RESEARCH ARTICLE

Land Transformation Study of Bakhira Tal Ramsar Site Through Space-Borne Techniques

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DOI: 10.18811/ijpen.v11i01.11

Abstract

This study focuses on Bakhira Tal, a Ramsar Site of global ecological significance, renowned for its biodiversity. Using high-resolution space-borne tools and geospatial technologies, the study evaluates land use and land cover (LULC) changes within a 1 km buffer of Bakhira Tal. Data from the Survey of India Toposheet (1972) and satellite imagery (Landsat 8, 2014 and 2024) were utilized to analyze temporal variations in the wetland's spatial extent and LULC patterns, revealing the impact of anthropogenic and natural processes on the ecosystem. Bakhira Tal's surface area has notably shrunk from 5031.52 ha in 1972 to 2985.75 ha in 2024. The study categorizes LULC into four classes: agricultural fields, built-up areas, plantations, and waterbodies. Significant changes were observed between 1972 and 2024. Agricultural fields decreased from 3311.65 ha in 1972 to 3074.88 ha in 2014, but increased to 3582.43 ha by 2024, with many fields replaced by plantations. Traditional croplands have gradually been converted to commercial agriculture, affecting water demand and land use intensity. Encroachment for agriculture has degraded some waterbodies, while rapid urbanization, population growth, and illegal settlements have expanded built-up areas, increasing from 204.12 ha in 1972 to 266.15 ha in 2024. The study produced comprehensive LULC maps using a Geographic Information System (GIS) integrated with high-resolution satellite data, helping to track these changes. The findings underscore the need for adaptive management and continuous monitoring to protect Bakhira Tal's ecological integrity and sustain its Ramsar status. This approach serves as a model for evaluating and managing LULC changes in other Ramsar Sites globally, ensuring sustainable resource use and wetland conservation.

Highlights:

- Bakhira Tal, a Ramsar Site of global significance, has experienced a reduction in surface area from 5031.52 ha in 1972 to 2985.75 ha in 2024 due to land use and land cover changes.
- Satellite imagery and geospatial technologies were used to analyze temporal changes in the wetland's LULC, highlighting the impact of anthropogenic activities and natural processes.
- Agricultural fields decreased from 3311.65 ha in 1972 to 3074.88 ha in 2014, followed by an increase to 3582.43 ha in 2024, driven by changes in commercial agriculture and water demand.
- Urbanization and illegal settlement have expanded built-up areas, from 204.12 ha in 1972 to 266.15 ha in 2024, contributing to significant LULC changes.
- The study emphasizes the need for adaptive management and continuous monitoring to protect Bakhira Tal's ecological integrity, using GIS-integrated LULC maps to guide sustainable resource use.

Keywords: Ramsar Site, GIS, LULC, Space-borne Technology.

International Journal of Plant and Environment (2025); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Wetlands are vital parts of ecosystems because they encourage biodiversity, offer special benefits to the environment, help to alleviate poverty and support both terrestrial and aquatic life. As the world's population grows, so does the water demand, which highlights the fact that there is rarely enough safe surface water for human use because surface water is more susceptible to pollution and contamination. The quality of many surface and groundwater systems is rapidly declining as a result of various human activities, such as encroachment, the destruction of aquatic resources, siltation, agricultural discharge, and inadequate waste management. Over the past few years, wetlands have experienced significant alteration, which has affected the biodiversity that already exists. Where there are human settlements next to or surrounding wetlands, there has been significant loss (Vance, 2009). Compared to aerial photography, the classification of land cover using Geospatial data is less expensive and time-consuming for vast geographic regions. In underdeveloped nations, where resources are limited and there is a lack of information about wetland characteristics such as extent, land use, and losses, space-borne technology might be useful for wetland research including monitoring and inventory work (Ozesmi and Bauer, 2002).

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How to cite this article: Tiwari, V.K., Singh, P., Shukla, M., Verma, S. (2025). Land Transformation Study of Bakhira Tal Ramsar Site Through Space-Borne Techniques. International Journal of Plant and Environment. 11(1), 101-108.

Submitted: 28/02/2024 **Accepted:** 11/02/2025 **Published:** 28/03/2025

Abera *et al*., (2018) investigated the spatio-temporal dynamics of land use in the Wanaka watershed, northwestern highlands of Ethiopia. Utilizing remote sensing and GIS tools, the study identified the main drivers of land use change, including agricultural expansion, population growth, and deforestation. The findings underscored the implications of these changes for sustainable resource use, emphasizing the importance of land management practices that align with environmental conservation efforts. Hassan *et al*., (2016) conducted a case study in Islamabad, Pakistan, using geospatial techniques to assess LULC changes over time. The research found that urban areas and built-up spaces have significantly increased at the expense of natural vegetation and agricultural lands. This highlights the impact of urban expansion on natural ecosystems and the necessity for sustainable urban planning. Li and Yeh (2004) analyzed the spatial restructuring of land use patterns in rapidly growing regions using remote sensing and GIS. Focusing on the Pearl River Delta in China, the study illustrated how urban development leads to significant spatial changes, including the loss of agricultural land and natural habitats. The research emphasizes the necessity for land-use policies that consider the long-term ecological impacts of urbanization. As per recent estimates, the global extent of wetlands has declined between 64 and 71% during the twentieth century, and wetland degradation is continuing throughout the world (Barbier, 2019) and (Nalule and Mugisha, 2013). Prairie potholes are small, shallow depressions in the landscape that fill with water during wet periods and are important breeding habitats for waterfowl and other wetland-dependent species. Riparian wetlands are found along streams and rivers and provide important habitat and water filtration services. Playa wetlands are shallow, circular depressions in the landscape that fill with water during wet periods and are important for groundwater recharge and habitat for migratory birds (Gurung *et al*., 2017; Peng *et al*., 2021; Tulu and Desta, 2015).

Wetlands in the Plains region can be divided into several types, including prairie potholes, riparian wetlands, and playa wetlands. Wetlands in the form of lakes, rivers, marshes, swamps, peatlands, mangroves, and coral reefs provide an essential ecosystem service to the livelihood of people and play a remarkable role in the ecological sustainability of a region (Bassi *et al*., 2014). Bhagat and Mohanty (2009) examined the patterns of urbanization and the role of migration in India's urban growth. Their study found that migration significantly contributes to the expansion of urban areas, which has direct consequences for land use patterns, infrastructure development, and environmental sustainability. This research emphasizes the need for comprehensive urban planning to address the challenges of rapid urbanization in the country. Das and Angadi (2020) studied the relationship between LULC transformation and land surface temperature (LST) changes in Barrackpore Subdivision, India. The results revealed a direct correlation between land cover changes and LST, where urban expansion led to a significant increase in surface temperatures. The study highlights the importance of incorporating LULC considerations into urban development planning to mitigate the urban heat island effect. Ganaie *et al*., (2020) explored the changing LULC patterns in the Wular catchment of Kashmir Valley, India. The study identified increasing human population and associated land-use practices as key drivers of change, leading to the loss of agricultural land and natural vegetation. The research underscores the need for sustainable land management strategies to preserve the valley's ecological balance and natural resources. Kumar *et al*., (2007) utilized remote sensing to monitor the spatio-temporal changes in urban growth in Indore city, India. Their findings indicated that urbanization leads to the conversion of agricultural lands and open spaces into built-up areas, raising concerns about the sustainable use of land resources. The study underscores the role of remote sensing in urban planning and policy-making. Poyil and Misra (2015) explored the effects of urban agglomeration in Malegaon City, India, using remote sensing and GIS techniques. The study documented significant land use changes, including the conversion of agricultural lands into urban areas. It stressed the importance of adopting sustainable land management practices to mitigate the adverse effects of urban sprawl. Rawat and Kumar (2015) used remote sensing and GIS techniques to monitor LULC changes in Hawalbagh Block, Uttarakhand, India. The study found that agricultural lands and natural vegetation have undergone significant changes due to human activities. The research highlighted the importance of continuous monitoring to ensure sustainable land use and the preservation of natural ecosystems. Human activities have had a significant impact on wetlands in the Plains region and around the world. The deterioration of wetlands can have severe consequences for local people, particularly those who rely on wetland resources for a living (Rana *et al*., 2009).

The spatial extent of Bakhira Tal has been gradually shrinking over time, mostly as a result of unsustainable land use practices, urbanization, and agricultural growth. Natural ecosystems are fractured and vital water supplies are contaminated or diverted as agricultural fields and human settlements encroach upon wetlands and water bodies. Aquatic species that depend on these waterbodies are impacted by habitat loss, which also interferes with the sensitive ecosystem functions that wetlands provide, like flood control and water purification.

Effective management tactics, the identification of essential regions for conservation, and the monitoring of these changes are greatly aided by high-resolution space-borne techniques like satellite imagery and remote sensing. A comprehensive strategy that strikes a balance between socioeconomic development and conservation can help stakeholders restore and protect the Bakhira Tal Ramsar Site's ecological integrity for future generations.

Study Area

Bakhira bird sanctuary also known as Bakhira Tal (N 26°54′ E 83°06′), is located to the west of the Rapti river bank, is a shallow-water, river-connecting wetland, declared a bird sanctuary in 1990 by the Forest and Wildlife Department, Uttar Pradesh, India (Fig. 1). It is part of the natural floodplain of River Rapti in Uttar Pradesh, expanding over an area of 29 km^2. The landscape and terrain of the wetland are approximately flat having an average elevation of 100 meters above mean sea level representing a typical terai landscape. Flooding causes catastrophic losses in terms of both property and people. The main cause of flooding in the Sant Kabir Nagar district is heavy rainfall during the monsoon season. Due to the largely flat terrain, heavy rainfall can result in serious floods and water logging problems for a longer duration.

Mishra and Narain (2010) conducted an in-depth floristic and ecological study of Bakhira Wetland, documenting the wide variety of plant species found in this habitat. Their work highlighted the importance of vegetation in maintaining the wetland's ecological balance and supporting various forms of life. The study pointed out the presence of aquatic and semi-aquatic plant species that form the primary producers within the wetland ecosystem, thereby supporting the food web. Verma *et al*., (2018) conducted a comprehensive study on the ichthyofaunal diversity of Bakhira Lake, revealing the presence of numerous fish species that are economically and ecologically significant. The study emphasized the importance of conserving the lake's water quality to sustain its fish populations. Mishra *et al*., (2020) investigated the population structure and habitat utilization patterns of migratory birds at Bakhira Bird Sanctuary. They reported a high diversity of bird species, including some that are categorized as threatened. The study provided critical insights into the habitat preferences of these birds, highlighting the need to preserve various microhabitats within the wetland to ensure their continued survival. Bano and Serajuddin (2018) provided a checklist of fishes in the wetland, noting the conservation status of each species and emphasizing the necessity of implementing protective measures for those that are vulnerable or endangered. Kashyap *et al*., (2024) proposed a framework for the sustainable utilization, conservation, and management of Bakhira Tal. Their research outlined strategies for involving local communities in wetland management, promoting eco-tourism, and adopting land-use practices that minimize ecological damage. The study also recommended habitat restoration activities and the enforcement of regulations to curb illegal activities that threaten the wetland.

Materials And Methods

Toposheet

Toposheets are indispensable tools for understanding the landscape, terrain characteristics, and spatial features of the Bakhira Tal Ramsar Site and its surrounding areas. 63N/1 toposheet has been used on the 1:50,000 scale used for this present study. It provides information about 1972 data like waterbodies, plantations, agricultural land and settlements. This helps in identifying changes in land use/cover over time, assessing the Tal and understanding the spatial distribution of natural resources.

Satellite Imagery

High-resolution satellite imagery like Landsat satellites provides 30m multispectral spatial resolution for land use and cover change detection within and around the Ramsar Site. Satellite imagery was used for two different years such as 2014 and 2024 data for assessing the Bakhira Tal and changes in their surroundings. Time-series analysis of the Tal has been conducted using the same satellite imagery to detect changes in land use/cover and encroachment over time.

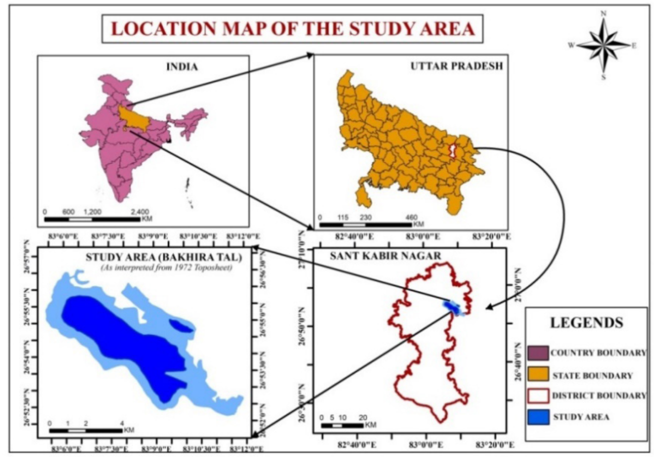

Fig. 1: Location map of the study area

Fieldwork

Through the precise recording of the latitude and longitude of the various places, GPS technology has shown to be indispensable in the collection of ground truth points throughout the field survey. The spatial distribution of the characteristics and phenomena under study has been documented in a systematic manner using these coordinates.

Methodology

This study has utilized a survey of India's toposheet (1972) and a combination of satellite imagery from high-resolution sensors such as Landsat 8 satellites along with GIS techniques and remote sensing algorithms (Table 1). Image processing will include spectral analysis, classification methods such as supervised maximum likelihood, and change detection techniques to quantify alterations in land use land cover and Bakhira Tal dynamics. The data has been processed using various geospatial techniques. (Fig. 2)

Georeferencing and Mosaicking

Georeferencing and mosaicking are essential processes in remote sensing and geographic information system (GIS) applications. Georeferencing involves assigning real-world coordinates to raster images, such as aerial photographs or satellite imagery so that they align with other spatial data. Mosaicking involves stitching together multiple georeferenced images to create a seamless and continuous representation of a larger area.

Digitization

Digitization in the context of GIS and remote sensing involves converting physical maps, documents, or other spatial data

Table 1: Types of data sources

S. No.	*Month/Year*	*Data*
1	1972	SOI Toposheet
2	April 2014	Landsat 8-9 OLI/TIRS C2 L2
3	April 2024	Landsat 8-9 OLI/TIRS C2 L2

sources into digital formats. This process typically includes scanning, georeferencing, and vectorizing features from the scanned images, enabling the data to be used for analysis, mapping, and other GIS applications.

Result And Discussion

The changing terrain brought about by human activity is making wetlands increasingly susceptible. Wetland deterioration is caused by anthropogenic activities that change the functions of the wetland inside and around its watershed. Ghobadi and Pradhan (2012) added that the depletion of wetlands led to biodiversity loss, erosion, flooding, and poor surface water quality, among other consequences of ecosystem degradation. For monitoring the wetland dispersion area and spatial-temporal dynamic abundance, remote sensing (RS) satellite data and geographic information systems (GIS) are appropriate tools (Emadi *et al*., 2010). Measurements of the qualitative and quantitative changes in terrestrial land cover have been made using remotely sensed data (Seto *et al*., 2002). To catalog and monitor wetlands, satellite remote sensing offers numerous benefits. It can also yield information about the surrounding land use and how it has changed over time. Using toposheet (1972) through digitization of the Bakhira Tal and calculate the area of 5031.527 hectares measured. Over the past 50 years, several factors contributed to the significant loss in Bakhira Tal, including wetland rehabilitation, ecological incursion, desertification; population growth, climate change and unplanned policies (Chen 2002). In 2014 the Tal was degraded, and the spatial extent was reduced to 3376.285 ha. Although the total surface area of wetlands worldwide is estimated to be between 12.1 million and 13.5 million square kilometers (Davidson *et al*., 2018). This accounts for approximately 6 to 9% of the Earth's land surface. These figures include a wide range of wetland types, such as swamps, marshes, peatlands, floodplains, mangroves, and coastal wetlands. After a decade in 2024, the area has shrunk to 2985.750 ha (Fig. 3).

The main cause of the lake's shrinkage is the constant influx of sediments made more abundant by the deforestation in its catchment areas, which causes the lake to lose a significant portion of its capacity to hold water and continually decline in size. The aquatic ecosystem and visual appeal of water bodies are eventually compromised by sedimentation (Kachoosangi *et al*., 2020). The area under this category reveals a continuously decreasing pattern during the selected period.

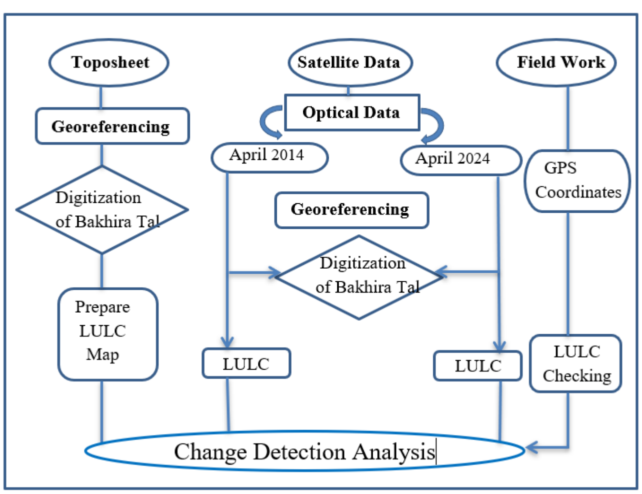

Fig. 2: Flowchart of methodology

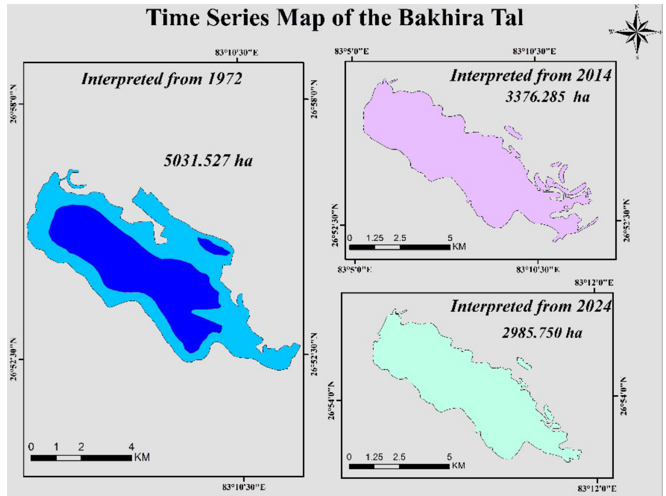

Fig. 3: Time series map of the Bakhira Tal

Land Use/Cover

The first stage in implementing sustainable land use management approaches is to develop and implement an appropriate land use plan for the entire wetland and surrounding area.

Land use and land cover are combined to form LULC. Generally, land cover is defined by the physical characteristics of surface features, while land use is the way that humans use the land. Due to their inseparability, the scientific community evaluated land use and land cover together as LULC. Any geographic setting LULC pattern is the result of human exploitation of environmental, institutional, and socioeconomic elements over time and place (Lesschen *et al*., 2005). While land use refers to human activities where land resources are used with the express purpose of producing goods land cover refers to the physical features that cover the earth's surface, such as flora, soil, water, and artificial buildings.

Using toposheet and Landsat datasets covering the years 1972, 2014 and 2024, the current study attempts to investigate the spatiotemporal dynamics of LULC in wetland ecosystems surrounding the Bakhira Tal. Supervised classification Maximum likelihood classifier was used to quantify LULC changes in ArcGIS software. A total of four categories were classified viz. agriculture, built-up, plantation and waterbodies. Degradation of the environment is discovered to be largely caused by LULC changes that have occurred in the last several decades as a result of human activity. These changes in LULC have a profound effect on a location's physical environment as well as on the social and economic circumstances of the local population (Zubair 2006). The outcome demonstrates that there have been notable changes in agricultural fields, built-up areas, and waterbodies during three distinct periods (from 1972–2024). The size of the agricultural field was 3311.65 ha in 1972 (Fig. 4) and decreased to 3074.88 ha in 2014 (Fig. 5); however, the next decade saw an increase to 3582.43 ha (Fig. 6). During that time,

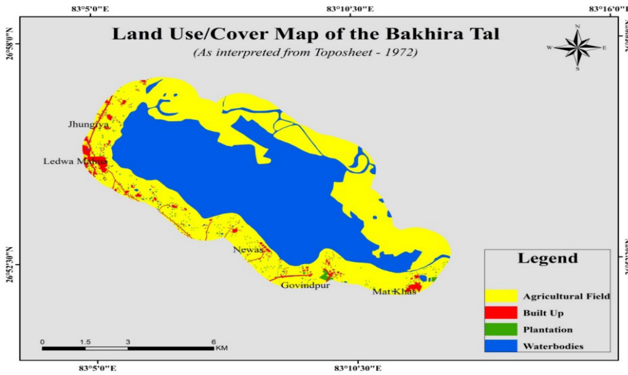

Fig.4: Land use/cover map of the Bakhira Tal 1972

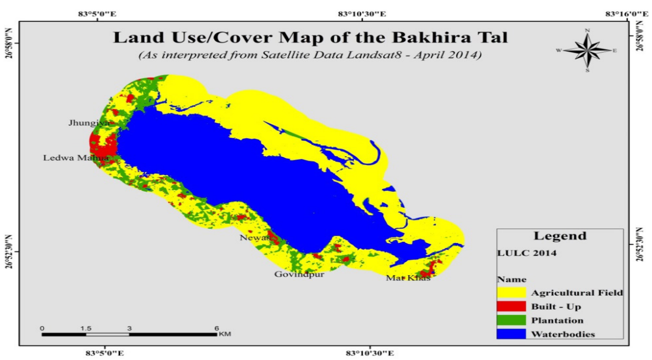

Fig.5: Land use/cover map of the Bakhira Tal 2014

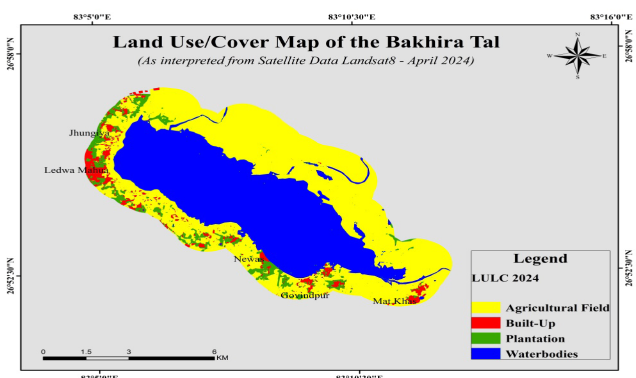

Fig. 6: Land use/cover map of the Bakhira Tal 2024

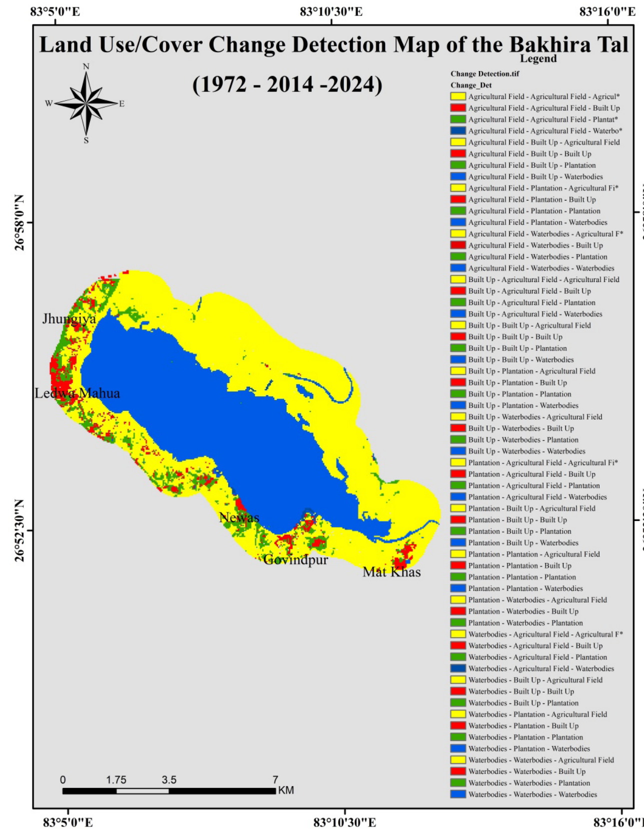

Fig. 7: Land use/cover change detection map of the Bakhira Tal

plantations replaced a large portion of the agricultural field. The region surrounding Bakhira Tal, which was formerly encircled by productive agricultural land, has recognized a change in LULC patterns. The area that has been built up has expanded over the past 52 years, from 204.12 ha in 1972 to 266.15 ha. This increase has been attributed to rapid urbanization, population expansion, and illegal habitation.

Plantations accounted for 92.730 ha of the total area under examination in 1972, 615.590 ha in 2014, and 396.467ha in 2024. This indicates a declining trend in the percentage of the overall area under investigation.

Water bodies accounted for roughly 3635.48 ha and 3363.00 ha of the total area in 1972 and 2014 and in 2024, 3008.211 ha respectively, continuing the trend of covering the bulk of the land.

Change detection processing applied to multi-temporal satellite images can identify land use and land cover features (Coppin *et al*., 2004) (Fig.7). The area covered by each class can be prepared and calculated for any class images that are produced as a result of the classification process. Following that,

Table 2: Land use/cover area for different time period

S. No.	*LULC Classes*	*The Year 1972*		*Year 2014*		*Year 2024*	
		Sum of area (ha)	*Percentage*	*Sum of area (ha)*	*Percentage*	*Sum of area (ha)*	*Percentage*
1	Agricultural field	3311.659	46	3074.880	42	3582.423	49
2	Built-up	204.121	3	207.701	3	266.158	4
3	Plantation	92.730	1	615.590	8	396.467	5
4	Waterbodies	3635.485	50%	3363.003	46%	3008.211	41%
5	Grand Total	7243.997	100%	7261.176	100%	7253.261	100%

Table 3: Land use/cover change detection for the year 1972-2014-2024

Row Labels	*Sum of Area Change (ha)*
Agricultural Field - Agricultural Field – Agricultural Field	2321.697
Agricultural Field - Agricultural Field - Built Up	46.771
Agricultural Field - Agricultural Field - Plantation	92.699
Agricultural Field - Agricultural Field - Waterbodies	21.667
Agricultural Field - Built Up - Agricultural Field	32.588
Agricultural Field - Built Up - Built Up	52.296
Agricultural Field - Built Up - Plantation	23.098
Agricultural Field - Built Up - Waterbodies	1.221
Agricultural Field - Plantation - Agricultural Field	231.983
Agricultural Field - Plantation - Built Up	47.561
Agricultural Field - Plantation - Plantation	156.731
Agricultural Field - Plantation - Waterbodies	14.501
Agricultural Field - Waterbodies - Agricultural Field	191.523
Agricultural Field - Waterbodies - Built Up	2.672
Agricultural Field - Waterbodies - Plantation	12.33
Agricultural Field - Waterbodies - Waterbodies	57.696
Built Up - Agricultural Field - Agricultural Field	17.825
Built Up - Agricultural Field - Built Up	6.648
Built Up - Agricultural Field - Plantation	11.157
Built Up - Agricultural Field - Waterbodies	0.1983
Built Up - Built Up - Agricultural Field	8.0848
Built Up - Built Up - Built Up	60.530
Built Up - Built Up - Plantation	9.8243
Built Up - Built Up - Waterbodies	0.635
Built Up - Plantation - Agricultural Field	14.668
Built Up - Plantation - Built Up	15.312
Built Up - Plantation - Plantation	38.237
Built Up - Plantation - Waterbodies	1.451
Built Up - Waterbodies - Agricultural Field	0.953
Built Up - Waterbodies - Built Up	0.358
Built Up - Waterbodies - Plantation	0.596
Built Up - Waterbodies - Waterbodies	1.502
Plantation - Agricultural Field - Agricultural Field	34.254
Plantation - Agricultural Field - Built Up	1.894
Plantation - Agricultural Field - Plantation	5.6347
Plantation - Agricultural Field - Waterbodies	0.3417
Plantation - Built Up - Agricultural Field	1.865
Plantation - Built Up - Built Up	2.040
Plantation - Built Up - Plantation	1.889

Plantation - Built Up - Waterbodies	0.1085
Plantation - Plantation - Agricultural Field	8.842
Plantation - Plantation - Built Up	2.599
Plantation - Plantation - Plantation	9.972
Plantation - Plantation - Waterbodies	0.1809
Plantation - Waterbodies - Agricultural Field	1.4631
Plantation - Waterbodies - Built Up	0.0974
Plantation - Waterbodies - Plantation	0.0363
Waterbodies - Agricultural Field - Agricultural Field	474.417
Waterbodies - Agricultural Field - Built Up	2.9419
Waterbodies - Agricultural Field - Plantation	7.818
Waterbodies - Agricultural Field - Waterbodies	10.260
Waterbodies - Built Up - Agricultural Field	1.360
Waterbodies - Built Up - Built Up	1.497
Waterbodies - Built Up - Plantation	0.814
Waterbodies - Built Up - Waterbodies	0.0580
Waterbodies - Plantation - Agricultural Field	30.030
Waterbodies - Plantation - Built Up	1.457
Waterbodies - Plantation - Plantation	3.635
Waterbodies - Plantation - Waterbodies	11.271
Waterbodies - Waterbodies - Agricultural Field	203.926
Waterbodies - Waterbodies - Built Up	0.515
Waterbodies - Waterbodies - Plantation	6.927
Waterbodies - Waterbodies - Waterbodies	2872.149
Grand Total	7195.3069

three distinct times were used for post-categorization change detection. Table 2 provides specifics about the data gathered from change detection analysis.

Four distinct types of altered land use and cover are displayed by the supervised classification based on maximum likelihood. The aforementioned map every significant class of the study area land cover and usage that has been examined throughout the change investigation (Table 3).

Conclusion

The study of land transformation at the Bakhira Tal, Ramsar site using space-borne technology has revealed significant changes in the wetlands landscape over the past few decades. The analysis of satellite imagery has shown a decline in water spread area, loss of vegetation cover and encroachment of agricultural land and human settlements. These changes have likely been driven by a combination of factors, including climate changes, human activities, and policy decisions. The use of space-borne technology has proven to be an effective tool for monitoring land transformation in this sensitive ecosystem. The findings of the study can inform conservation efforts and policy decisions aimed at protecting the ecological integrity of the Bakhira Tal Ramsar site. It is essential to continue monitoring the site using space-borne technology to track changes and assess the effectiveness of conservation measures. Additionally, integrating satellite data with ground-based information and engaging local.

Acknowledgment

The authors are especially grateful to the Department of Botany, Christ Church College, Kanpur, affiliated to CSJM University Kanpur for the helpful feedback and direction they offered. The authors would not have been able to complete the LULC study without the assistance of the Remote Sensing Applications Centre, Lucknow Uttar Pradesh.

Author's Contribution

VKT: Conceptualisation of idea, methodology and manuscript drafting, PS and MS: Data collection, analysis and manuscript editing SV: Supervised this research overall and provided required suggestions.

Conflict of Interest

The authors affirm that they do not have any potential conflict of interest related to their pursuits.

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