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Monitoring Land Use Land Cover Changes in the Yamuna River Basin Using GIS and Remote Sensing Techniques

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Abstract: *Analyzing changes in land use and land cover is essential to comprehending environmental changes and how they affect natural resources. The present study uses remote sensing and geographic information system techniques to examine the spatial and temporal dynamics of land use and land cover in the Yamuna watershed between 1994 and 2024. A variety of land cover categories, including farmland, forests, built-up land, aquatic bodies, and barren ground, were classified using multi-temporal satellite imagery. The techniques used to classify images and detect change were used to determine land cover changes over the time of the study. The findings show that there has been a great growth in built-up areas and agricultural land, and the areas of forest and natural vegetation have also reduced in specific areas of the watershed. Urbanization, infrastructure expansion, and fast population growth are the main causes of these shifts. The combination of the remote sensing data with GIS became an effective method of monitoring the LULC dynamics and assisting in the management of the watersheds and the environmental planning.*

Keywords: *Change Detection, Environmental Monitoring, Geographic information system, LULC, RS, Yamuna Watershed.*

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Introduction

It is established that LULC changes are considered to be one of the most important signs of environmental change under both natural and anthropogenic influence. Several decades ago, the situation was different since the rate at which the population was growing, cities were growing, industries were expanding, and agricultural output was growing; all these changes have transformed land resources in various parts of the world (Reis et al.2008). These changes have effects on the functioning of the ecosystems, preservation of biodiversity, soil fertility and water resources. Consequently, the tracking and assessment of the LULC dynamics have become a crucial part of the environmental study and sustainable planning of land management (Tesfaye et al.2025). Land use is the way in which human beings use land to serve various purposes which include agriculture, urban settlement, transportation, forestry and industrial purposes. The physical and biological features of the earth's surface, such as forests, grasslands, water bodies, bare land, and populated areas, are referred to as land cover (Lu et al.2007). Changes in land cover patterns typically accompany changes in land use, which can have significant effects on the ecosystem. The alterations may cause the impact on ecological balance, hydrological cycles, carbon storage, and soil erosion processes. As such, knowledge of the spatial and temporal trends of change in LULC is important to monitor the effects of the environment and planning an efficient management strategy of resources (Gong et al.2018). The change in land use has emerged as one of the primary factors contributing to environmental degradation and climate variability in the world. Deforestation and loss of natural vegetation to agricultural land or urbanization has enhanced soil erosion, diminished biodiversity and changed the climate patterns of the area (Al-Taei et al.2023). Unsustainable land management practices have been fuelled by the high rates of population growth and rapid urbanization in most developing countries that have strained the available land resources (Anderson et al.1976). In turn, LULC dynamics can offer valuable information on human-environment relationships and assist policy-makers in building sustainable development (Coppin et al.2004). Conventional means of environmental data gathering which include field surveys, census data, and ground-based measurements have been very common in land use research. Nevertheless, these methods are usually limited to a number of factors that comprise high cost, time, and spatial coverage. Large environmental systems like river basins, watersheds and regional landscapes demand large datasets which can only be obtained easily with the aid of conventional methods (Gebrehiwot et al.2024). Moreover, data collected manually might not be real time or accurate to be used in the process of tracking dynamic environmental shifts. Over the recent years, with the development of technologies, the opportunities to measure and examine the changes in the environment on various levels of space and time have become much more effective (Potapov et al.2020). GIS and RS are now useful tools for understanding the dynamics of LULC. These are technologies that allow the researcher to acquire, process, analyze and visualize the spatial data with great efficiency and precision. Remote sensing and Geographic information system together significantly contributed to the increased power to study complex environmental systems and identify the changes that take place over time (Ferdos et al.2026). Remote sensing technology offers aerial observation and synoptic reports of the surface of the earth using satellite imagery and aerial photography. The multi-temporal data of satellites enable scientists to study the environmental changes over a long period of time and over a vast area. The spectral data of the various surfaces on the land is captured by the satellite sensors which can be used to classify various land cover types e.g. vegetation, water bodies, urban, and barren land. The presence of high-resolution satellite images like Landsat, Sentinel, and MODIS has gone a long way in enhancing the precision of land use and land cover classifications. GIS supplement RS by offering the sophisticated means of processing and managing the spatial data (Dimyati et al.1996). GIS allows a researcher to combine several data sets, conduct spatial modeling and create thematic maps that include land use pattern and ecological variations. With the help of GIS-based spatial analysis, one can determine trends, assess environmental concerns, and facilitate decision-making in the management of land resources. Remote sensing data integrated with GIS methods has thus become a common methodology in studies of the environment and watersheds. LULC changes directly affect hydrological processes, they often have a substantial impact on river basins and watersheds. Vegetation cover, agricultural growth and urbanization changes can dramatically alter the runoff, groundwater recharge, sediment movement and soil erosion (Roy et al.2010). Changes can have an ultimate impact that would be water availability, ecosystem stability and agricultural productivity in the basin. Hence, research on LULC alterations in river basins can be used to comprehend the processes occurring in watersheds and formulate the strategy of sustainable water resource management. The Yamuna River Basin is a major tributary of the Ganges River and an extremely important river system for northern India. It is a river which has its origin in Yamunotri Glacier within the Himalayan region and passes through various states before joining Ganges at Triveni Sangam. The basin is a vast geographical region with varying topography, climate and land use activities. The Yamuna watershed is very diverse with numerous ecosystems and human activity from the rich alluvial plains of the middle and lower basins to the mountainous regions of the top basin (Tesfaye et al.2024).

The basin is also known to have some of the fast growing urban centers like the city of Delhi, Agra and Mathura which have seen tremendous growth over the past several decades. The development of cities within these areas has placed strain on the land resources and also led to the shift in land use patterns. The further increase in landscape transformation in the basin has been promoted by agricultural intensification, industrial activities, and infrastructure development. Besides urban development, the agricultural activities are also significant in influencing the land use patterns within the Yamuna watershed (Palaniyandi et al.2024). The Indo-

Gangetic plains have fertile soils that have allowed the breeding of large quantities of crops like wheat, rice, and sugarcane (Kadak et al.2025). But it has led to high population and intensive farming that has enhanced pressure on soil and water resources. The alteration in the cropping pattern, irrigation schemes, and land management activities can alter the soil erosion, sediment loads and water quality in the basin. Deforestation, land degradation, soil erosion and water pollution are also reported in certain areas of Yamuna watershed. These problems are directly connected to the change of land use and the use of resources in an unsustainable manner. It is therefore important to observe the spatial distribution and temporal changes of LULC to understand environmental conditions of the basin and be in a position to identify regions prone to degradation. The focus of the researchers was on the studies that were mostly relevant to the changes of environmental conditions after the implementation of the lockdown strategy. During COVID-19 they conducted several studies with the monitoring of the vegetation condition, air and water quality, agricultural region changes, land surface temperature changes, and waste management (Antil et al.2025).

Remote sensing and the GIS methods give a sure and efficient way through which land use and land cover changes can be evaluated with time. Satellite images of various years can be used to identify changes in the landscape and assess their environmental effects. The poor and infertile soils brought about by the continuous monoculture, poor recycling of organic matter, uncertainty of rainfalls and the occurrence of dry seasons have been seen to cause low crop yields in most countries. These aspects have also increased poverty, food insecurity and child malnutrition (Malik et al.2025). These studies are especially applicable in managing watersheds, environmental planning and policy formulation. Studying how land use and land cover patterns evolve over time is necessary given the Yamuna River Basin's ecological and socioeconomic significance. The knowledge of such changes may be used to pinpoint the key agents of landscape change and give some understanding on how to manage land resources in a sustainable manner. Thus, this study will examine the spatial distribution of LULC and temporal changes in Yamuna watershed between 1994 and 2024 by using RS and Geographic information system analysis. The aim of the study is to determine the key dominant land cover types, changes in land cover types during the study period and their implications on watershed management and environmental sustainability. This research will have implications on the understanding of the dynamic of the Yamuna basin landscape as the research will assist in the formulation of effective strategies to manage the land and water resources sustainably.

Methodology (Remote Sensing &GIS Classification)

Study area

Yamuna watershed is considered to be one of the largest river basin in the northern part of India and a significant tributary to the Ganga River system. In Figure1, the watershed spans across some states such as Uttarakhand, Himachal Pradesh, Haryana, Delhi and Uttar Pradesh. The area has a subtropical climate with clear summer, monsoon and winter seasons. Rains are also unpredictable with an average rainfall of 600mm to 1500mm per year and they are mostly experienced during the southwest monsoon season. Watershed sustains a wide range of land development activities such as agricultural land, forest, urban settlements, and water bodies. Rapid population increase and economic development have caused significant changes in the land use patterns of the basin.

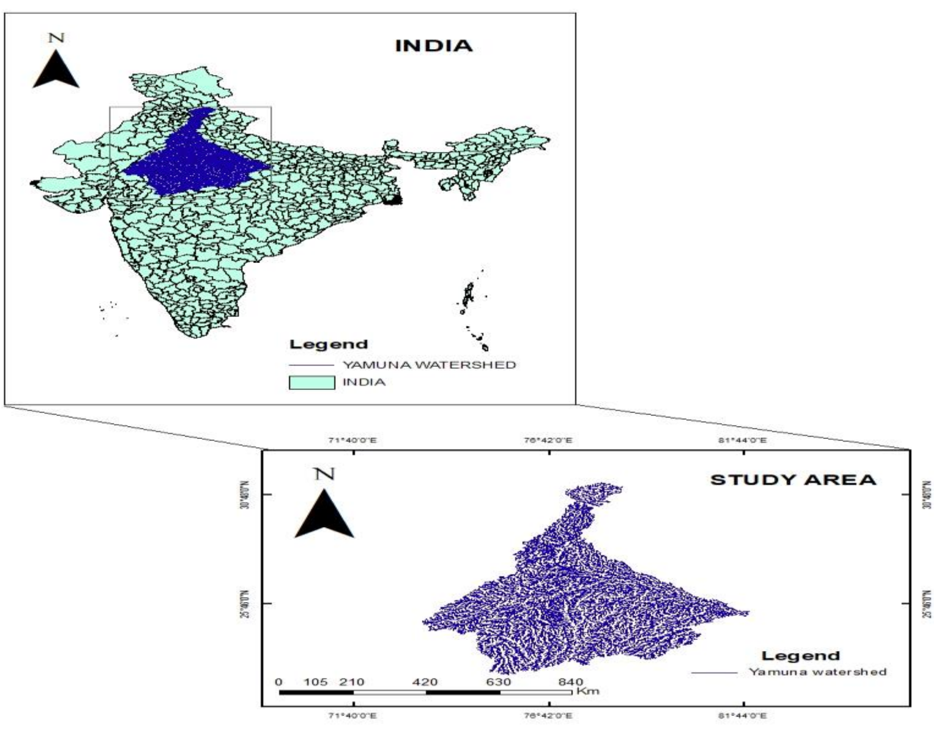

Fig. 1: Location map of the study area showing the spatial extent of the Yamuna River Basin in India.

Data Collection

The LULC dynamics on Yamuna River Basin were analyzed using multi-temporal satellite images. The archive of Landsat images provided by the United States Geological Survey was used to get the Landsat images of the various years. Such datasets offer medium-resolution images that can be used in watershed-scale LULC research. Imagery of Basin boundaries and other ancillary spatial data were incorporated in a GIS environment. Basin boundary data and ancillary spatial datasets were integrated within a GIS environment.

Image Pre-Processing

- The satellite images were undergone preprocessing to enhance the quality of data and to have the spatial consistency. Steps: Radiometric correction, Atmospheric correction, Geometric correction, Image mosaicking, Clipping with the basin boundary. These preprocesses were conducted through normal tools in GIS and remote sensing software.

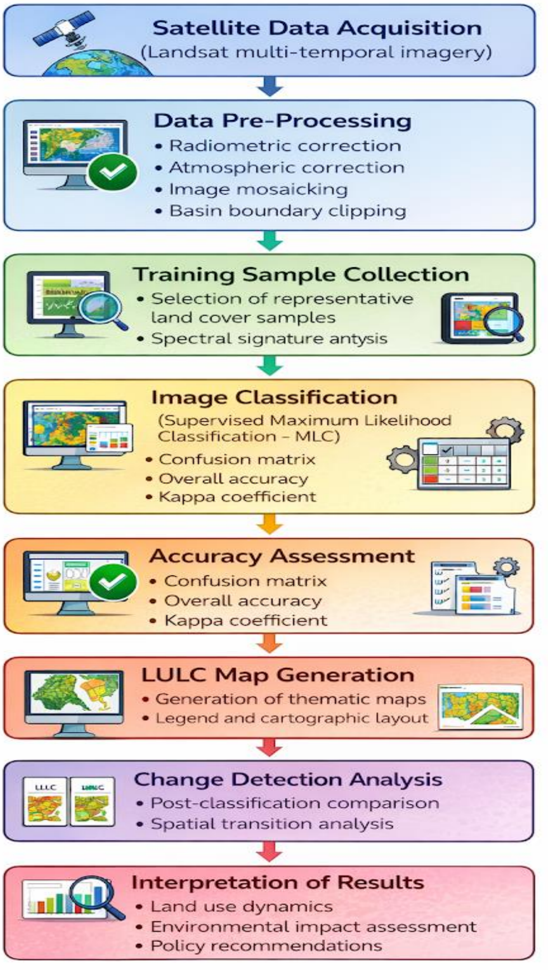

Fig. 2: Methodology adopted for Land Use Land Cover analysis using Remote Sensing and GIS.

In Figure 2 Methodological approach based on multi-temporal Landsat program imagery for mapping Land Use Land Cover (LULC) and detecting changes in the Yamuna River Basin using remote sensing and GIS.

LULC Classification

The supervised maximum likelihood Classification (MLC) was applied to create the LULC map in the year 2024. Sampling of the training samples according to spectral characteristics and visual interpretation was made based on the different land cover types. Eight classes of LULC were recognized: Agriculture, Vegetation, Scrub land, Built-up area, Bare ground, Grassland, Water bodies, Snow/ice. The classification outcomes were looked at visually and were refined to enhance thematic accuracy.

Change Detection Analysis: It was compared by using post-classification comparison techniques to compare LULC maps created in various years. The approach enabled the discovery of spatial changes among land cover types and evaluation of long-term landscape change throughout the watershed.

Table 1: Land Use Land Cover Classification Scheme

Class No.	LULC	Description
1	Built-up Area	Urban settlements, roads, and infrastructure
2	Agricultural Land	Cropland and cultivated fields
3	Forest/Vegetation	Dense forest, plantations, and natural vegetation
4	Water Bodies	Rivers, lakes, reservoirs, canals
5	Barren Land	Fallow land, rocky areas, wasteland

Table 1 shows the land use land cover (LULC) scheme that was used in the present study. It was identified to have five large land cover classes, such as built-up area, agricultural land, forest/vegetation, water bodies, and barren land. The classes depict certain landscape features, including urban infrastructure, cultivated fields, natural vegetation, water features and wastelands, which were applied to thematic classification of satellite images**.**

The table 2 represents the temporal variations in LULC of the Yamuna River Basin in 1994 and 2024. The findings also show that built-up areas have been steadily rising since 1994, with the figures standing at 3,450 sq km in 1994, and 6,480 sq kgm in 2024, which attributes to high-rate urban growth. On the contrary, the gradual decrease in agricultural land and forest/vegetation areas is seen whereas barren land displays a trend of increasing value throughout the study. Based on the table, agriculture is the leading land use category as it is almost two-thirds of the basin.

Table 2: LULC Change Table (1994-2024)

LULC Class	1994 Area (sq km)	2004 Area (sq km)	2014 Area (sq km)	2024 Area (sq km)
Built-up Area	3,450	4,120	5,210	6,480
Agricultural Land	102,300	101,850	100,900	99,700
Forest/Vegetation	41,200	40,500	39,700	38,600
Water Bodies	6,800	6,700	6,650	6,500
Barren Land	9,100	9,680	10,390	11,570

Table 3 demonstrates the LULC classes percentage breakdown in 2024. The findings indicate that agriculture forms the mainstream land use category, with almost two-thirds of the area of the basin (62.96%). The vegetation and scrub land cover 14.94 percent and 10.10 percent respectively and the built-up areas cover 8.71 percent. Water bodies, bare ground, grassland and snow/ice cover relatively small areas of the basin. Overall Accuracy: 89%, Kappa Coefficient: 0.87

: LULC Percentage Distribution (2024)

LULC Class	Area (sq km)	Percentage (%)
Agriculture	214,748	62.96
Vegetation	50,981.53	14.94
Scrub Land	34,457.40	10.10
Built-up	29,724.50	8.71
Water Bodies	7,112.00	2.08
Bare Ground	3,837.93	1.12
Grassland	800.20	0.23
Snow/Ice	201.44	0.06

These values mean a valid type of classification that can be used in analyzing the environment. Table 4 shows the performance evaluation of the classified LULC map against the high resolution imagery and field observations. The classification had an overall accuracy of 89 percent and the Kappa coefficient was 0.87 which showed a strong and valid classification outcome. Accuracies reached by producers and users per class are between 78 and 97 percent, as evidence that the supervised classification method was viable in identifying the significant land cover types in the basin.

Table 4: The measurement of the accuracy was conducted with the help of the imagery of high resolution and field observations.

Class	Producer Accuracy (%)	User Accuracy (%)
Agriculture	92	90
Vegetation	88	87
Scrub Land	85	83
Built-up	91	89
Bare Ground	84	82
Grassland	80	78
Water	95	94
Snow/Ice	97	96

Overall Accuracy: 89%
Kappa Coefficient: 0.87
These values mean a valid type of classification that can be used in analyzing the environment.

LULC Change Matrix

Land Use Land cover transition matrix assists in understanding the changes in the various land cover categories with time. The conversion between one land use class to another of 1994 to 2024 is depicted in the matrix.

Table 5: LULC Change Matrix (sq km)

	Agriculture	Vegetation	Scrub	Built-up	Water	Others
Agriculture	190,000	5,200	6,500	10,200	2,100	700
Vegetation	4,100	38,900	4,600	2,000	900	400
Scrub	3,500	4,200	21,800	3,900	700	300
Built-up	500	200	400	18,900	50	20
Water	200	150	100	300	6,200	80

In Table 5, the transition matrix implies that: There has been rapid urban growth represented by conversion of large share of agricultural lands to developed lands. Some of the vegetation areas have been converted to agricultural land implying agricultural growth. The development of land has seen conversion of scrub lands into agriculture and built-up areas. Water bodies are quite stable, but a slight variation is found since seasonal factors and human activities influence them. These changes show high level of anthropogenic impacts on the landscape particularly in the middle and lower portion of the basin.

Result

The distribution of the land covers in the Yamuna River Basin varies greatly, according to the LULC categorization. It is found that the agricultural land is the most popular type and it covers about 214,748 km 2 which is almost half of the entire basin. The great spatial area of agricultural land shows the relevance of the basin in terms of agricultural activity, which features fertile soils and an irrigation system that supports agriculture activity. Forest and natural vegetation occupy approximately 14.9 percent of the basin area and are mostly found in the upper part of the basin especially in the Himalayan and sub-Himalayan areas. These regions are quite pristine places as opposed to the plains which are heavily exploited. The outcomes of the classification show that about 10 percent of the basin is covered with scrub land. They are usually sparsely vegetated area with scattered shrubs and low density vegetation and occur commonly in the areas of semi-arid climatic conditions or in degraded land surfaces. Settlement and infrastructure are featured by almost 8.7 percent of the basin covered by built-up area. These places are mainly concentrated around large cities and fast developing urban centers in the basin. Water bodies such as rivers, canals, reservoirs, and lakes occupy an area of about 2 percent of the total basin area. Though these features have limited spatial coverage, they are critical in the irrigation as well as water resource management in the area. The other minor classes that cover the basin are grasslands, barren land, and snow-covered areas which are not given much space and are mostly limited to geographic regions. On the whole, the results of classification show the prevalence of agricultural landscapes, then natural vegetation and other types of land cover in the Yamuna River Basin.

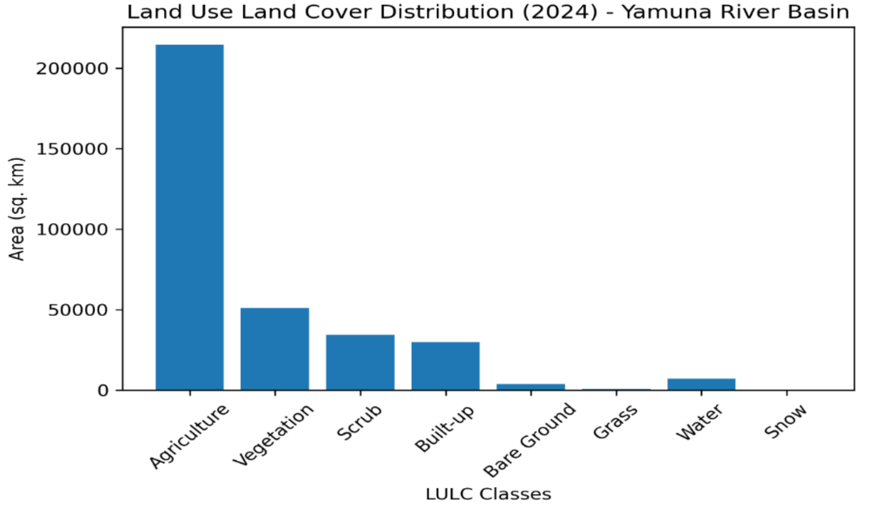

Fig. 3: LULC in 2024 in the Yamuna River Basin.

The bar graph shows the LULC of the Yamuna River Basin in the year 2024 showing in Figure 3. These findings indicate that agricultural land is the most significant land use category as it controls the highest portion of the basin area, which indicates the high reliance of the area on agriculture. The second largest category is vegetation which is primarily forested and natural vegetation. The basin is also covered by scrub land and built-up areas that cover a significant portion of it. Scrub land implies the sparsity of vegetation, whereas built-up land implies the growing urban communities and infrastructure. A smaller, yet significant part of the basin is covered by water bodies, such as the Yamuna River, canals and reservoirs. Other classes of land covers like bare ground, grasslands, and snow-covered areas cover very small areas as opposed to the dominating classes. In general, in the graph, it is clear that the Yamuna River Basin landscape is largely comprised of agricultural activities with moderate urbanization and minimal types of natural land cover.

The Spatial Distribution of LULC (2024)

This was created by supervised maximum likelihood classification of satellite images to create the Land Use Land Cover (LULC) map of the Yamuna River Basin as of 2024. The classification classified the eight large land cover classes as agriculture, vegetation, scrub land, built-up area, bare ground, grassland, water bodies and snow/ice.

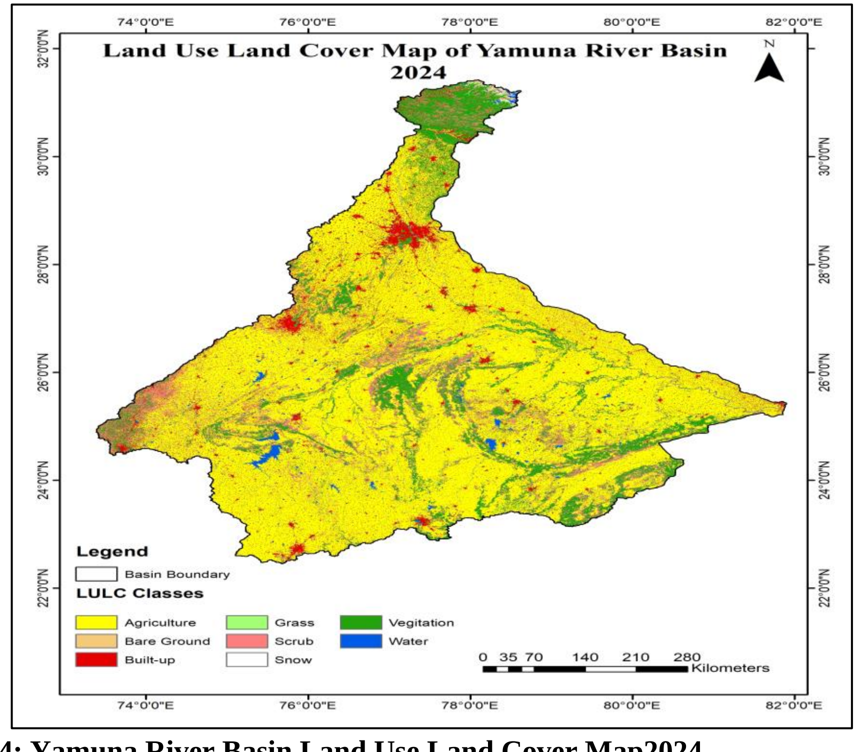

Fig. 4: Yamuna River Basin Land Use Land Cover Map2024.

In Figure 4, the pattern of the spatial distribution indicates that the basin is dominated by agricultural land especially in the central and southern plains. These are the fertile alluvial plains where irrigation and intensive cultivation is a bit rampant. The fact that agriculture was the major activity means that farming was a key activity in the basin. The natural vegetation and forest cover are mostly located in the upper himalayan area in the northern part of the basin where there are favorable climatic conditions with dense forest cover. The scrub land and grassland are found mainly in the transitional zones and semi arid regions where the vegetation density is low. The concentration around the zone of the development of a built-up area is applicable mainly to the major cities like Delhi, Dehradun, Agra, and Mathura. There are considerable urbanization in these areas with the increase of population and development of infrastructures. The Yamuna River, reservoirs and lakes that are spread throughout the basin represent water bodies. The snow and ice are only experienced in the high-altitude Himalayan area where the river originates. In general, the map shows the prevalence of agricultural areas and growing urbanization, which denotes the high anthropogenic activity in the basin. These land cover patterns have significant effects to watershed hydrology, soil erosion processes, and environmental sustainability.

Discussion

The distribution of the Yamuna River Basin by LULC indicates the dominance of agricultural land by far which is an indication of the reliance of the region to farming activities and irrigation systems. The high agricultural density suggests that the basin is highly important in food production and it provides a high rural population. Nonetheless, the agricultural activities can also lead to soil degradation and erosion in case sound land management techniques are not adopted. Most vegetation and forest lands are only left to the upper and hilly sides of the basin where natural scenery remains relatively intact. These lands are relevant in the ecological balance, biodiversity conservation and control of hydrological conditions like the runoff and groundwater recharge. Another benefit is that vegetation cover will reduce soil erosion and keep the slope steady. Other transitional or degraded landscapes with relatively low vegetation density are scrub land and barren areas. Such environments can be due to climatic conditions, over grazing or un-sustainable land use activities. These areas can be easily affected by land degradation and thus proper conservation strategies are needed to replenish the soil and vegetation cover. The percentage of land cover suggests that there is a growing urbanization in the basin. The fast urbanization of the area surrounding big cities may cause alterations to the land surface features, augmented surface runoff and stress on water resources. Thus there is a need to have appropriate urban planning and sustainable development practices to reduce the environmental impacts. Even though water bodies take relatively low share of the basin area, they are needed to supply irrigation and household water and also to sustain the environment. Altogether, the identified LULC pattern implies that human activities have a great impact on the landscape of Yamuna River Basin and there is a need to manage the watershed and plan land use sustainably.

Conclusion

This paper characterized the space distribution and time dynamic of Land Use Land cover in Yamuna River Basin using the technique of remote Sensing and GIS. The findings reveal that agriculture is the leading land use category since it occupies most of the basin area. Nevertheless, there have been massive growths of the built-up land over the last decades because of the high rate of urbanization and increase in population. The reduction of natural vegetation and expansion of urban space indicates the rising anthropogenic forces on the watershed ecosystem. These changes can be quite significant to the hydrological process, soil erosion, and environmental sustainability. It was found that the combination of RS and Geographic information system was a successful method to trace the dynamics of the landscapes, as well as measuring environmental changes on the basin level. Selective surveillance of the changing LULC needs to be considered in aiding sustainable watershed management and informed decision-making.

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Conflict of Interest

The authors do not have any conflict of interest.

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