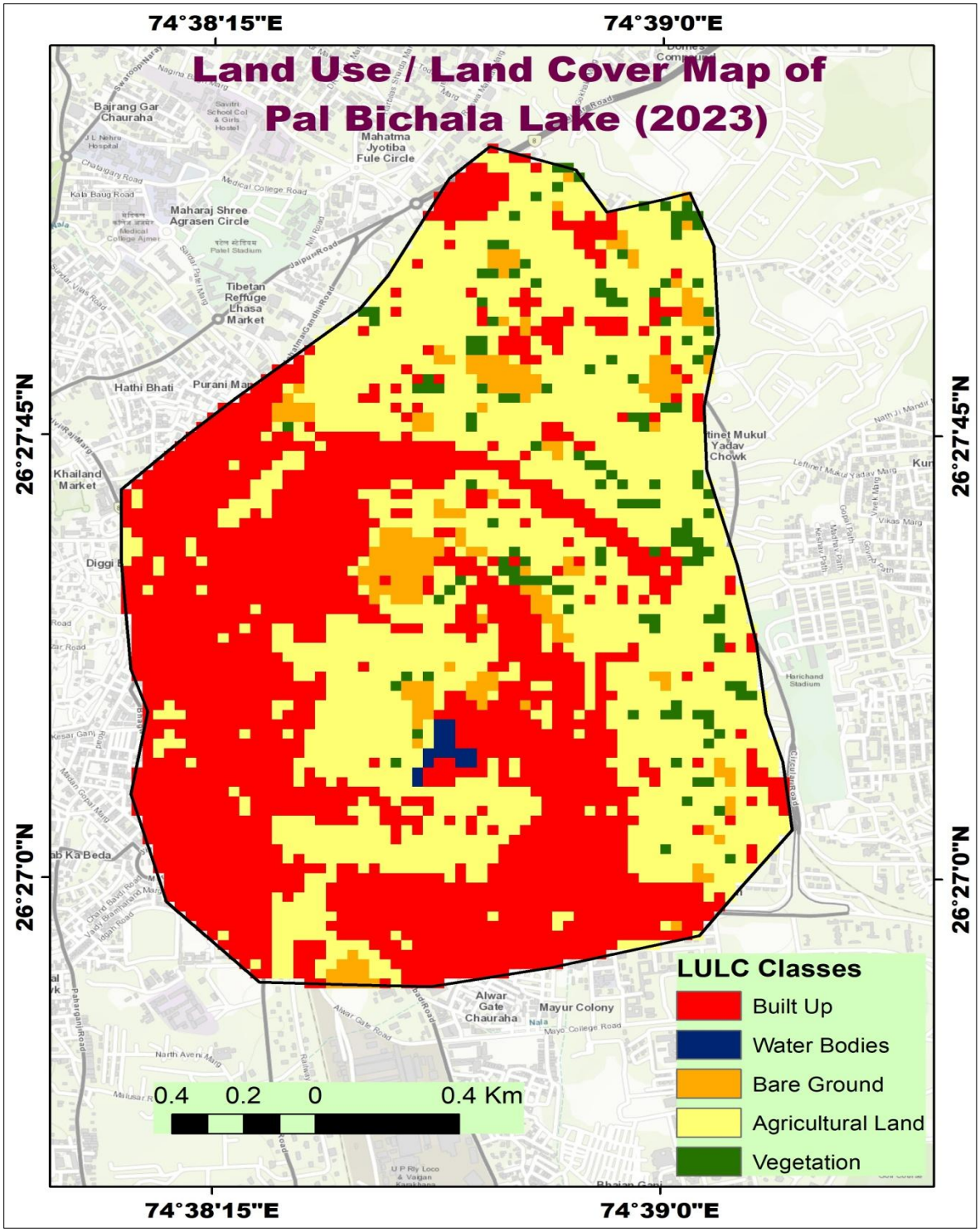
2011	
Class name	**Area Hectare**
Agricultural Land	207.628
Bare Ground	14.7346
Built Up	127.759
Vegetation	9.02311
Water Bodies	1.41131
Total	360.67181

Map 04: LULC Map of Pal Bichala Lake (2011)



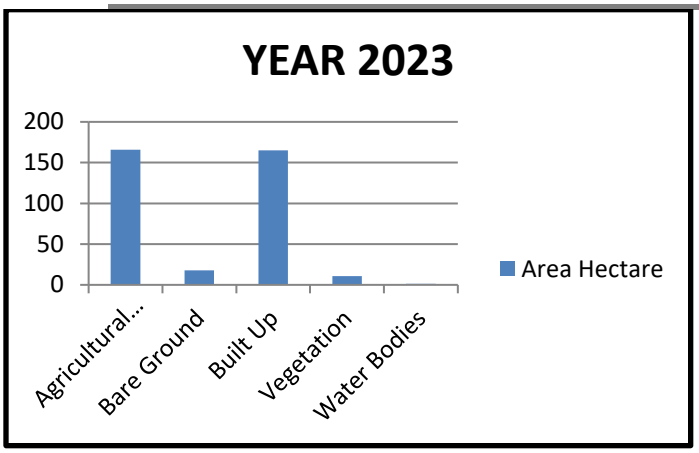
Source: LULC Map of Pal Bichala Lake (2011) created using ArcGIS Desktop, version 10.8 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA), with data sourced from the United States Geological Survey (USGS)

Map 05: LULC Map of Pal Bichala Lake (2023)



Source: LULC Map of Pal Bichala Lake (2023) created using ArcGIS Desktop, version 10.8 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA), with data sourced from the United States Geological Survey (USGS)

Graph 4 and Table 4 showing the classification of land use and land cover area per hectare for year 2021



2023	
Class name	**Area Hectare**
Agricultural Land	165.642
Bare Ground	17.6984
Built Up	165.086
Vegetation	10.8641
Water Bodies	1.33996
Total	360.6305

Source: Research Work Analysis

1.6 Land use changes

The rate of land use change in Pal Bichala Lake is shown in Figure 1991 to 2023. The analysis of land use dynamics over the two distinct time periods, 2001-2010 and 2010-2020, revealed notable fluctuations in various land use categories. The rates of change, expressed as percentages, provide insights into the shifts within each category.

Table 5: Showing the observed changes for each land use category

Difference in %1991-2001	
Class name	**1991-2001 Area % Change**
Agricultural Land	-0.51
Bare Ground	1.07
Built Up	2.22
Vegetation	-2.45
Water Bodies	-0.33
Difference in % 2011-2023	
Class name	**2011-2023 Area % Change**
Agricultural Land	-11.64
Bare Ground	0.82
Built Up	10.34
Vegetation	0.51
Water Bodies	-0.019

Source: Research Work Analysis

1.6.1 Agriculture

The category of Agriculture exhibited a decrease in its rate of change over both time periods. From 1991 to 2001, there was a decrease in Agriculture of -0.51%, indicating a slight reduction in agricultural land. Similarly, from 2011 to 2023, the increase was -11.64%, suggesting a continued decline in agricultural land expansion.

1.6.2 Built-up

The Built-up category experienced consistent growth in its rate of change. In the first decade 1991-2001, there was an increase of 2.22%, indicating a moderate increment in urbanization and built-up areas. This growth escalated further during the second decade 2011-2023, with a rate of change of 10.34%, highlighting an intensified urban expansion.

1.6.3 Bare Land

Fallow Land exhibited varying trends. During the initial decade 1991-2001, the rate of change was 1.07%, signifying an increase in fallow land. However, this trend reversed in the subsequent decade 2011-2023 with a decrease of 0.82%, suggesting a reduction in fallow land areas.

1.6.4 Vegetation

Vegetation experienced a downward trend over both time periods. From 1991 to 2001, the rate of change was -2.45%, highlighting a decrease in vegetation cover. This trend persisted, albeit at a slower pace, during the period from 2011 to 2023, with a decrease of 0.51%.

1.6.5 Water Body

The Water Body category demonstrated mixed patterns in its rate of change. In the first decade 1991-2001, there was a slight decrease of -0.33%. However, the subsequent decade 2011-2023 witnessed a reversal in this trend, with a rate of change of -0.019%, suggesting a modest increase in water bodies.

1.7 Accuracy Assessment

Accuracy assessment values the performance of the classifiers. Accuracy assessment and kappa coefficient are common measurement use to exhibit the utility of the classification (2001-2020).

Accuracy Assessment Formula:

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixel(diagonal)}}{\text{total number of referance pixels number}} \times 100$$

Time Period	Kappa Coefficient	Overall Accuracy
1991	**83%**	**84%**
2001	**81%**	**82%**
2011	**80%**	**88%**
2023	**81%**	**90%**

Source: Research Work Analysis

This study area accuracy assessment of land use land cover classification using Google Earth in the case of Pal Bichala Lake, for the year 1991 to 2023. For this study, Landsat data image of 1991 to 2023 was used and analyzed using ArcGIS 10.2 Supervised classification scheme was used to classify the images. Under land use and land cover categories Agriculture, Built up, Bare Land, Vegetation, Water Body. Following the classification of land use and cover categories, 100 random points were created in Arc GIS 10.2 and converted to KML when they could be opened in Google Earth. For the accuracy assessment, the value of each random point was confirmed via Google Earth. To determine how many ground truth pixels are successfully categorized, the Google Earth model was employed. According to the results, land use and land cover overall accuracy for 1991 was 84%, and Kappa (K) accuracy was 83%. For 2001, overall accuracy was 81%, and Kappa (K) accuracy was 82%. For 2011, overall accuracy was 88%, and Kappa (K) accuracy was 80%. For 2023, overall accuracy was 90%, and Kappa (K) accuracy was 81%. These results demonstrate that both overall accuracy and Kappa accuracy are acceptable.

1.8 CONCLUSION

The obtained results through the study confirm that Landsat data are indeed appropriate for performing regional scale I level LULC assessments, due to its moderate spatial resolution and excellent overall quality. The methods and procedure used for the

study is capable of generalizing quite well over the entire Pal Bichala Lake, an area of 360.6718 hectare accurately identifying areas of Agriculture, Built-up .Bare land, and Vegetation and Water body. Moreover it was also capable of classifying the different classes in all the 6 major classes.

From 1991 to 2001, there was a decrease in Agriculture of -0.51%, indicating a slight reduction in agricultural land. Similarly, from 2011 to 2023, the increase was -11.64%. In the first decade 1991-2001, there was an increase of 2.22%, indicating a moderate increment in urbanization and built-up areas. This growth escalated further during the second decade 2011-2023, with a rate of change of 10.34%, highlighting an intensified urban expansion. . During the initial decade 1991-2001, the rate of change was 1.07%, signifying an increase in fallow land. However, this trend reversed in the subsequent decade 2011-2023 with a decrease of 0.82% from 1991 to 2001, the rate of change was -2.45%, highlighting a decrease in vegetation cover. This trend persisted, albeit at a slower pace, during the period from 2011 to 2023, with a decrease of 0.51%. In the first decade 1991-2001, there was a slight decrease of -0.33%. However, the subsequent decade 2011-2023 witnessed a reversal in this trend, with a rate of change of -0.019%

The result shows that overall accuracy of land use and land cover for 1991 is 84% and Kappa (K) is 83%, and overall accuracy for 2001 is 81% and Kappa (K) is 82%, overall accuracy for 2011 is 88% and Kappa (K) is 80%, and overall accuracy for 2023 is 90% and Kappa (K) is 81%, which is acceptable in both accuracy overall and Kappa accuracy

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