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Assessing Land use Dynamics and Policies in the Waghur Basin Using Geospatial Techniques

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Abstract

Changes in land use and land cover (LULC) are key indicators of human–environment interactions, especially in river basins where anthropogenic pressure is increasing. This study evaluated land use change and policy implications in the Waghur Basin, India, through a geospatial analysis of 35 years (1990–2025). Remote sensing and GIS-based supervised classification with the help of machine learning methods were applied to multi-temporal Landsat satellite images to create LULC maps and measure spatial–temporal changes. It was found that there are five large LULC classes, including agricultural land, forest land, bare land, settlements, and water bodies. The findings show that agricultural land increased significantly by 987.45 sq. km (39.74 percent) in 1990 to 1389.13 sq. km (55.90 percent) in 2025 at the expense of bare land, which reduced by 408.00 sq. km. Forest land showed a moderate loss of 26.89 sq. km, which is a sign of further forest degradation and fragmentation. Settlement areas almost doubled, indicating slow urbanization, and water bodies also increased because of water resource development efforts. These transformations point to the high impact of land-use policies, agricultural intensification, and infrastructure development on the landscape structure of the basin. The paper shows that geospatial methods are efficient in tracking LULC dynamics and that the method can be used to assess land-use policies. The results highlight the necessity of integrated, sustainable land-use planning that would balance agricultural development with forest protection, water management, and controlled settlement development to achieve environmental sustainability in the Waghur Basin in the long term.

Keywords: Artificial intelligence, GIS, land use change detection, machine learning, remote sensing

INTRODUCTION

Changes in land use and land cover (LULC) have become one of the most important indicators of environmental change in rapidly developing areas. Competition over land resources has increased in densely populated nations,, such as India, due to the growing population, agricultural activities, and infrastructural development. River basins are dynamic socio-ecological systems that are susceptible to, such changes. Observable landscape changes have occurred in the Waghur Basin in recent decades; however, there has been no systematic basin-scale assessment. Although remote sensing and geographic information system (GIS) tools are available, there is still a lack of policy-based evaluation of long-term LULC processes in semi-arid basins,, such as the Waghur basin. Uncontrolled agricultural development, slow forest cover degradation, and scattered settlement development can threaten ecological stability and the sustainable management of resources. Thus, a comprehensive spatiotemporal evaluation is needed to facilitate evidence-based land-use planning. This study focuses on the meso-scale watershed known as the Waghur Basin, which extends between 20º 27' 32" to 21º 05' 43" N latitude and 74º 30' 7" to 76º 05' 11" E longitude. The study rigorously considers five primary LULC categories: agricultural land, forested areas, built-up regions, bare land, and water bodies.

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Similar to other river basins, the Waghur Basin is experiencing enormous changes in land use and land cover (LULC) due to urbanization, agricultural development, and industrialization. These are significant dynamics in the management of natural resources and environmental sustainability. This study attempts to follow the history of land use and land cover in the Waghur Basin between 1990 and 2025, and the primary objective is to determine the changes in land use patterns and their policy implications in the Waghur Basin.

LITERATURE SURVEY

Machine learning and remote sensing have great potential for monitoring and mitigating the effects of land use and land cover (LULC) changes in the Waghur Basin. High-resolution satellite imagery and the use of advanced classification algorithms, including maximum likelihood classification (MLC) and random forest (RF), improve the quality of LULC mapping and change detection, providing timely and accurate data that are required to manage the land (Tripathi and Verma, 2024; Pandit et al., 2024) [1,2]. These technologies can be used to evaluate the LULC effects on water resources, which is essential in semi-arid areas, such as the Waghur Basin, by allowing the monitoring of changes in water quality and quantity in detail through the combination of remote sensing data with hydrological models (Mashala et al., 2023) [3].

Machine learning models,, such as support vector machines (SVM) and artificial neural networks (ANN), have shown high accuracy in LULC classification, which is essential for forecasting future land use trends and informing sustainable development plans (Rash et al., 2023; Dapke, 2024) [4,5]. With the help of services, such as Google Earth Engine (GEE), it is possible to efficiently process large amounts of data and conduct comprehensive temporal analyses, which can help to identify major changes in the landscape, including an increase in the size of built-up areas and a shrinkage of natural habitats (Pandit et al., 2024) [2]., such lessons are essential in solving the problems of high urbanization and industrialization, which have been associated with massive losses of water bodies and the rise of unproductive land (Tripathi and Verma, 2024) [1]. Moreover, remote sensing with machine learning can be used to build predictive models to predict future LULC changes, which can be used to proactively plan and mitigate (Indra et al., 2024) [6]. These technologies will enable stakeholders to make informed choices that will support the sustainable utilization of the natural resources of the Waghur Basin by offering a robust framework for LULC change detection (Lahane, 2025; Aggarwal, 2023) [7, 8].

Geospatial methods are important in the evaluation and analysis of land use policies in the Waghur Basin because they provide specific information on land use and land cover (LULC) dynamics, which are critical for sustainable land management and policy development. Methods, such as remote sensing and geographic information system (GIS) applications can be used to trace LULC changes over time, providing a complete picture of how land is used and transformed by several anthropogenic and natural factors. For example, Landsat satellite data and supervised classification methods have played a crucial role in mapping LULC changes, revealing substantial changes in the number of cultivated and fallow lands, influenced by population growth and agricultural needs (Reddy et al., 2024) [9]. Similarly, GIS and multi-criteria decision analysis can be used to model future land use, providing planners with the means to prioritize land use allocation (Nyeko, 2012) [10].

, such methodologies are used to detect zones of ecological conflict and guide sustainable land use management projects (Udovychenko, 2021) [11]. Moreover, research has revealed that geospatial methods can identify important land use alterations, including the growth of agricultural lands at the expense of forests and wetlands, with severe consequences for biodiversity and water resources (Idrissi et al., 2024) [12]. These methods can be integrated into land use planning to aid in the creation of data-driven policies and reduce the negative effects on natural ecosystems, ensuring a balance between urban development and ecological preservation (Durga & Yadav, 2025) [13]. In general, the application of geospatial methods in the Waghur Basin is an example of how these methods can be used to track environmental alterations, evaluate the effectiveness of resource management approaches, and make sustainable policy decisions (Kumar et al., 2022; Dervash et al., 2024) [14, 15].

Similar to other river basins, the Waghur Basin is undergoing tremendous land use and land cover (LULC) changes because of urbanization, agricultural growth, and industrialization (Agone, 2014) [16]. These dynamics are important for the management of natural resources and environmental sustainability. Remote sensing (RS) and geographic information systems (GIS) are geospatial methods that offer effective instruments for tracking and analyzing LULC changes. This literature review is a synthesis of recent research that uses these techniques in different river basins and identifies the methodology, findings, and implications that could be used to inform the assessment of the Waghur Basin.

Geospatial methods have become unavoidable in the evaluation and monitoring of land use. Research has repeatedly shown that remote sensing is effective in monitoring land cover changes and is useful in examining broad geographical regions over a long period. For example, Shukla et al. focused on the importance of remote sensing and geographic information systems (GIS) in mapping land use/land cover (LULC) distributions in river basins to aid in vulnerability assessment and resource management (Shukla et al., 2014) [17]. This is in line with the results of Singh and Mohapatra, who employed satellite imagery to depict that the area of agricultural land has been growing substantially at the cost of forest cover in the Betwa River Basin (Singh & Mohapatra, 2023) [18]. These methodologies are essential in the development of temporal LULC maps that point to the dynamics involved.

According to a few recent studies, the relevance of these approaches in various regions has been highlighted. For example, Voronkov et al. demonstrated how Sentinel satellite data can be used to analyze land cover in the Desna River basin, demonstrating how the spatial distribution and classification of land cover types can be achieved using remote sensing (Voronkov et al., 2025) [19]. Similarly, Lal et al. used Landsat images to examine LULC dynamics in the Ken River Basin and showed that a systematic method was used to measure fragmentation and determine ecological effects (Lal et al., 2025) [20]. These case studies offer a methodology that can be applied to the Waghur Basin assessment.

The dynamics of LULC alterations in river basins take different forms,, such as urban sprawl, agricultural intensification, and ecological degradation. In his study of the Jia dhal River basin, Mili emphasized that rapid urbanization has caused the environment to experience high levels of stress, including the natural hydrological regime (Mili, 2025) [21]. In addition, the combination of multi-temporal satellite imagery enables a more subtle understanding of these dynamics. For example, Yao et al. found that the alteration of cropland and forest areas had a significant effect on the land use matrix in the Yanhe River Basin, indicating the interdependence of various land uses and the factors that influenced them (Yao et al., 2021) [22].

Moreover, research in the Black Volta Basin (Dayinday ,2023) [23] and the Agusan River Basin (Bocobo et al., 2023) [24] has demonstrated systematic changes and increases in vegetation cover, which can be discussed as anthropogenic pressure and climatic factors that may also apply to the context of the Waghur Basin. These results highlight the need to use a continuous monitoring plan to learn how these dynamics change over time to make informed policy decisions.

The consequences of changes in LULC extend beyond land cover statistics and have serious impacts on ecosystems and hydrological processes. Liu et al. emphasized the effects of land use alterations in the Liaohe River basin, which led to intensified soil erosion and affected water quality (Liu et al., 2004) [25]. Conversely, Na et al. depicted the hydrological impacts caused by upstream LULC alterations in the Zhalong wetland, revealing significant ecological impacts that should be closely observed in other basins (Na et al., 2013) [26]. Faye et al. also studied the extent to which variability in vegetation indices with respect to alterations in land cover influenced the hydrology of the Casamance River Basin (Faye et al., 2020) [27]. These insights highlight the overall ecological impacts of land use choices in river basins.

The results of land use change analyses can be used to develop policies geared towards sustainable land management. Research has shown that knowledge of the drivers and patterns of LULC changes can be used to inform effective policy frameworks (Raj & Azeez, 2010) [28]. Pilatti et al. support evidence-based government policies on the use of soils, which highlights the importance of a balance between human needs and environmental sustainability (Pilatti et al., 2022) [29]. Therefore, it is critical to combine the results of research,, such as that by Derebe et al., which recommends the application of geospatial methods in systematic land use planning to facilitate the efficiency of resources and environmental protection (Derebe et al., 2022) [30].

Research Gap & Novelty

Studies on land use dynamics in river basins using geospatial methods provide useful information on the same in the Waghur Basin. The approaches presented in the studies reviewed provide powerful frameworks for evaluating changes in LULC. Given that the environment is still under pressure due to urbanization and climate change, the use of these geospatial methods helps not only in the monitoring process but also in the formulation of policies that will help in the sustainable management of land use and conservation of the ecosystem (Bhamare & Agone, 2012) [31].

Although it has been established that remote sensing and GIS are effective in studying land use and land cover (LULC) dynamics in major river basins, the Waghur Basin remains under-researched regarding long-term and basin-wide geospatial evaluations (Agone & Bhamare, 2014 and Raikwar et al., 2024) [32, 33]. The current literature is more concerned with change detection and ecological effects than with land-use dynamics and policy implications, especially in semi-arid river basins.

Furthermore, few studies have conducted multi-decadal analyses of the relationships between agricultural growth, forest transformation, settlements, and water resource development in a single framework. This study fills these gaps by providing a multi-temporal geospatial evaluation of LULC changes in the Waghur Basin and their applicability in sustainable land-use planning and policy development.

This study sought to trace the development of land use and land cover in the Waghur Basin from 1990 to 2025, with the main aim of identifying the alteration of land use patterns. Remote sensing data presupposes a central place in this undertaking owing to its exclusive ability to observe synoptically, repeat coverage, and obtain data in real time. Landsat satellite imagery, as digital data, can be categorized accurately to identify the different types of land cover and land use, and at the same time, it can be used as a vital component of spatial data infrastructure that is required to track urban growth and change detection research.

AIM AND OBJECTIVES

Aim

The aim of this research is to detect and analyze land use and land cover changes in the Waghur Basin in India from 1990 to 2025 using remote sensing data and machine learning algorithms. This manuscript emphasizes the importance of understanding and monitoring land use and land cover changes for effective land management and conservation strategies.

Objectives

- To study land use and land cover changes in the Waghur Basin, India, from 1990 to 2025.
- To analyze the implications of land use changes on the environment and land management.
- To use remote sensing data and machine learning algorithms for the classification and analysis of land use and land cover patterns.
- To generate accurate land use and land cover maps to support decision-making and policy development.

MATERIALS AND METHODS

Materials

This study analyzed land use and land cover (LULC) changes from 1990 to 2025. In Table 1, the Multispectral satellite data were employed for supervised classification to develop a land use map. The data utilized are presented in the subsequent tables for the years 1990 and 2025. ArcGIS Pro 3.5 and ERDAS 2022 were utilized for the geographical analysis, integration, and presentation of both spatial and non-spatial data pertinent to LULC change detection. These tools are particularly effective for monitoring and modeling land cover and land use changes. The following are the detailed steps for preparing LULC map data using machine learning. LULC classification through machine learning methods involves employing algorithms and models to automatically categorize and label various land cover and land use types within satellite or remote sensing imagery. The subsequent section provides an explanation of the steps involved in the classification of LULC using machine learning.

Table 1. Materials and data used for LULC classification and analysis of the Waghur Basin.

S. No.	Material/Data	Source	Purpose
1	Landsat 5 TM (1990)	USGS Earth Explorer	Historical LULC mapping
2	Landsat 8 OLI (2025)	USGS Earth Explorer	Recent LULC mapping
3	Toposheets	Survey of India	Georeferencing and basin boundary
4	ArcGIS Pro 3.5	ESRI	Spatial analysis and mapping
5	ERDAS Imagine 2022	Hexagon	Image preprocessing
6	Ground truth data	Field survey	Accuracy assessment

(Source: Compiled by the author from USGS Earth Explorer, Survey of India toposheets, and field survey data using ArcGIS Pro 3.5 and ERDAS Imagine 2025.)

Methodology

In Figure 1, The methodology adopted in this study involved multi-temporal satellite image processing, supervised classification using machine learning, and change detection analysis. The major steps are as follows:

Step 1: Data Acquisition

Multi-temporal Landsat satellite images for 1990 and 2025 were downloaded from USGS.

Step 2: Image Pre-processing

Radiometric correction, atmospheric correction, and geometric correction were performed to ensure data consistency. The images were clipped to the Waghur Basin boundary.

Step 3: Training Sample Preparation

Representative training samples for five LULC classes were collected using field knowledge and high-resolution Google Earth imagery.

Step 4: Feature Extraction

Spectral bands and indices were used to enhance class separability.

Step 5: Supervised Classification (Machine Learning)

Support Vector Machine (SVM) classifier was applied to generate LULC maps for both years.

Step 6: Accuracy Assessment

Confusion matrix, overall accuracy, and Kappa coefficient were used for validation using ground truth points.

Step 7: Change Detection Analysis

Post-classification comparison technique was used in ArcGIS Pro to quantify LULC transitions between 1990 and 2025.

Step 8: Map Preparation and Interpretation
Final thematic maps and statistical tables were prepared for analysis and policy interpretation.

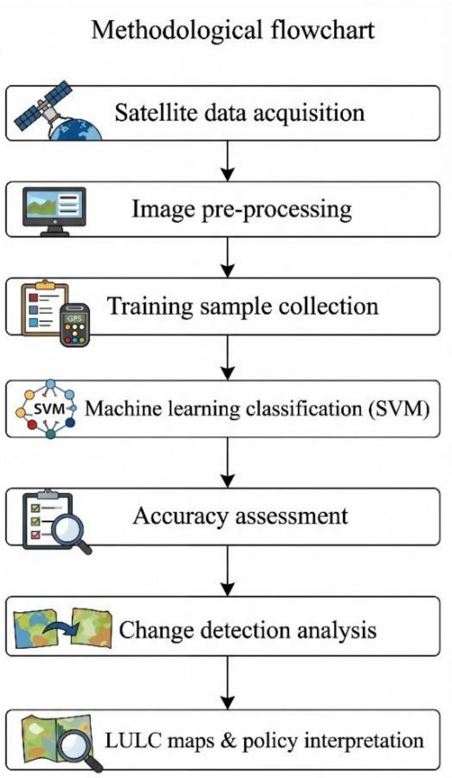


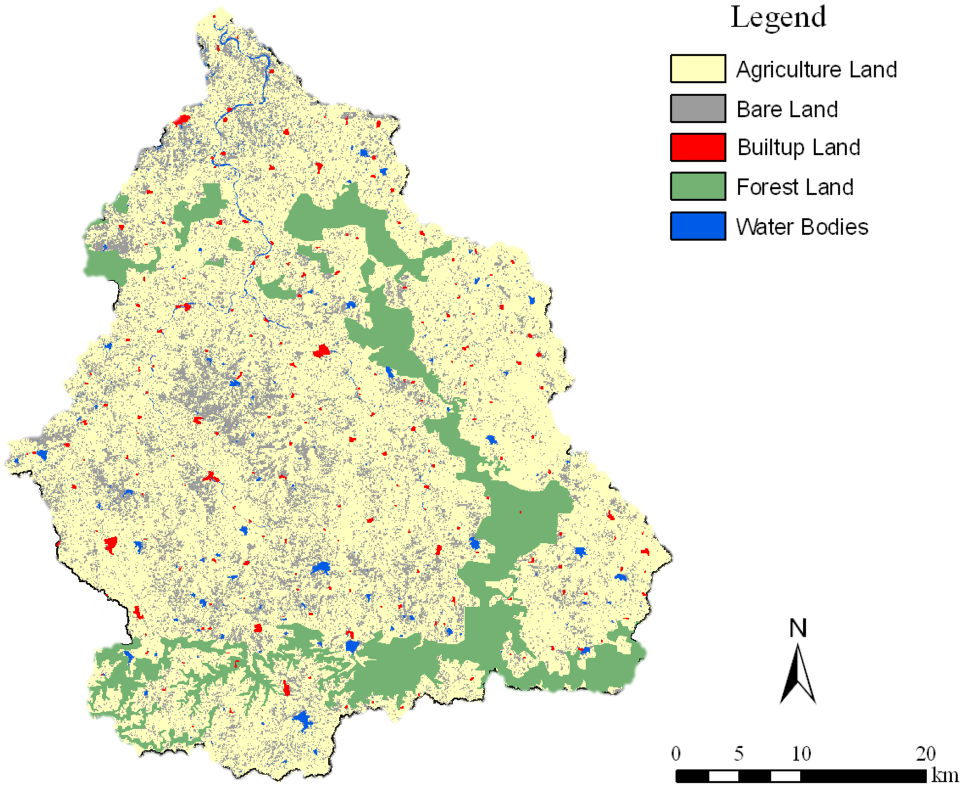
Figure 1. Methodological flowchart for LULC change detection in the Waghur Basin using remote sensing and machine learning techniques.

RESULTS
The Land use maps of Waghur basin for both the years reveal five classes of Land use. Viz Land under agriculture, Land under forest, Land under Built-up area, bare land and Land under water bodies. The classified images obtained after preprocessing and supervised classification, which show the land use and land cover of the Waghur basin, are shown in Figures 2 and 3. These images provide information about the land use patterns of the study area.

The Land Use and Land Cover (LULC) of the Waghur Basin in 1990 Figures indicates that there was a high spatial and temporal variation in all the major land use categories. The geographical area of the basin did not change and was 2485.00 sq. km, which made it possible to directly compare the LULC dynamics during the 35-year study period.

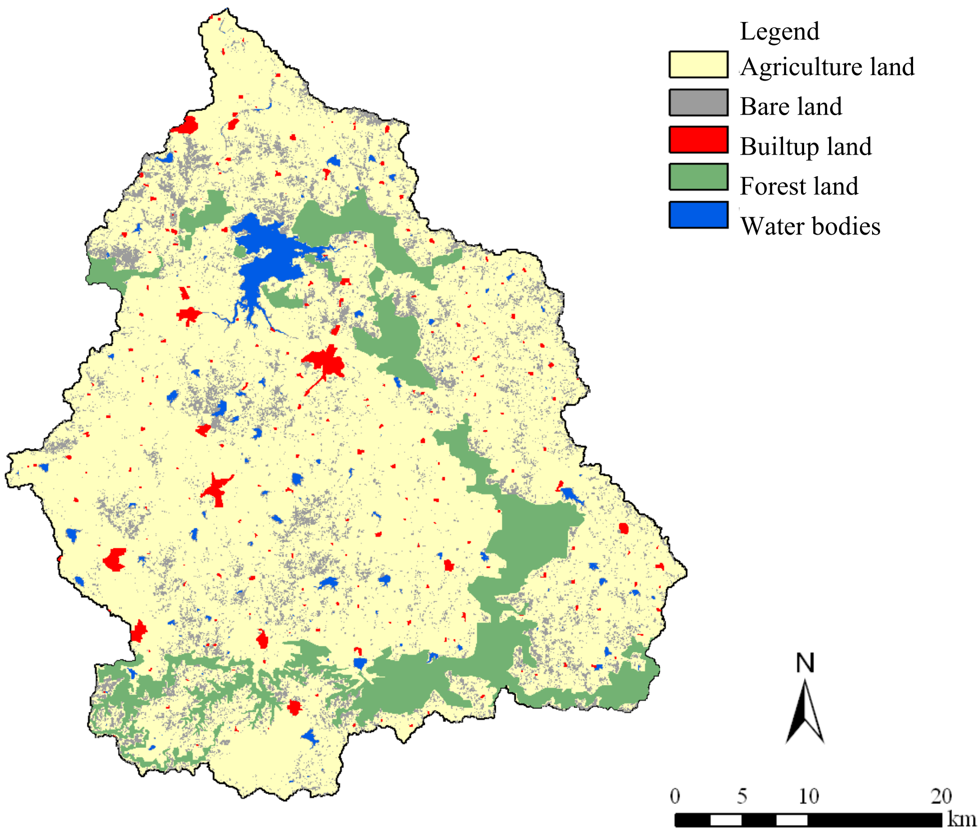
In 1990, the bare land class had the largest area at 1152.50 sq. km (46.38%), followed by agricultural land with an area of 987.45 sq. km (39.74%). Forest land occupied 310.71 sq. km (12.50%), settlements and water bodies occupied relatively small proportions of the basin, which were 19.30 sq. km (0.78%) and 15.04 sq. km (0.61), respectively as shown in Table 2.

The LULC composition of the basin will have significantly changed by 2025. Agricultural land will become the dominant class, expanding to 1389.13 sq. km and representing 55.90% of the total area. In contrast, bare land will be reduced to 744.50 sq. km (29.96%). There was a minor decrease in forest land with 283.82 sq. km (11.42%) in 2025. The Settlement areas rose to 35.26 sq. km (1.42%), which shows a significant urban and rural growth. The water bodies also increased and occupied 32.29 sq. km (1.30) of the basin area.



Source: Landsat 5 satellite image.

Figure 2. Land use/ Land cover map of Waghur basin 1990.



Source:Landsat 8 satellite image.

Figure 3. Land use/ Land cover map of Waghur basin 2025.

Table 2. Spatio-Temporal distribution of LULC of Waghur basin.

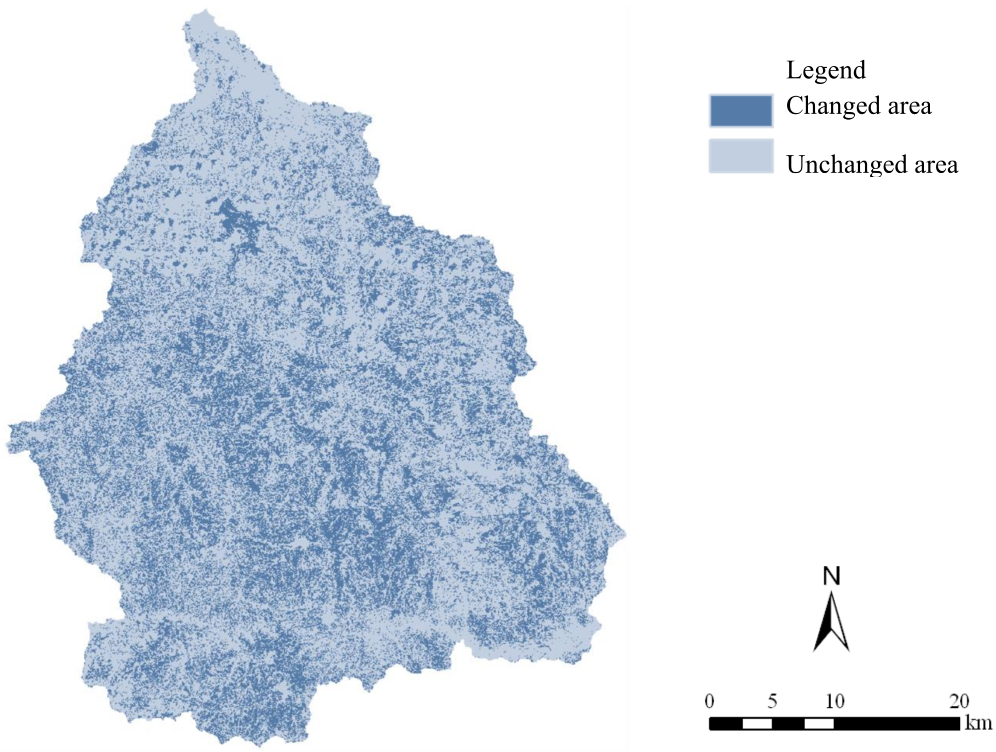
LULC	Year 1990 Area (sq.km)	Area in %	Year 2025 Area (sq.km)	Area in %
Forest Land	310.71	12.50	283.82	11.42
Agriculture Land	987.45	39.74	1389.13	55.90
Bare Land	1152.5	46.38	744.5	29.96
Settlement	19.30	0.78	35.26	1.42
Water Bodies	15.04	0.61	32.29	1.30
Total Area	2485.00	100	2485.00	100

(Source: Landsat 5 & 8 satellite data)

Table 3. LULC change detection during 1990–2025.

LULC	Year 1990 Area (sq.km)	Year 2025 Area(sq.km)	Increase Area(sq.km)	Decrease Area(sq.km)
Forest Land	310.71	283.82	--	26.89
Agriculture Land	987.45	1389.13	401.68	--
Bare Land	1152.50	744.50	--	408.00
Settlement	19.30	35.26	15.96	--
Water Bodies	15.04	32.29	17.25	--
Total Area	2485.00	2485.00	--	--

(Source: ArcGIS Pro change detection analysis)



Source: ERDAS & ArcGIS Analysis

Figure 4. Land use/ Land cover change detection map.

In Table 3, The change detection analysis shows the magnitude and direction of LULC transitions between 1990 and 2025. The greatest increase was in agricultural land, which gained 401.68 sq. km, settlement areas gained 15.96 sq. km and water bodies gained 17.25 sq. km. On the other hand, bare land had the highest decline of 408.00 sq. km and forest land had a decline of 26.89 sq. km during the period of study as shown in Figure 4.

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In general, the findings suggest a definite transition to agricultural use and increasing urbanized land cover in the Waghur Basin. These quantitative variations provide a clear picture of how the basin's land use structure has changed over the years and form the basis for further interpretation of the driving forces and environmental implications.

DISCUSSION

The analysis of land use dynamics in the Waghur Basin through geospatial methods indicates that land use patterns have undergone significant changes between 1990 and 2025 because of a combination of factors, including demographic pressure, agricultural development policies, and land use policy changes. Spatial analysis demonstrates the shift toward more intensive land use and the significant consequences of policy efficiency, environmental sustainability, and long-term land management in the basin (Bhamare & Agone, 2012) [31].

The most significant change is the increase in agricultural land, which has grown by 401.68 sq. km and now accounts for 55.90% of the basin area, compared with 39.74% in 1990. This growth indicates that there is strong policy support for agricultural growth, possibly due to food security, irrigation development, and government incentives that encourage the cultivation of lands that were not fully utilized. The transformation of vast areas of bare land into agricultural land is an indication of efforts to increase land production however, it also reflects the growing intensity of land use. Without proper soil conservation and water management,, such expansion can hasten soil erosion, loss of nutrients, and strain on groundwater supplies (Agone, 2014) [32].

Meanwhile, bare land decreased by 408.00 sq. km, representing a decline of 46.38 to 29.96 of the total area of the basin. This decline highlights the dynamic reuse of marginal and fallow lands for productive activities, which may be considered a positive outcome of land development policies. However, extensive conversion of bare land can also decrease ecological buffers that aid in the control of runoff and sediment transport, especially in semi-arid regions, such as the Waghur Basin (Agone & Bhamare, 2012) [31].

There was a moderate yet consistent loss of forest land, which lost 26.89 sq. km during the study period. Although the proportional change appears small, it is environmentally important because forests are of paramount importance to ecosystem services, carbon sequestration, and biodiversity preservation. This tendency indicates the possibility of loopholes in forest protection policies or the inability to implement land-use policies at the local level. Landscape connectivity may be compromised by incremental forest degradation and fragmentation, which can be fuelled by agricultural encroachment and settlement expansion, and enhance susceptibility to land degradation.

Continuing urbanization and rural infrastructure development are manifested in the growth of settlement areas, which increased from 0.78% to 1.42% of the basin area (almost twofold). Spatially restricted, settlement growth can frequently cause disproportionate effects in terms of land fragmentation, resource pressures, and land-use clashes (Agone & Bhamare, 2014) [31]. The identified trend indicates the necessity of more integrated spatial planning systems that balance settlement development with agricultural and ecological concerns.

A key observation is that the number of water bodies increased by 17.25 sq. km between 1990 and 2025. This transformation is probably due to the introduction of water resource management policies,, such as the construction of reservoirs, check dams, and irrigation facilities. Although the increase in surface water leads to increased agricultural output and water security, it causes a change in the natural hydrological regime and can impact downstream ecologies unless well controlled.

Overall, the land use processes that have been experienced in the Waghur Basin show the high impact of land use policies and development interventions in the last three decades. Geospatial methods were useful in the process of capturing, such spatial and temporal changes, which provide useful information for policy assessment and land use planning. The results indicate that policies need to be integrated to balance agricultural development and forest protection, sustainable water use, and controlled settlement development. Geospatial monitoring, adaptive policies, and ecosystem-based planning are critical for strengthening land use governance to guarantee sustainable land management and environmental resilience in the long term in the Waghur Basin.

CONCLUSION

The current study evaluated land use dynamics in the Waghur Basin based on geospatial analysis and revealed considerable changes in land use and land cover (LULC) between 1990 and 2025. The findings show that there is a distinct change towards increased human land use, which is mainly due to agricultural activities, settlements, and the development of water resources. Agricultural land increased significantly by 39.74% to 55.90% of the total area of the basin at the expense of bare land, which decreased by 46.38% to 29.96%. This tendency is the result of policy-based attempts to increase land productivity and food security through irrigation and land development programs.

The forest land experienced a moderate but ecologically meaningful loss, which fell by 26.89 sq. km during the study period. Although the proportional decrease appears to be small, it is an indicator of continued forest degradation and fragmentation, with possible implications for ecosystem services, biodiversity conservation, and carbon sequestration. The settlement areas almost doubled, indicating slow urbanization and infrastructure development, and the growth of water bodies implies the active implementation of water conservation and irrigation policies in the basin.

In general, the observed dynamics of land use suggest a high impact of land-use policies and development interventions on the landscape structure of the basin. Remote sensing and GIS applications were effective in capturing these spatial and temporal changes to provide credible evidence for assessing land-use trends and policy outcomes. This study highlights the importance of coordinated, policy-based land management policies that will balance agricultural growth with the preservation of the environment to make the Waghur Basin sustainable in the long run.

Suggestions

Enhance Forest Protection Policies

Forest loss and fragmentation should be countered by targeted afforestation, reforestation, and protection of the remaining forest patches. Enhancing land-use control and encouraging community-based forest management can increase ecosystem services and biodiversity conservation.

Promote Environmentally Friendly Agriculture.

Given the rapid expansion of agricultural land, it is necessary to adopt soil and water conservation practices, including contour farming, crop diversification, and effective irrigation methods, to prevent land degradation and achieve the long-term sustainability of agriculture.

Combined Land-Use Planning

Land-use policies must be integrated on a basin scale to harmonize agricultural growth, settlement growth, and ecological conservation. Zoning laws can be used to reduce land-use conflicts and manage unplanned settlement development.

Future Work Should Improve Geospatial Monitoring To Support Policies

It should be institutionalized to monitor LULC changes regularly using high-resolution satellite data and geospatial tools to enable evidence-based decision-making and facilitate timely policy responses.

Sustainable Water Resource Management

Although an increase in the number of water bodies is a sign of good policy intervention, the hydrological effects should be thoroughly evaluated to ensure a fair distribution of water and to reduce disruption of the ecological system down the river.

Future Policy and Research Integration

Further research should combine socioeconomic, land tenure, and climate variables with geospatial analysis to better comprehend the causes of land use change and to implement adaptive and resilient land use policies in the Waghur Basin.

These interventions can assist in sustainable land management and ensure that land-use policies are consistent with environmental conservation and developmental objectives in the Waghur Basin.

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