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Mapping the Transformation: A GIS Analysis of Urban Sprawl for Sustainable Futures

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Abstract- Urban sprawl, characterized by the rapid and unplanned expansion of urban areas, poses significant challenges to sustainable development and environmental conservation. This research paper analyzes urban sprawl in Nashik City using LANDSAT 8 satellite imagery from Earth Explorer, covering the period from 2013 to 2023. In 2013, the land use was as follows: 31.81% built-up areas, 29.68% vegetation, 35.70% barren land, and 2.81% water bodies. The built-up area had grown to 38.15% by 2023. While the amount of vegetation dropped to 22%, the amount of barren land dropped slightly to 37.16%, and the amount of water bodies dropped slightly to 2.69%. This comparison shows significant changes in how land is used at that point to urban sprawl. This emphasizes the need for smart urban planning, protecting the environment, and long-term growth strategies.

Keywords: Urban Expansion, Remote Sensing, GIS, Sustainable Development, Spatial Analysis, Land Use Land Cover, Spatial Data.

I. INTRODUCTION

Urbanization, which is an unavoidable result of social and economic progress, has caused cities around the world to grow quickly, which is known as urban sprawl. Land-use land cover (LULC) change detection is one of the methods that can be used to identify the expansion of urban sprawl studies [1]. This is especially true in developing countries, where growing populations cause urban areas to spread out in ways that are not planned or controlled. Recent studies from around the world on urban sprawl show that cities are growing faster than ever, often at the cost of natural areas and farmland. Stokes and Seto, (2019) looked at how cities around the world have grown since 2000 and found that urban areas grew by 30% between 2000 and 2015.

This was mostly because of population growth and economic growth in Asia and Africa. This study showed that urban sprawl has negative effects on the environment, such as higher carbon emissions, loss of biodiversity, and changes to hydrological cycles. This shows how important it is to plan cities to save environment. In a similar vein, the World Urbanization Prospects report said that more than half of the world's population now living in urban areas are expected to rise to 68% by 2050 [3]. The report highlights how hard it is to control urban sprawl in cities that are growing quickly, especially in developing countries where urbanization often outpaces efforts to build infrastructure. Angel et al., (2021) did a thorough study of the spatial structure of cities around the world. They found that urban sprawl is not just a problem in developing areas; it is also common in developed countries, though in diverse ways. Their research showed that cities in the Global South tend to sprawl outward with low-density developments, while cities in the Global North have problems with suburbanization and the decline of urban cores. This difference is important for understanding the ways that urban sprawl shows up and for making urban planning strategies that work for each one.

Naikoo et al., (2020), looked at studies of LULC change and built-up area growth in the suburbs. The growth of built-up areas into peri-urban and rural areas was a major concern. Their research found that this growth is often not controlled, which means that agricultural land is lost, ecosystems are broken up, and people are more vulnerable to climate change. In the same way, similarly [6] looked at urban sprawl in the Mathura district of Uttar Pradesh. They showed how Landsat OLI images and GIS can be used in studies of urban sprawl. The study found that Bangalore's built-up area grew islands between 2000 and 2020, which made green spaces and water

bodies smaller on the cost of environmental degradation, urbanization, urban heat island, water shortages, and air pollution. Roy et al., (2021) looked at the social and economic effects of urban sprawl in Hyderabad. This GIS-based methodology provides a detailed and accurate assessment of urbanization and land cover changes, offering valuable insights for sustainable urban planning and management [8]. This shows how hard it is to provide basic services and infrastructure in these areas that are growing quickly.

The study suggested that urban development should be more open to everyone, considering the needs of underrepresented groups and the need to protect natural resources.This paper's new way of thinking about urbanization looks at how building infrastructure fits in with changes in land use and population growth. It focuses on places where investments in services like water, sanitation, and electricity either keep up with or fall behind urban growth. The main questions asked are whether infrastructure growth keeps up with changes in population and land, and whether satellite data can find places with infrastructure problems, like slums, or improvements, like electrification [9]. Remote sensing data also aids in resource use studies, such as those by [10], which examine how urban expansion influences natural resource consumption. By following infrastructure along with land and population trends, this research helps us understand the paths of urbanization and helps us keep an eye on the UN's SDG 9 (Infrastructure) and SDG 11 (Sustainable Cities) [3] . It gives policymakers vital information to help them decide where to put money into urban infrastructure.

II. STUDY AREA

The study area (Fig. 1) focuses on Nashik City, located in the northern part of the state of Maharashtra, India. Nashik lies between 19°55'00" N to 20°05'00" N and 73°40'00" E to 73°55'00" E, encompassing an area of approximately 267.15 km^2. Nashik is characterized by its semi-arid climate with hot summers and mild winters, receiving an average annual rainfall of about 700 mm, primarily during the monsoon season from June to September. Nashik City has seen significant urban growth and transformation over the past few decades. As of the 2021 census, the population stands at approximately 1.8 million, with rapid urbanization leading to an expansion of residential, commercial, and industrial zones. The Godavari River, the main water source, plays a vital role in the city's socio-economic activities, but urban sprawl has posed challenges in maintaining ecological balance. Nashik strategic location as a pilgrimage center and its industrial and agricultural contributions makes it a key area for studying urbanization and land use changes.

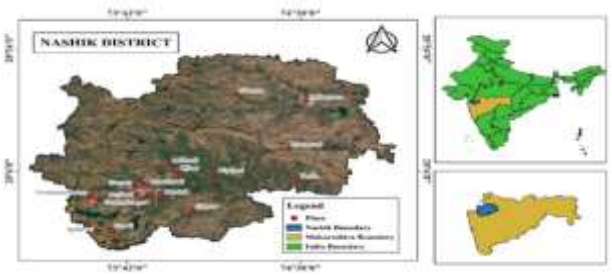

FIG. -1: STUDY AREA

III. METHOD

GIS tools and methods are used to study changes in urbanization and land cover. The first step in this method is to get and georeferenced topographic maps and satellite images, and pictures. The method uses high-resolution satellite data to look at changes in population, land use, and infrastructure over time. This makes it possible to accurately map and classify urban areas. In second step, we will make composite images to make it easier to see features, extract the study area for focused analysis, and use supervised classification methods to accurately tell the difference between land cover types. This methodical way ensures a detailed and reliable assessment of urban sprawl and land use dynamics which follows by Data Acquisition (Table 1) and Pre-processing, Urban Growth, Image Enhancement and Composites, Extraction, Supervised Classification, Maximum Likelihood Classification (MLC), Change Detection, Spatial Analysis, Accuracy Assessment and Validation, Mapping and Visualization.

Table 1: Satellite data Details

Sr. No.	Satellite Sensor	Date of acquisition	Path	Row	Resolution
1.	Landsat 7 ETM+	09-03-2013	147	046	30m
2.	Landsat 8 OLI/TIRS	30-04-2023	147	046	30m

IV. RESULTS AND DISCUSSIONS

The results show LULC changed in Nashik City from 2013 to 2023, that the city's landscape changed in considerable amounts because of urban sprawl.

Identification of Urbanization Hotspots

The study's spatial analysis found parts of Nashik City where urbanization was happening a lot. These places have seen a big rise in built-up land, which shows that infrastructure and cities are growing. Urban planners need to know where urban clusters are so they can produce clever ways to deal with rapid urbanization. These clusters could become important places for future growth. To lessen the adverse effects of sprawl, like putting a strain on infrastructure, transportation, and public services, there needs to be good planning.

Urban Growth and Expansion (2013–2023)

The study found that the built-up area grew significantly from 31.81% in 2013 to 38.15% in 2023. This shows how quickly cities have grown in the last ten years. This rise is due to Nashik's growing population, economy, and the rising need for land for homes, businesses, and factories. As the city grows, it becomes clearer that farmland and green spaces are being turned into urban infrastructure. This shows that we need to manage growth in a way that protects the environment while still allowing for development. If urban growth is not controlled, it could lead to more depletion of natural resources, worse air quality, and fewer green spaces. All these things make the city less livable and less environmentally friendly. This means that smart growth strategies that focus on urban densification instead of horizontal sprawl need initiative-taking policy changes.

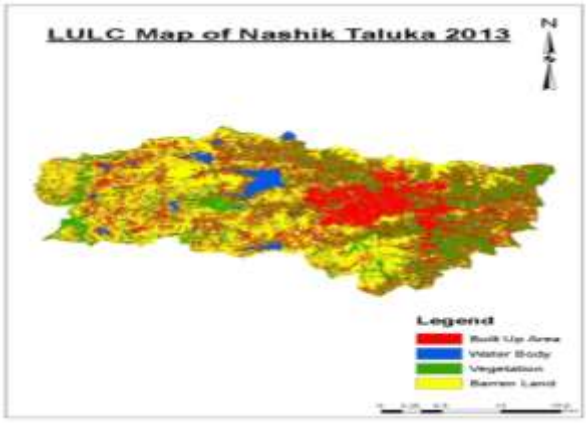

FIG -2: LULC MAP OF NASHIK 2013

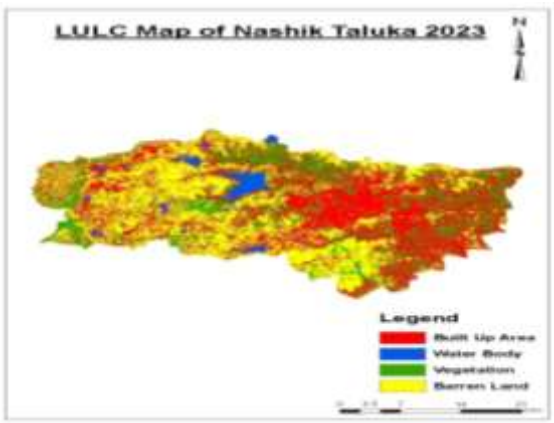

FIG -3: LULC MAP OF NASHIK 2023

Changes in Land Cover and Land Use

The LULC analysis showed (Fig 1&2) that land cover patterns have changed a lot. The area covered by vegetation went from 29.68% in 2013 to 22% in 2023. This means that green spaces were turned into urban or barren land. This loss of plant life is worrying because it could harm the local ecosystem, lower biodiversity, and make urban heat islands worse. Also, the amount of empty land has stayed high, going up from 35.70% in 2013 to 37.16% in 2023. This trend suggests that places may be clearing land for future development but not building anything on it yet. This could cause problems with dust pollution and land degradation. The water bodies have shrunk a little, from 2.81% in 2013 to 2.69% in 2023. This is not a substantial

change, but it does show that local water resources may be vulnerable to pressures of urbanization. This requires investigation to stop water bodies from getting bigger and protect important aquatic ecosystems.

Temporal Dynamics of Urbanization

The LULC maps for Nashik from 2013 and 2023 show how urbanization patterns change over time. As cities grow, the way they are laid out changes. For example, built-up areas have spread into areas that were once open or covered in vegetation. Understanding these changes over time is important for understanding how Nashik's landscape is changing. This shows how important it is to keep an eye on things and plan to stop uncontrolled sprawl. The trends we have seen show how important it is to use sustainable urban development methods. As cities grow, they need greener infrastructure, transportation options that do not hurt the environment, and land use policies that help the environment and make cities more resilient in the long term.

In Figures 2 and 3, the changes over the decade from 2013 to 2023 are observed. The built-up area in Nashik experienced substantial growth, increasing from 402.11 km² (31.81% of the total area) to 482.27 km² (38.15% of the total area). This expansion, vividly represented in red on the LULC maps, signifies significant urban sprawl. Conversely, the vegetation area saw a marked decline, shrinking from 375.05 km² (29.68%) to 278.18 km² (22.00%), depicted in diminishing green regions, indicative of deforestation and the loss of agricultural lands. The barren land, shown in brown or gray, also increased slightly from 451.16 km² (35.70%) to 469.58 km² (37.16%), suggesting land degradation. Water bodies, represented in blue, experienced a minor reduction from 35.61 km² (2.81%) to 33.91 km² (2.69%), reflecting a slight decrease in water resources. These changes underscore the dynamic and evolving nature of Nashik's landscape, highlighting the need for a balance between development and environmental sustainability.

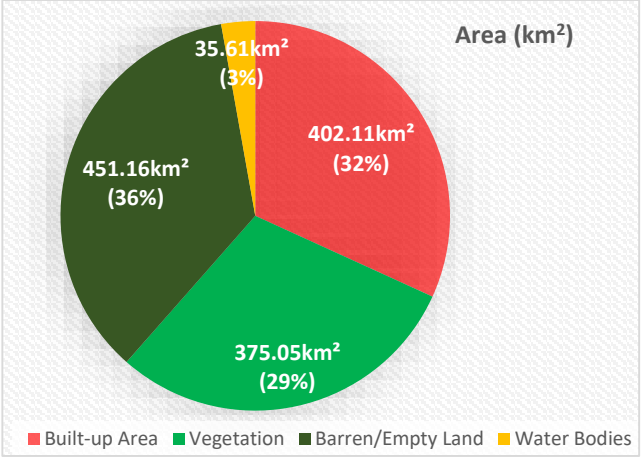

FIG.4: LULC Map of Nashik in the Year 2013 in percentage

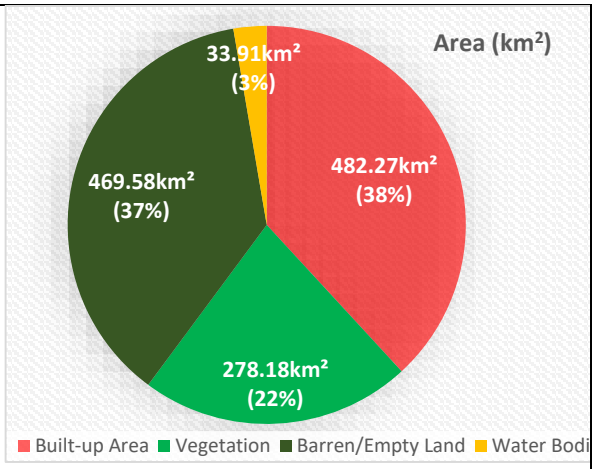

FIG.5: LULC Map of Nashik in the Year 2023 in percentage

Calculation of Shannon's entropy index:

Shannon's Entropy is proposed by Yeh and Li (2001). Here, it is used to compute the urban sprawl phenomenon, and it is expressed as in equation (1):

$H_n = \sum P_i \log_e$_e(Pi) ..... Eq. 1

It is used to quantify the degree of urban sprawl in Nashik between 2013 and 2023. The entropy value increased from 0.10 in 2013 to 0.14 in 2023, as calculated, reflecting a gradual shift toward a more dispersed and sprawling urban development pattern. Shannon's Entropy ranges between zero and the natural logarithm of the number of zones, with values closer to zero indicating a compact or concentrated development, while the maximum value indicates maximum diversity. The slight increase in entropy suggests that urban sprawl has intensified over the decade, with more land being converted into built-up areas in a less concentrated

manner. Although the increase in entropy is moderate, it is a clear signal that the city's growth is spreading outward, leading to a more fragmented urban form. This has implications for infrastructure efficiency, public service delivery, and environmental sustainability, making it imperative for city planners to adopt policies that promote more compact, efficient land use as shown in Fig 4 and 5.

Table 2: LULC Changes in Area and amount of change in different land use /cover categories in Nashik during (2013-2023)

Land Use Type	2013		2023 %		Change 2013-2023	
	Area (km²)	%	Area (km²)	%	Area (km²)	%
Built-up Area	402.11	31.81%	482.27	38.15%	80.16	6.34%
Vegetation Area	375.05	29.68%	278.18	22.00%	-96.87	-7.68%
Barren Land	451.16	35.70%	469.58	37.16%	18.42	1.46%
Water Bodies	35.61	2.81%	33.91	2.69%	-1.7	-0.12%
Total Area	1263.93 km²	100%	1263.93 km²	100%	0.00	0.00
Shannon's Entropy value	0.10		0.14		0.04	

V. CONCLUSION

The study of how land use and land cover changed in Nashik City between 2013 and 2023 has given us useful information about urbanization trends and what they mean for long-term development. The study used multi-temporal satellite images and advanced GIS techniques to accurately measure changes in space and time that would be hard to see with regular mapping methods. The results show how important these technologies are for helping us learn more about how cities grow and how they affect the environment (Table 1).

Urbanization Trends: The large rise in built-up areas, from 31.81% in 2013 to 38.15% in 2023, shows how quickly Nashik's landscape is changing as cities grow. The main reasons for this growth are population growth and economic growth, which have led to a greater need for housing, businesses, and infrastructure. This kind of tremendous change means that we need to produce effective ways to plan and run cities to deal with the problems that come with this rapid urbanization.

Urbanization Trends: Built-up areas grew from 31.81% in 2013 to 38.15% in 2023. This was because the population grew, and the economy grew. This quick growth needs better urban planning to deal with the problems that are coming up.

Land Use Transformations: The amount of vegetation cover went down from 29.68% to 22%, which means that green spaces are being lost to development, which raises concerns about the balance of the ecosystem. There was also a drop in barren land, which shows that land was not being used efficiently.

Spatial Distribution Shifts: A rise in Shannon's Entropy from 0.10 to 0.14 suggests increased urban sprawl and fragmented growth, necessitating compact development strategies.

Methodological Insights: Remote sensing and GIS technologies proved crucial for monitoring land use changes, offering better accuracy than traditional methods.

Policy Recommendations: Urgent policies are needed for sustainable urban growth, including zoning for mixed-use development, investment in public transport, and integration of green spaces.

Furthermore, stakeholder engagement in the urban planning process will be crucial to ensure that development aligns with the community's needs and environmental sustainability, with the following observations.

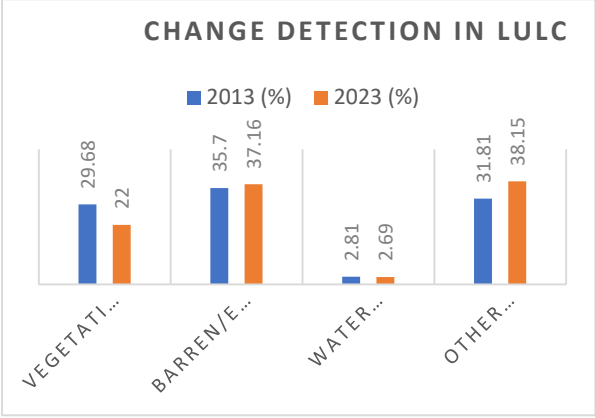

Fig 6. Spatial distribution of % change in LULC classes

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The increase in built up areas highlights significant urbanization, reflecting population growth and economic development. The considerable reduction in vegetation suggests major environmental impacts due to urban expansion and deforestation. The increase in barren land indicates worsening land condition due to overuse and poor management. The slight decrease in water bodies indicates issues like water extraction and pollution.

The shifts between 2013 and 2023 highlight the dynamic nature of Nashik's landscape, underscoring the balance needed between development and environmental sustainability. The land use and land cover dynamics in Nashik City reflect the broader trends of urbanization that pose both opportunities and challenges. By leveraging the findings of this study, Nashik can navigate its growth trajectory towards a more sustainable and resilient future, ensuring the well-being of its residents while preserving its ecological integrity.

The methodologies applied in this research can serve as a model for similar studies in other urban areas, emphasizing the critical role of remote sensing and GIS in contemporary urban studies and planning. The study's findings serve as a critical baseline for future research and policy formulation aimed at achieving sustainable urban development.

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