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Geo-Spatial Insights into Urban Sprawl and Land Use Transformation: A GIS-Based Case Study of Narsinghgarh, Madhya Pradesh

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Abstract Urban sprawls are locations where the lines separating rural and urban areas are crossed. Urban sprawl is caused by a variety of factors, such as population expansion, socioeconomic situations, technological improvements, and development rules. In India, the rapid expansion of cities and towns due to urbanization and population growth has raised serious concerns about urban sprawl. Because urban sprawl has resulted from unplanned and uncontrolled growth, having its boundaries indefinitely is seen as a serious issue. To get rid of these issues, plans for resolving uncertainties in urban sprawl should be put in place. In this sense, rapid data generation and the identification of urban sprawl boundaries would be aided by Geographic Information Systems (GIS). The objective of this study is to monitor the land cover and land use of a portion of Narsinghgarh city and urban sprawl over two time periods, from 2005 to 2015, to detect changes and evaluate urban sprawl using topographic sheets and Google map data in a GIS environment for better decision-making and sustainable urban growth.

Introduction

Unregulated urban growth in India causes serious problems for urban governance and planning. Semi-rural and peri-urban areas are rapidly changing due to rapid demographic shifts and socioeconomic pressures, and traditional planning and regulatory frameworks are frequently unable to keep up with the pace of change (Hossein 2025). Degradation of the environment, loss of agricultural land, fragmentation of landscapes, and increased vulnerability of natural resources are all consequences of inadequate planning. In particular, urban growth is encroaching on forests, water bodies, and arable fields in smaller towns like Narsinghgarh in Madhya Pradesh, endangering the region's ecological balance and impacting sustainability and livelihoods. Understanding how human settlements alter natural habitats and locating areas with the greatest ecological and socioeconomic stresses requires close observation of urban development. Despite their accuracy, traditional survey and mapping techniques are frequently costly, time-consuming, and unavailable to smaller communities in underdeveloped nations (Goetz 2013; Soni et al. 2018). In addition to providing geographical and temporal insights into patterns of urban growth, GIS and remote sensing are technologically sound, dependable, and reasonably priced alternatives (Bhatta 2010). Using these techniques, the project aims to produce evidence-based insights that can guide resource management, policymaking, and sustainable urban development in Narsinghgarh town. Objectives of the Study: The present study aims to analyse the spatial and temporal dynamics of urban sprawl in Narsinghgarh, Madhya Pradesh, using GIS and remote sensing techniques. The specific objectives are: To map and quantify land use and land cover (LULC) changes over time in Narsinghgarh. To identify spatial patterns of urban sprawl and assess their implications for ecological sustainability. To demonstrate the utility of remote sensing and GIS as cost-effective tools for monitoring and evaluating urban growth dynamics in small but rapidly changing urban centres. Rapid population increase and rising land demands are the main causes of urban sprawl, which is the unplanned and frequently haphazard extension of urban centers into the surrounding rural landscapes (Theobald 2001; Bugliarello 2003). Low-density, auto-dependent development that transforms agricultural and natural areas into built-up areas is usually what defines this phenomenon. Land cover and land use patterns are drastically altered by urbanization, often at the price of green spaces and ecological integrity (Herold 2003; Lathrop & Liu 2002; Grimm 2002). In addition to upsetting ecological processes, the transformation of rural areas into impermeable urban surfaces has an impact on local hydrology, productive farmlands, and surface water bodies, frequently posing new problems for environmental sustainability (Banzhaf et al. 1999; Alberti et al. 2000; Grimm 2000).

Research Methodology

Study Area

Narsinghgarh is located on the Malwa Plateau at a Latitude 23°35’N to 24°0’N and a Longitude 76°20’E to 77°10’E. It has an elevation of 483 meters. The town is surrounded by the Satpura Range and has three lakes. Narsinghgarh is selected for the study area, which includes 6 villages notified under the Town and Country Planning Act 1973, which cover an areaof 18.73 km^2. Narsinghgarh town is located in the Rajgarh district of Madhya Pradesh, India. The distance of Narsinghgarh from Rajgarh, the district headquarters, is 50 km and the state capital Bhopal is 83 km away.

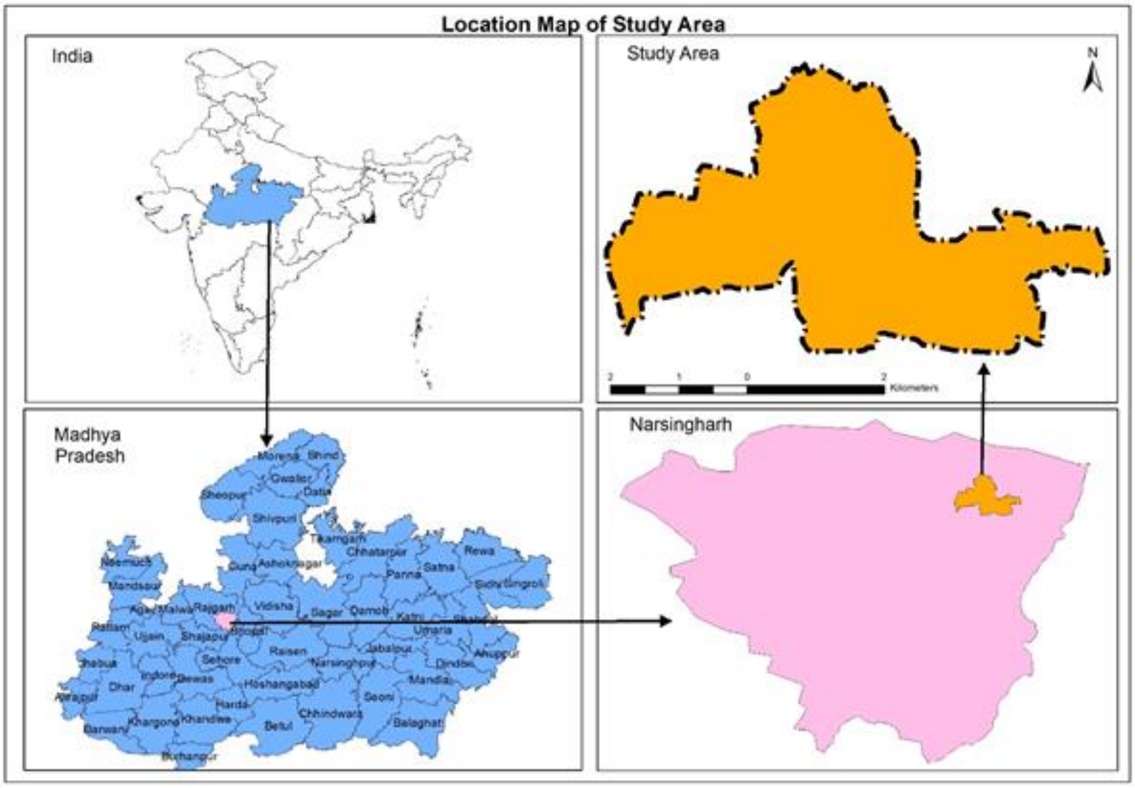

Figure 1 Location Map of Narsingharh Study Area

Methodology

Land use change and urban sprawl have been identified as two of the main features of urban development. With a focus on land use change and urban sprawl from 2005 to 2015, this study attempts to examine the urban growth process in Narsinghgarh city, Madhya Pradesh, India. Urban sprawl, land use/cover trends, and transportation features, including road networks, will be analysed in this study using a scientific methodology and cutting-edge remote sensing and GIS technology. Narsinghgarh town's urban dynamics have been analysed using remote sensing data and Google Earth data from various years.

GIS platform to carry out the analytical part of the estimation and calculation. GIS is adopted for analysing the trends of urban development. We have composed all the maps in Arc GIS 10.6.1 software. Population data of the district Rajgarh, Narsinghgarh town was taken from the Census data 2001 and 2011. Demographic analysis includes the calculation of the average annual growth rate and population density of the study area.

Large-scale, high-resolution satellite data is being mapped in the current investigation, utilizing a very comprehensive classification system. A comprehensive classification system is being created for mapping Narsinghgarh's high-resolution satellite data with the current Google map. For this study, the following land use types have been digitalized: 1. Urban areas; 2. Farmland; 3. Wastelands; 4. Water features 5. Woods 6. Transportation.

For population projection, we used four Incremental Increase, Arithmetic Progression, geometric, and Exponential methods for future projections.

The following formula used for **Population Projection by** the Incremental increase method

Pn=Po+nx+n*(n+1/2*y)

Pn=Population of the year to be projected

Po=Population of the base year

n= number of decad

X= Avg. decadal increase

Y= Avg. Incremental increase

Population Projection by Arithmetic Progression Method

Pn=Po+nx

Population Projection by Geometrical Method

Pn=Po(1+r/100)^n

r=Average decadal growth rate

Population Projection by exponential Method

Pt=P0*e^kt

Results & Discussion

The urban expansion of Narsinghgarh town over the span of a decade, from 2005 to 2015, reveals significant transformations in land use and settlement patterns, as observed through high-resolution Google Earth imagery and GIS-based urban sprawl maps. This narrative captures the progressive shifts in urban form, land conversion trends, and environmental implications, based on visual interpretation and spatial analysis.

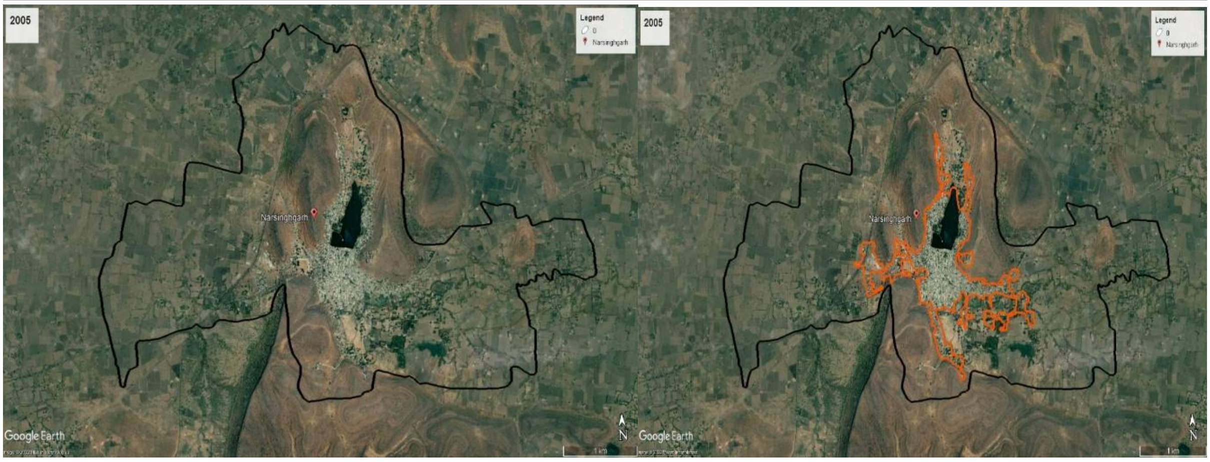

Figure.2 Open Source Google Earth Image & Urban Sprawl 2005

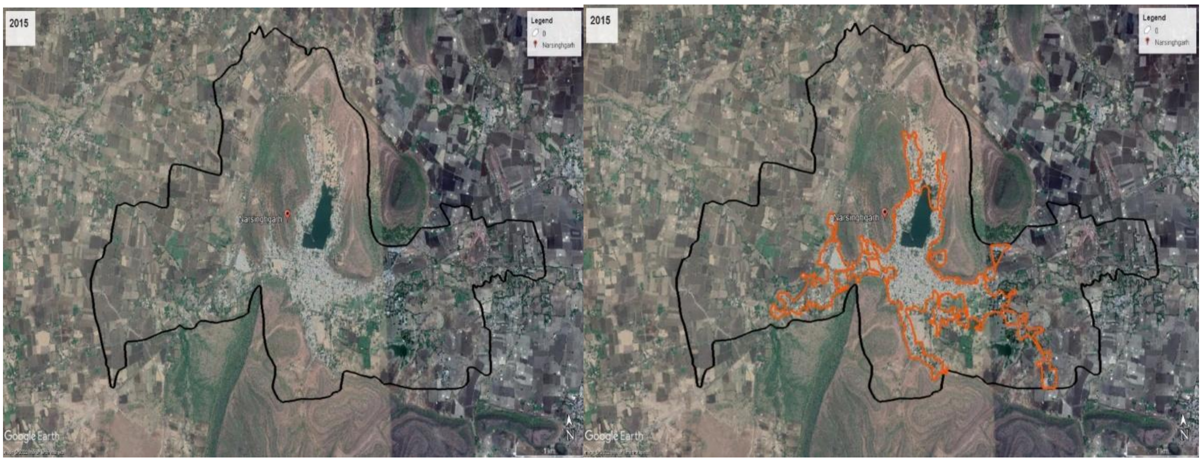

Figure 3 Open Source Google Earth Image & Urban Sprawl 2015

Urban Footprint in 2005

In 2005, Narsinghgarh exhibited a relatively compact and contained urban core. The Google Earth image from this year portrays a traditional urban morphology with clear spatial limits and minimal intrusion into surrounding agricultural or forested zones. Built-up areas were concentrated around the historical centre and major transportation routes. The urban fabric appeared organized, with agricultural fields dominating the peripheral landscape and forested areas maintaining ecological continuity.

This containment is confirmed by the 2005 Urban Sprawl Map, which was created using a GIS. With a population density of 191.27 people per hectare, about 144.94 hectares of land were occupied by built-up areas. This suggests that the settlement was moderately dense and followed a traditional, centralized pattern of development. Peripheral zones were largely rural, with minimal signs of encroachment or leapfrogging development. The town's expansion appeared gradual and largely in alignment with existing road networks (Figure.1 & 2).

Urban Expansion in 2015

By 2015, the town's physical footprint had expanded substantially. The Google Earth imagery from this year shows clear signs of peripheral growth in multiple directions especially toward the north, northeast, and eastern fringe areas. Built-up clusters had begun to appear beyond the traditional urban core, with noticeable fragmentation of agricultural land. The boundaries of the town's woodland appeared disturbed, and adjacent natural features, such as sources of water, indicated the presence of growing communities. The traditional pattern of urban sprawl, horizontal expansion at the expense of productive and green land, is reflected in these visual alterations (Figure. 4).

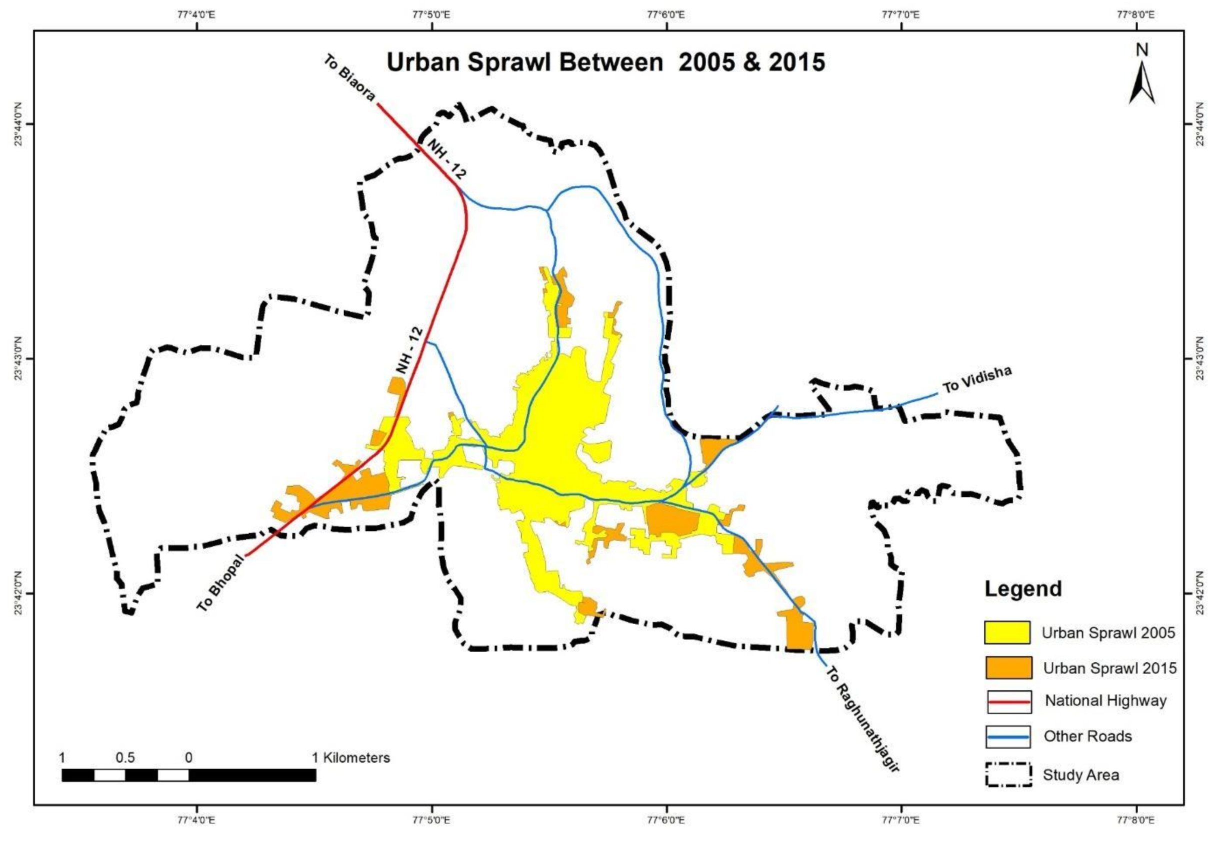

Figure. 4 Urban Sprawl between 2005-2015

Transportation Map

The map highlights the primary transportation arteries serves as a major backbone, connecting Narsinghgarh to larger regional centers like Biaora and Bhopal. Several other roads shown in blue, form a secondary network, facilitating intra-city movement and connecting many parts of the study area. The distribution of these transportation elements suggests a radial and somewhat linear development pattern, influenced by the existing road infrastructure. The presence of a well-defined road network is vital for economic activities, commuting, and the overall functioning of the urban area. The map implicitly suggests that future urban growth will likely continue along these established transportation routes (Figure. 5).

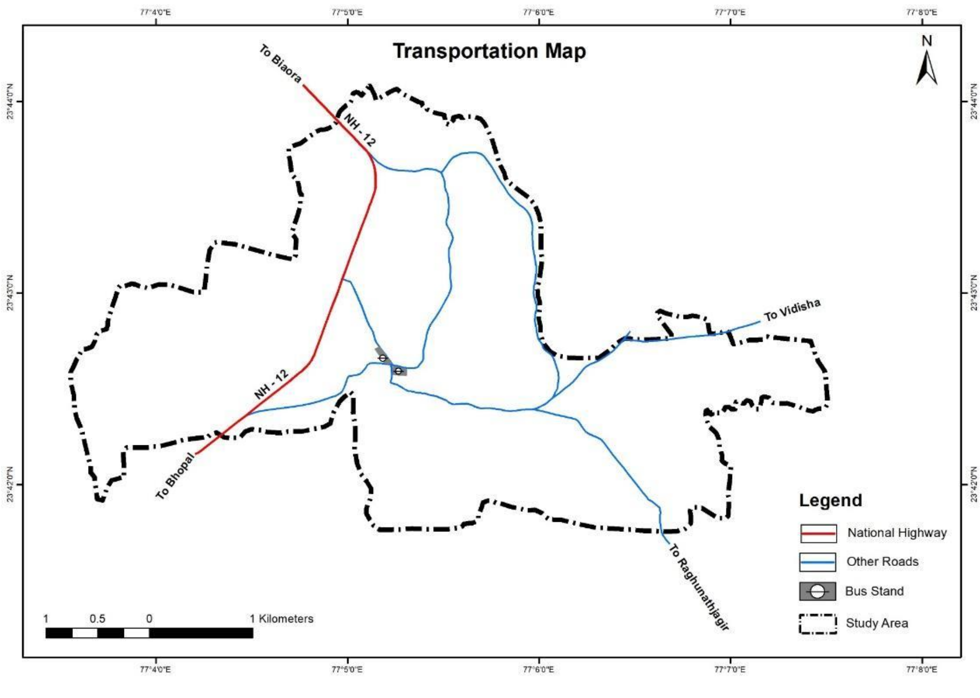

Figure. 5 Transportation map of study area

Land Use Analysis

The land use data provides a quantitative breakdown of how the total area of 1424.97 acres within the study region is utilized (Figure.5). This categorization is fundamental for understanding the dominant environmental and developmental characteristics of the area. In 746.98 acres, or 52% of the total geographical area, agricultural land makes up the greatest portion (Figure. 6). Indicating that farming continues to be a major economic activity and land use, this demonstrates the region's substantial agricultural base. The Built-up Area, or the portion of the land that is developed and urbanized, is 219.59 acres (15%) in total. This graphic indicates the size of human settlements and infrastructure in comparison to the change detection map. There is a considerable quantity of natural forest cover, with 272.91 acres (19%) covered by forest. The provision of environmental services, biodiversity, and ecological balance depend on forests. Wastelands occupy 165.01 acres (12%). Wastelands are typically unproductive or degraded lands that may have potential for future development or restoration. Water Bodies comprise the smallest category, with 20.48 acres (2%), representing rivers, ponds, or other aquatic features within the study area (Fig. 7).

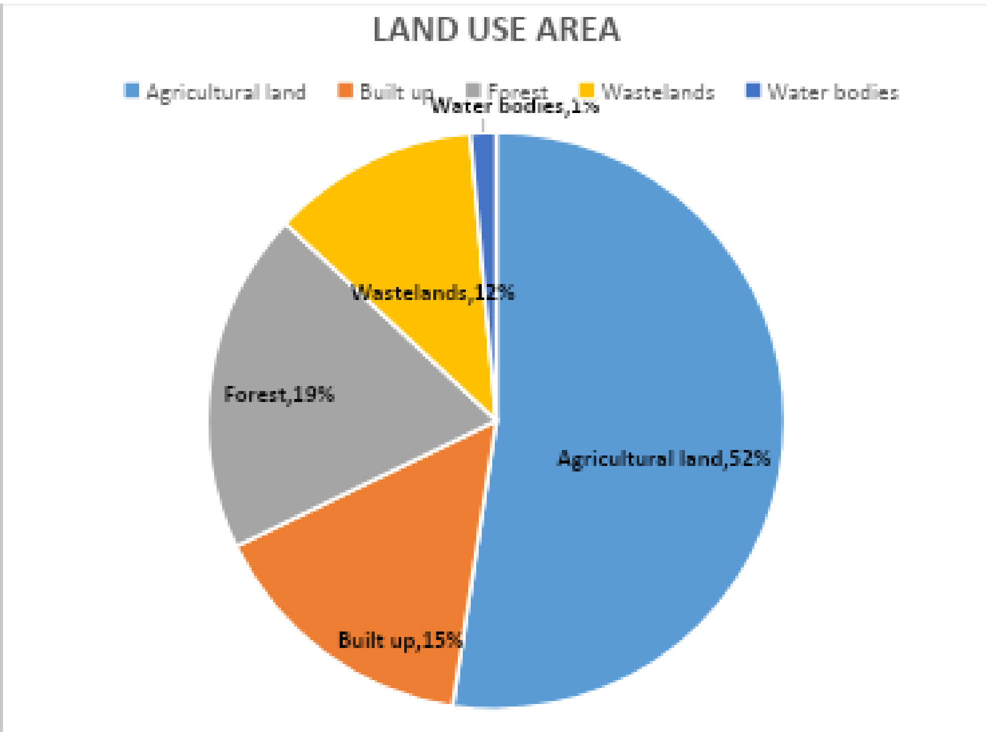

Figure. 6 Major Classes of Land use type of study area

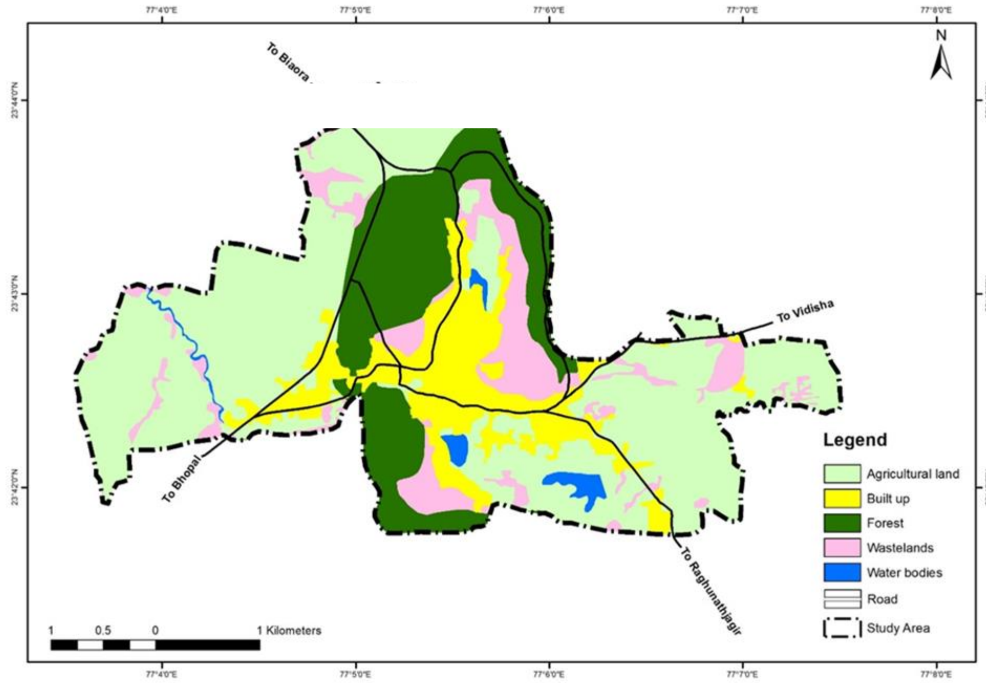

Fig. 7 LULC map of study area

Table: 1 Population Projection (Population Growth Next 20 years) as per Census 2011

Year	Incremental Increase Method	Arithmetic Progression Method	Geometrical Method	Exponential Method
2021	36,658	36,062	39,383	37,700
2031	41,583	39,794	47,975	43,964

The projections for 2021 range from 36,062 (Arithmetic) to 39,383 (Geometrical), with the Incremental and Exponential methods falling in between. For 2031, the range widens significantly, from 39,794 (Arithmetic) to 47,975 (Geometrical). The average of these projections, as noted in the Canvas, provides a balanced estimate, but the spread highlights the uncertainty inherent in long-term forecasting (Table 1).

Table: 2 Decadal Comparative Summary of Population Projections

Year	Incremental Increase Method	Arithmetic Progression Method	Geometrical Method	Exponential Method	Average
1951	9933	9933	9933	9933	9933
1961	11558	11558	11558	11558	11558
1971	13814	13814	13814	13814	13814
1981	17572	17572	17572	17572	17572
1991	22157	22157	22157	22157	22157
2001	27723	27723	27723	27723	27723
2011	32329	32329	32329	32329	32329

2021	36658	36062	39383	37700	37450
2031	41583	39794	47975	43964	43329

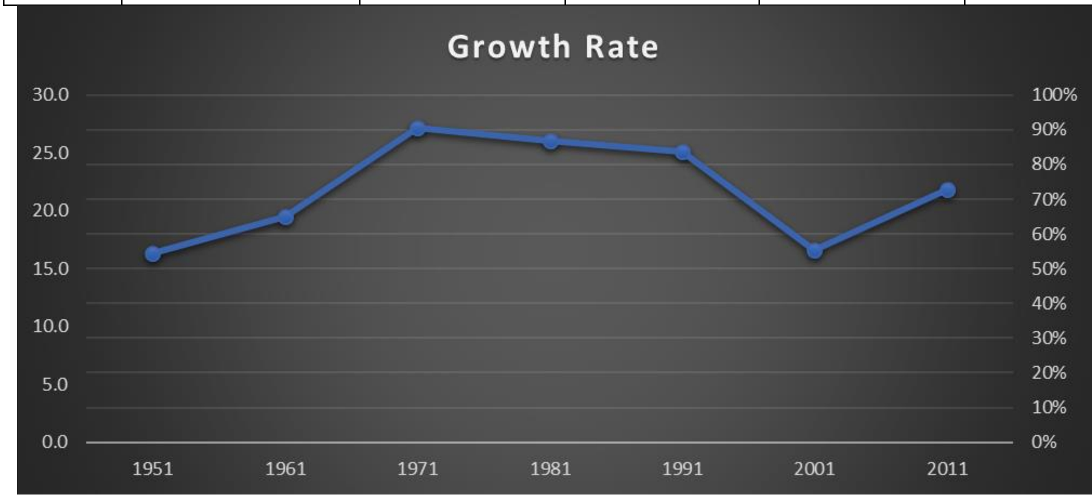

Figure.8 Population growth rate of study area

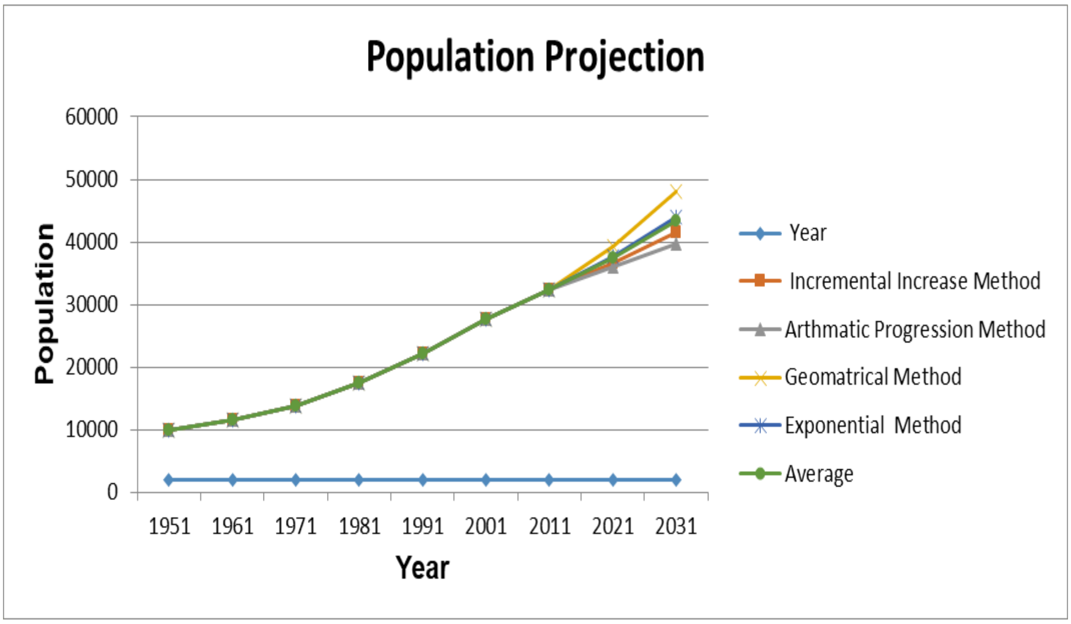

Figure 9 Comparative population projection (1951-2031)

The "Urban Sprawl Between 2005 & 2015" map visually depicts the expansion of built-up areas within the study region over a decade. The map uses distinct colour coding yellow represents urban sprawl in 2005, while orange indicates additional urban sprawl that occurred by 2015. This differentiation clearly illustrates the extent and direction of urban growth. The map shows that significant expansion has taken place, particularly along existing transportation corridors. The urban expansion appears to be radiating outwards from the core built-up areas, consuming adjacent agricultural or vacant lands. This visual evidence of sprawl underscores the need for careful land-use planning to manage the conversion of non-urban areas into built environments. The irregular dashed line outlines the overall study area, providing geographical context to the observed changes. Agriculture still dominates land use, but built-up area now constitutes ~15% of the total, indicating growing urban pressure. The presence of forests and water bodies remains significant, though vulnerable. The dominance of agricultural land, followed by forest and built-up areas, suggests a peri-urban or semi-urban landscape where rural and urban characteristics coexist. The presence of significant wastelands also points to areas that could be targeted for future development or ecological restoration, subject to proper planning.

The map suggests that transportation growth is reactive rather than planned, emphasizing the need for integrated urban mobility plans in upcoming decades. New local roads have emerged around the periphery to service low-density residential clusters. Connectivity between central Narsinghgarh and its outskirts has improved. However, informal or unplanned layouts raise concerns about traffic congestion, public transport reach, and increased vehicular emissions.

Analysing these decadal trends is fundamental for developing realistic and sustainable urban development plans that can effectively manage the city's evolving demographic landscape. The historical data shows a consistent increase in population from 9,933 in 1951 to 32,329 in 2011 (Figure. 9). The decadal growth rate has fluctuated, peaking at 27.2% in 1981 and showing a significant drop to 16.6% in 2011, with an average decadal growth rate of 21.8%. The average decadal increase was 3,733, and the average incremental increase was 596. This historical trend indicates a sustained, albeit varying, population growth in Narsinghgarh. The historical decadal growth patterns have significant implications for urban planning and resource management in Narsinghgarh. Periods of high growth (1981-2001) would have placed immense pressure on existing infrastructure, including housing, water supply, sanitation, transportation, and public services. Understanding these past pressures can inform strategies for managing future growth. The sustained population increase necessitates careful planning for resource allocation, particularly for essential services. The fluctuations in historical growth rates, especially the recent drop, are critical inputs for the population projection models. A simple arithmetic progression might overestimate future populations if the recent deceleration is a sustained trend, while a geometrical or exponential method might capture compounding effects if growth re-accelerates. The use of multiple projection methods, as presented in the Canvas, is therefore a prudent approach to account for this variability and provide a range of possible future scenarios.

The use of multiple projection methods provides a range of possible future populations for Narsinghgarh, reflecting different assumptions about the nature of growth (Figure. 9). The population projections for Narsinghgarh consistently indicate continued growth over the next decade, albeit with varying magnitudes depending on the methodology used. The Geometrical Method suggests the most aggressive growth, while the Arithmetic Progression Method offers a more conservative outlook. Planning for increased demands on housing, water supply, sanitation, electricity, transportation, and social infrastructure (schools, healthcare facilities). Ensuring sustainable management of natural resources, particularly water and land, to support a larger population. Developing strategies to create sufficient employment opportunities for the growing workforce for future generation. Recognizing the inherent uncertainty in long-term projections and adopting flexible planning frameworks that can adapt to different growth scenarios and adaptive planning.

By considering the range of these projections, Narsinghgarh can develop more robust and resilient urban development plans to effectively manage its evolving demographic landscape and ensure a sustainable future for its residents.

Conclusion

The investigation reveals that land use and land cover changes, as well as trends in urban spatial growth, may be accurately and thoroughly assessed using remote sensing and GIS approaches. Through the integration of demographic and infrastructure data with geographical data, the study highlights how these approaches are effective instruments for planning for the future at both rural and urban areas. The results demonstrate that while urban sprawl cannot be totally avoided, its effects can be considerably lessened with the use of sustainable and structured planning frameworks. The results, especially when it comes to examining land use dynamics, transportation connections, and population growth patterns, provide a strong foundation of knowledge that helps planners and policymakers build solutions that take into account both developmental requirements and ecological factors.

However, the study also recognizes certain limitations, including the difficulty of including local socioeconomic aspects into extensive spatial analysis, potential gaps in temporal datasets, and the reliance on the quality and resolution of accessible satellite data. These limitations show that although the strategy works, it needs to be carefully interpreted and enhanced by information from the ground to guarantee precision and contextual relevance. Thus, the use of such techniques not only improves planning abilities but also emphasizes the value of inclusive procedures where local expertise may support technological evaluations for comprehensive solutions.

Potential next steps for this work include developing the use of higher-resolution information, adding real-time monitoring technology, and expanding the analysis to incorporate ecological services and climate resilience into urban planning models. Urban growth estimates may become even more accurate if machine learning and predictive modelling are combined with GIS. Furthermore, the scientific and social aspects of sustainable development would be strengthened by incorporating local populations in ecological monitoring and land-use planning. These guidelines suggest a more flexible and inclusive planning paradigm in which community involvement and technology work together to steer Narsinghgarh and surrounding areas toward sustainable urban expansion that is balanced over the long run.

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Data Availability- All of the GIS data used in this work is publicly accessible. Data from remote sensing and Google Earth from several years has been analysed.

Conflict of Interest: The authors declare that there are no actual or potential conflicts of interest related to this study

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