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"ASSESSING SUSTAINABLE URBAN GROWTH THROUGH GIS-BASED LULC DYNAMICS (2000–2025) AND AHP FOR ROHTAK CITY"

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ABSTRACT

The rapid urban growth in mid-sized Indian cities has underlined the need for spatially informed strategies that seek to balance development and environmental integrity. This study investigates the patterns and sustainability dimensions of land transformation in Rohtak municipal boundary between 2000 and 2025 using a geospatial and multi-criteria analytical framework. Multi-temporal Landsat satellite images were processed at five-year intervals to generate detailed land cover maps through supervised Maximum Likelihood Classification enabling quantitative assessment of spatial change trajectories. Classification accuracy was validated using Kappa statistics, which confirmed strong agreement and consistency across all temporal datasets. To evaluate the spatial potential for future development, a site suitability model was developed employing the Analytic Hierarchy Process (AHP). Different environmental, demographic and infrastructural parameters—population, urban density, road density, elevation, slope, and prevailing land characteristics—were standardized, weighted, and integrated within a weighted overlay framework in GIS. The derived suitability index map delineated four priority zones ranging from very low to very high potential for urban expansion. Model validation, achieved through overlay analysis of observed built-up growth patterns, revealed a strong spatial correlation between actual expansion and areas of high predicted suitability, demonstrating the model's reliability and applicability. The results indicate a continuous conversion of agricultural land to impervious surfaces, particularly along major corridors, raising concerns about ecological balance and resource security. The integrated approach applied here illustrates how geospatial modelling and decision-support tools can effectively guide sustainable land management, helping policymakers identify optimal zones for balanced urban growth. The methodological framework offers a replicable model for medium-sized cities aiming to integrate environmental considerations into spatial planning.

KEYWORDS: Spatial Decision Modelling, Land Transformation Analysis, Remote Sensing Applications, Urban Sustainability, Geospatial Assessment, Multi-Criteria Evaluation.

Introduction

The increased pace of urbanization in India over the past few decades has fundamentally transformed country's socio-economic structure. The shift from largely rural economy to an increasingly urban one reflects broader processes of industrialization, economic liberalization, and demographic change. The relevance of middle and second tier cities is increasingly increasing as the engines of regional growth though academic and policy attention has traditionally embroiled itself in the metropoles (like Delhi, Mumbai). These cities increasingly act as growth poles, soaking up population spillover from metropolitan centers, while pulling investment in infrastructure, industry and services. As a result, they are undergoing rapid and often uneven spatial growth.

The growth is differentiated by extensive land-use transformation, particularly the conversion of agricultural and peri-urban land into built-up areas. These are driven by administrative expansion, real estate development, institutional growth, and infrastructural investments. According to Census 2011, India's urban population accounted for 31% and is projected to exceed 40% by 2036 (Census of India, 2011; NITI Aayog, 2021). A significant proportion of this growth is concentrated in medium-tier cities and urban fringes, which often lack robust planning frameworks with fragmented governance structures. As a result, these areas frequently experience unregulated urban sprawl.

The consequences of such rapid and unplanned urbanization are multifaceted. Ecologically, degraded ecosystems, loss of agricultural land, depletion of water resources, increases vulnerability and climate risks. Encroachment on wetlands, drainage systems, and green spaces further undermines ecological balance and resilience. Economically, urban growth boosts employment and productivity, but can also intensify spatial inequalities. Socially, population influx exerts pressure on housing, infrastructure, and services, often resulting in informal settlements and unequal access to resources (Bhagat, 2018).

In this regard, it is essential to assess the nature and sustainability of urban growth for effective planning. Spatial analysis allows the understanding of temporal transformation of land and identifies growth hotspots, infrastructure deficits, and ecological sensitive areas. Such insights support evidence-based policymaking, zoning regulations, and targeted infrastructure development. Moreover, spatial analysis aligns with global sustainability frameworks such as the United Nations Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action), which emphasize resilient and sustainable urban development (United Nations, 2015).

Improved geospatial technologies, particularly remote sensing and Geographic Information Systems (GIS), significantly enhance the study of urbanization. These tools allow detailed temporal and spatial analysis of Land Use Land Cover (LULC) changes, offering accurate and cost-effective alternatives to traditional methods. They facilitate the integration of multi-temporal datasets, allowing for the monitoring of land transformation patterns and the assessment of their sustainability implications (Jat et al., 2008; Herold et al., 2003). Furthermore, spatial modelling techniques enable the simulation of future growth scenarios, supporting proactive and informed planning.

Within this national context, Rohtak presents a notable example of rapid urban transformation in a mid-sized city. Located in the south-eastern part of Haryana, approximately 70 km northwest of Delhi, Rohtak lies within the National Capital Region (NCR) and experiences strong spillover effects from Delhi's expansion. This strategic location has facilitated its emergence as an important administrative, educational, and commercial hub. Over the past two decades, the city has transitioned from a predominantly agrarian economy to a more diversified urban-industrial system, driven by infrastructural development, industrialization, and improved connectivity along corridors such as the Delhi–Hisar axis (Haryana Urban Development Authority, 2020).

Rohtak's socio-economic structure reflects a hybrid character, where agriculture coexists with expanding service-sector activities. The city noted significant population growth and spatial expansion since the late 1990s, with the municipal population reaching approximately 374,000 by 2011 (Census of India, 2011). Its upgradation to a Municipal Corporation in 2010 further accelerated urban growth through administrative expansion and the incorporation of peripheral areas (Sharma & Joshi, 2012). Spatially, Rohtak exhibits a concentric-cum-dispersed pattern, with the

historic core expanding outward along transport corridors and industrial zones.
Remote sensing analyses reveal that the built-up area in Rohtak has increased nearly fourfold between 1991 and 2021, largely at the expense of agricultural land (Kumar & Dahiya, 2022). Economic drivers such as the development of the Industrial Model Township (IMT) Rohtak, expansion of educational institutions, and improved connectivity with Delhi have further stimulated growth and in-migration (Haryana State Industrial and Infrastructure Development Corporation [HSIIDC], n.d.). However, this rapid expansion introduced significant challenges, like unregulated land-use change, environmental degradation, and pressure on urban infrastructure. The integration of Rohtak within the NCR framework necessitates coordinated planning approaches to address these challenges and ensure sustainable development (National Capital Region Planning Board [NCRPB], n.d.). In this context, understanding the spatial patterns and drivers of urban growth is essential for effective policy intervention. A comprehensive assessment of land-use changes, combined with suitability analysis for future development, can provide critical insights for managing urban expansion in a sustainable and equitable manner.

In **2001, Michael P. Johnson** summarized the potential implications of urban sprawl, primarily environmental. The direct implications of sprawl are defined and characterized, including fragmentation of habitat, increased pollution, and loss of biodiversity related to low-density development patterns. Johnson critiques previous studies for merely focusing on the quantifying and modeling and addresses the need for assessing consideration of environmental factors within land-use planning to avoid negative impacts. Johnson stresses the need for further research into this evolving field.

Vishal Chettry's 2022 research, provides an analysis of urban sprawl in Thiruvananthapuram, an Indian medium city. Significant growth of built-up land was apparent with overall growth of 126% across the two decades and a decline of 21% of non-built-up land cover. Shannon's entropy index method was utilized to assess urban sprawl indicating shifting characteristics to more dispersed, low-density development. The work also assessed peri-urban areas and identified scatter development typologies as prevalent in the peri-urban areas. The author's work points to sustainable urban planning and policy for mitigating the issues caused by uncontrolled urban expansion.

Kundu (2019) studies the complex patterns of peri-urban expansion in North Indian towns. The focus is on interconnections between land transformation, livelihood shifts, and governance challenges. The paper highlights the blurring lines between rural-urban areas which generate hybrid socio-spatial forms and contested land relations. The author suggests inclusive governance frameworks to integrate peri-urban areas into broader urban planning processes. By linking land, livelihoods, and governance, the paper contributes to understanding the uneven geographies of urbanization in India and the need for policy responses attuned to local contexts.

Sharma and Kumar (2023) studies the urbanization patterns and shifts in urban hierarchy in Haryana. By making use of demographic and spatial data, the authors trace the economic restructures, expansion of infrastructure, and policy interventions that have changed the states' urban landscape. The shift is noticeable by the rapid rise of medium towns and peri-urban centers alongside industrial hubs like Gurugram and Faridabad and in the NCR region. Although the uneven pace of urban growth creates disparities and differential access to infrastructure, governance efficiency, and economic opportunities in cities across the state. Overall, it contributes to spatial inequality, regional planning, and smart urban growth in Haryana.

Javadian, et. al (2011) applied the Analytical Hierarchy Process (AHP) with Geographic Information System (GIS) to assess the environmental suitability of educational land use in Tehran. The work focuses on the environmental dimension of sustainable urban development by identifying optimal locations for schools based on slope, accessibility, and land-use compatibility. Expert driven pairwise comparison was used for weighted index for the spatial factors and suitability mapping. The study showed spatial differences in spread educational infrastructure due to lack of planning. The model identifies suitable zones for further development. AHP-GIS integration is a key decision-support tool for urban sustainability in the research.

Chandio et al. (2011) applied GIS and AHP techniques for optimal sites for public parks in Larkana, Pakistan. Three parameters were considered which were land availability, land value, and population density to generate multiple suitability maps. The weighted linear combination method was applied for interrelating spatial and non-spatial data. Results revealed differences in suitability of land across scenarios and aided in land-use allocation. It highlights the implication of AHP in green space planning in urban cities specially in developing countries.

Kumar and Kumar (2014) assessed site suitability for urban development in Nahan, Himachal Pradesh. The work was based on slope, land use/land cover, drainage, road proximity, and soil characteristics as the main parameters to evaluate terrain constraints and development potential. Weights were assigned to each thematic layer using the AHP, based on their relative importance in sustainable hill-area planning. The various zones highlighted in the findings were high, moderate, and low suitability for expansion while minimizing environmental risks highlighting the role of GIS–MCE for balancing ecological sensitivity with urban growth in hilly terrains.

Aburas et al. (2015) critically analyzed the application of GIS-based Analytic Hierarchy Process (AHP) for land suitability analysis particularly for urban growth. The work talks about multiple works employing GIS and AHP for sustainable land-use evaluation. The common parameters undertaken for the study in urban suitability models are —physical, accessibility, socio-economic, and environmental. AHP's effectiveness in managing multiple criteria through expert-derived weights and pairwise comparisons are appreciated. The comprehensive review showcases that GIS–AHP integration enhances spatial decision support systems for urban planning presenting a framework for improving future urban development models.

Aburas et al. (2017) conducted land suitability analysis for urban growth in Seremban, Malaysia using a GIS-based AHP model. The work was based on combined physical, environmental, and socio-economic variables including elevation, slope, population density, and proximity to infrastructure. AHP weighting and consistency checks helped identify areas most suitable for sustainable development. The results revealed 48% of Seremban's area as highly suitable for urban expansion, while 35% unsuitable.

Parry, et. al (2018) use a GIS-AHP model for land suitability for urban service provisions in Srinagar and Jammu. The work focused on rapid urbanization and unequal distribution of facilities. It was based on multiple physical and socio-economic determinants such as slope, altitude, land use, and existing amenities. Urban wards were classified into suitability zones by utilizing AHP's pairwise comparison and weighted parameters integrated in GIS. The peripheral areas revealed lack of essential services like health and education. The authors suggest that GIS-based multi-criteria analysis can be useful for equitable urban planning providing insights for planners to optimize future urban development.

Santosh, et. al (2018) employed multicriteria evaluation using AHP for urban site suitability in Chikodi Taluk, Karnataka. The study is based on six thematic layers—slope, land use, road proximity, land cost, lineaments, and aspects assessed the potential for development in the area balancing both economic and environmental parameters. Weighted overlay analysis classified land into five suitability categories. The findings point out that an area of 66.88 km^2 was highly suitable while 22.44 km^2 very highly suitable for urban expansion suggesting its reliability for sustainable urban land-use planning in hilly regions.

Gabril et al. (2019) used geospatial tools and the Analytical Hierarchy Process (AHP) to determine suitable sites for urban development in Prayagraj, India. The work is based on seven thematic layers—LULC, lithology, soil, drainage, slope, road, and river proximity and weighted using Saaty's scale, which were then combined using weighted linear combination in GIS. The findings highlighted a suitability map which classified land into five suitability zones, assisting urban planners in decision-making. The work suggested a replicable model for sustainable development in rapidly urbanizing Indian cities

Patil and Jamgade (2019) conducted a GIS-based multicriteria evaluation (MCE) study to identify suitable areas for urban development in Navi Mumbai, Maharashtra. The research was based on spatial layers including slope, land use, proximity to roads, and water bodies with socio-economic parameters to develop a comprehensive suitability model. Using weighted overlay analysis in GIS, each criterion was assigned importance values through the Analytical Hierarchy Process (AHP). The findings suggested the central and southern zones of Navi Mumbai with the highest suitability for sustainable development guiding rational urban planning in rapidly expanding metropolitan areas.

Deliry and Uygucgil (2020) investigated sustainable urban development in Eskisehir, Turkey, through GIS-based multi-criteria analysis using AHP. The study evaluated six main planning goals—safety, connectivity, socio-economic equity, compactness, topography, and eco-environmental conservation. The data for geology, roads, education, and health centers was used to demarcate suitable zones. The findings suggest that only 0.01% of the area was highly suitable, while most land was low or unsuitable for sustainable expansion.

Levend and Sağ (2023) conducted suitability analysis for the "Bizim Şehir Project" in Konya, Türkiye, for integrating sustainability principles into urban development planning. The main factors—soil, geology, natural disasters, aspect, slope, and property status—were considered to evaluate site suitability. The work focused on identifying ideal construction zones by emphasizing spatial analysis of datasets with AHP weighting to prioritize criteria influencing suitability. It was noted that 54.9% of the project area was best suited for urban expansion suggesting sustainable urban planning frameworks in rapidly developing cities.

Kumar and Sehgal (2024) studies magnitude, direction, and pace of urbanization in Yamuna Nagar with help of analytical techniques and map land use / land cover (LULC) change. There is significant urban increase due to population pressure, industrialization and infrastructure intervention with increased pressure on land and natural resources. The paper also describes the evolution of peri-urban transformation with the help of space metrics and quantitative measures. The paper adds to the local perspectives to discussions of urbanization patterns and spatial planning in Indian medium urban centers by including environmental and planning concerns regarding sprawl, and the need for sustainably driven and managed urban growth.

Nina Singh and Jitendra Kumar (2011) notes analysis of rapid urbanization and its impacts on Rohtak's environmental and physical environment. By examining land use and land cover changes over time the authors assess urban growth with increased urban growth and city's incorporation in the National Capital Region (NCR). The impacts of the changing cityscape have led to loss of open spaces, changes in drainage pattern, and increased environmental stress. The paper presents policy relevance with supported accounts of urban transformation and contributes to sustainable urban planning and regional development policies in developing urban centers across the country such as Rohtak.

Singh and Kumar (2012) investigate the urban growth of Rohtak and find that built-up areas have significantly expanded at the expense of vegetative and agricultural land. The study highlights the effects of urbanization on open spaces, drainage patterns, and environmental stress while tying it to population pressure, development, and NCR inclusion. To direct sustainable urban development in developing cities, it highlights the necessity of data-driven planning.

RS Sangwan et al. notes the spatial-temporal changes in Rohtak city over a span of eight years. The transformation of agricultural fields to built-up points to spatial growth associated with the emerging role within the National Capital Region (NCR). The paper also discusses socio-economic impacts and the environmental concerns like unplanned growth and increasing land pressure that arise with urban growth. The study provides a comprehensive understanding of spatial urban changes in medium-sized Indian cities setting the foundation for sustainable urban and regional planning in Rohtak.

Priyanka Malik and Naresh Kumar (2021) investigate the environmental implications of unscored urban growth and sprawl in Rohtak. The study applies geospatial techniques and field observations to explore the effects of urban sprawl on land use and change, diminishing agricultural and green cover, and elevating environmental stress as pollution increases and land begins to degrade. The authors demonstrate a direct relationship between population growth, infrastructure expansion and declining environmental quality as indicated by air, water and soil health indicators. The study also illustrates the ecological imbalance from unplanned spatial growth, especially in peri urban regions. It is useful for understanding ecological consequences of urban sprawl, and in developing environmentally sensitive urban development solutions in fast growing regional cities like Rohtak.

Sharma and Kumar (2022) used GIS and remote sensing methods to examine the spatial dynamics of Rohtak's urban growth between 1991 and 2020. According to their research, built-up regions have significantly expanded outward, especially along important transit lines, resulting in land-use change and peripheral sprawl. Uneven urban development patterns were highlighted by the findings, underscoring the necessity of smart growth policies and sustainable spatial planning to control Rohtak's rapidly increasing urbanization.

Ruchi and A. Rajshekhar (2024) gives information about Rohtak's urban evolution using geospatial techniques. The study maps urban growth patterns and notes greater built-up areas reflecting greater urban sprawl. The morphology of the growth is also studied, and the land use changes are noted in accordance with policy interventions providing insights about factors for urban change. It uses an interdisciplinary approach making it a comprehensive study to understand urbanization and land management in growing Indian urban centers.

Meena Deswal and J.S. Laura (2018) integrate environmental, socioeconomic, and infrastructure factors to determine the best landfill locations in Rohtak using GIS and the Analytic Hierarchy Process (AHP). Their multi-criteria approach minimizes ecological and social impacts while highlighting sustainable waste disposal zones. The study shows how useful spatial decision-making tools are for effective urban environmental planning and management.

The review of existing literature reveals that substantial research has been conducted on the urban transformation of Rohtak, encompassing environmental, physical, and economic dimensions, but largely remain descriptive and sector-specific in nature. There is also considerable research on GIS-based Analytic Hierarchy Process (AHP) models and their ability to assess urban growth patterns and determine suitable sites for potential development. Nonetheless, there is a distinct data gap within the available literature in terms of applying an integrated methodological framework to explore both historical land-use changes and future growth suitability regarding urban expansion potential for Rohtak.

Despite increasing attention to sustainable urbanization in India, there remains a limited number of integrative spatial studies focusing on mid-sized cities such as Rohtak. Existing research on the city's urban transformation, though substantial, largely examines isolated dimensions—environmental, physical, or economic—and tends to be descriptive and sector-specific. While GIS-based techniques and the Analytic Hierarchy Process (AHP) are widely recognized for assessing urban growth and site suitability, their application has been largely confined to metropolitan regions like Gurugram and Faridabad.

In the case of Rohtak, most studies are restricted either to multi-temporal LULC mapping or to singular environmental assessments, without integrating past land-use dynamics with future growth potential. This fragmented approach limits the development of comprehensive and sustainable planning strategies. Despite Rohtak's rapid expansion and its growing significance as a regional center within the NCR, no study has systematically combined LULC change detection with GIS-based AHP modelling to establish a linkage between historical urban growth and future suitability.

Thus, this study addresses this gap by proposing an integrated spatial-temporal and multi-criteria framework to support sustainable urban planning in Rohtak.

Objectives:

1. To analyze LULC changes in Rohtak (2000–2025) using multi-temporal satellite data.
2. To map the spatial pattern of urban expansion and its sustainability implications.
3. To develop a site suitability model for sustainable urban growth using AHP.
4. To recommend planning strategies for balanced development.

The study adopts an integrated GIS–AHP framework to examine urban growth and assess land suitability for sustainable development within the municipal boundary of Rohtak. By combining multi-temporal LULC change detection (2000–2025) with AHP-based suitability modelling, the study establishes a direct linkage between historical land transformation and future urban growth potential. Remote sensing facilitates the analysis of spatial and temporal land-use changes, while GIS enables the integration of multiple criteria, including environmental, infrastructural, and socio-economic factors. The application of AHP (Saaty, 1980) allows for systematic weighting and prioritization of these factors, ensuring a transparent and consistent decision-making process. When integrated with GIS, this approach translates complex spatial relationships into actionable suitability maps, thereby strengthening planning interventions (Malczewski, 2006).

The novelty of the study lies in its spatial-temporal and multi-criteria integration, which not only evaluates past urban expansion but also provides a predictive framework for future growth. Consequently, the research offers a methodologically robust and regionally relevant model to support sustainable urban planning and policy formulation in Rohtak and similar mid-sized cities (Prakasam, 2010).

Study area

Rohtak is a medium-sized urban area which is also a class -1 census town and administrative headquarter of Rohtak district. The urban landscape of the city is undergoing rapid transformation largely governed by Municipal Corporation. The Municipal Corporation Rohtak (MCR) administrative boundaries, which covers roughly 135 square kilometers of urban and peri-urban land in Haryana, India, is the research area.

Rohtak, located in the Indo-Gangetic Plains, with subtropical monsoon climate ranging from semi-arid to sub-humid, with hot summers, cool winters, and a distinct monsoon season, indicating strong climatic seasonality. The absence of major perennial rivers makes the region dependent on seasonal drains and groundwater (Central Ground Water Board). These climatic and hydrological characteristics shapes resource availability, vulnerability, and sustainable urban planning.

Economically, Rohtak is diversified, with agriculture and education hubs like Maharshi Dayanand University and Indian Institute of Management Rohtak, and industrial development under Haryana State Industrial and Infrastructure Development Corporation. Its strategic position along National Highway 9 and the Delhi–Rohtak corridor enhances connectivity, making it a commuter and industrial hub. These factors drive urban expansion, influence land-use change, and attract a migrant population, contributing to evolving demographic and economic patterns.

Methodology

This section describes methodology including the collection of data, preprocessing, classification, change-detection, multi-criteria AHP modelling, and validation steps used to assess Rohtak's historical urban growth (2000–2025) and to produce a site suitability map for sustainable urban expansion

Data Sources

The study integrates multi-temporal remote sensing data and ancillary spatial datasets to assess the dynamics of urban growth in Rohtak and to evaluate future site suitability through a GIS–AHP framework. Multi-temporal satellite images were acquired for the years at the gap of 5 years for 2000, 2005, 2010, 2015, 2020 and 2025. For temporal consistency and comparability, Landsat data were chosen for their medium spatial resolution, free accessibility, and compatibility with urban studies. The satellite images were taken for Landsat 5 (TM) and Landsat 8 (OLI) for the early months of the year between the months of March and May with nearly zero cloud cover to have clear images for land classification.

Supplementary data sources were used to strengthen spatial interpretation and modelling accuracy:

1. **Census of India (2001, 2011):** demographic, density, and economic activity data.
2. **Municipal Land-Use Plans (Rohtak Master Plan 2031):** reference for land-use zoning and development regulations.
3. **Digital Elevation Model (SRTM 30 m):** slope and elevation inputs for suitability analysis.
4. **Transportation Layers:** vector data on highways, major roads, and rail networks from the Haryana GIS portal and OSM layer.

All datasets were georeferenced to the Universal Transverse Mercator (UTM) coordinate system, Zone 43N, WGS-84 datum for uniform spatial analysis.

Data Preprocessing included aligning images to the Rohtak administrative boundary using ground control points derived from topographic maps and municipal base layers and creating multi-band composite images for each year. This facilitated better discrimination of land-cover classes.

LULC mapping (supervised classification)

The supervised classification method is commonly used and reliable approaches in remote sensing for Land Use Land Cover (LULC) studies allowing precise mapping and quantification of urban expansion.

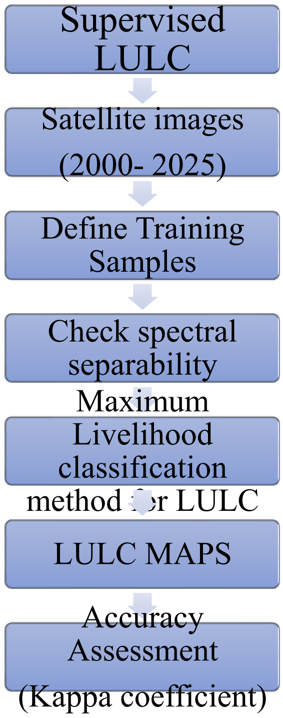


Figure1: Methodology LULC

The Maximum Likelihood Classification (MLC) algorithm was used to generate LULC maps for 2000, 2005, 2010, 2015, 2020, and 2025. It involves the classification of satellite imagery into predefined land cover categories based on spectral signatures derived from training samples representing each class using ArcGIS. This algorithm assumes a normal distribution of spectral signatures and classifies pixels based on statistical probability.

1. **Selection of Classification Scheme and Training Samples**
   Maximum Likelihood Classification was tailored to the local context. The primary classes included: Built-up Area, Agricultural Land, Vegetation and Water Bodies. Training samples for each class were identified using a combination of field observations, high-resolution imagery from **Google Earth**, and local knowledge. A minimum of 30-40 training pixels per class were digitized to ensure spectral variability within each land cover type was adequately represented. Regions of Interest (ROIs) were delineated in the GIS environment (ArcGIS).

2. **Training & validation.**
   Training samples are collected from a mix of field GPS points (where available), high-resolution imagery (Google Earth), cadastral/municipal plans and historical topo maps (Survey of India). Spectral separability is checked (e.g., Jeffries–Matusita) and training signatures refined iteratively.

3. **Post-Classification Refinement**
   Refinement was performed after classification to remove misclassified pixels. Manual editing was done using reference data where confusion between spectrally similar classes was observed. Subsequently, **area statistics** were computed to quantify the extent and proportion of each land class. The resulting maps were re-classified and symbolized to enable temporal comparison of built-up expansion and land transformation.

4. Accuracy assessment
   The accuracy of LULC maps was checked using ground truth points obtained from high-resolution imagery from Google Earth. A **Confusion matrix** (error matrix) was generated to compare classified pixels against reference data. The **Overall Accuracy**, **Producer's Accuracy**, **User's Accuracy**, and **Kappa Coefficient** were calculated.

Overall Accuracy $(P_0) = \frac{\text{Total true points}}{\text{Total points demarcated}}$

Producer Accuracy $(P_e) = \frac{(P^1 \times U^1)+(P^2 \times U^2)+(P^3 \times U^3)+(P^4 \times U^4)}{N^2}$

Kappa Co-efficient $= \frac{P_0 - P_e}{1 - P_e}$

Where, 'p' is producer total, 'u' is user total and 'N' is Total Points demarcated. A Kappa value > 0.80 indicates strong agreement between classification and reference data (Congalton & Green, 2009).

Analytic Hierarchy Process (AHP)

The **Analytic Hierarchy Process (AHP)**, developed by **Thomas L. Saaty** (1980), is a multi-criteria decision-making (MCDM) technique which aids in structuring complex decision problems for both qualitative and quantitative parameters. It is used for geospatial studies employing multiple spatial layers. Various suitable zones for sustainable urban expansion for Rohtak city have been demarcated using AHP and GIS.

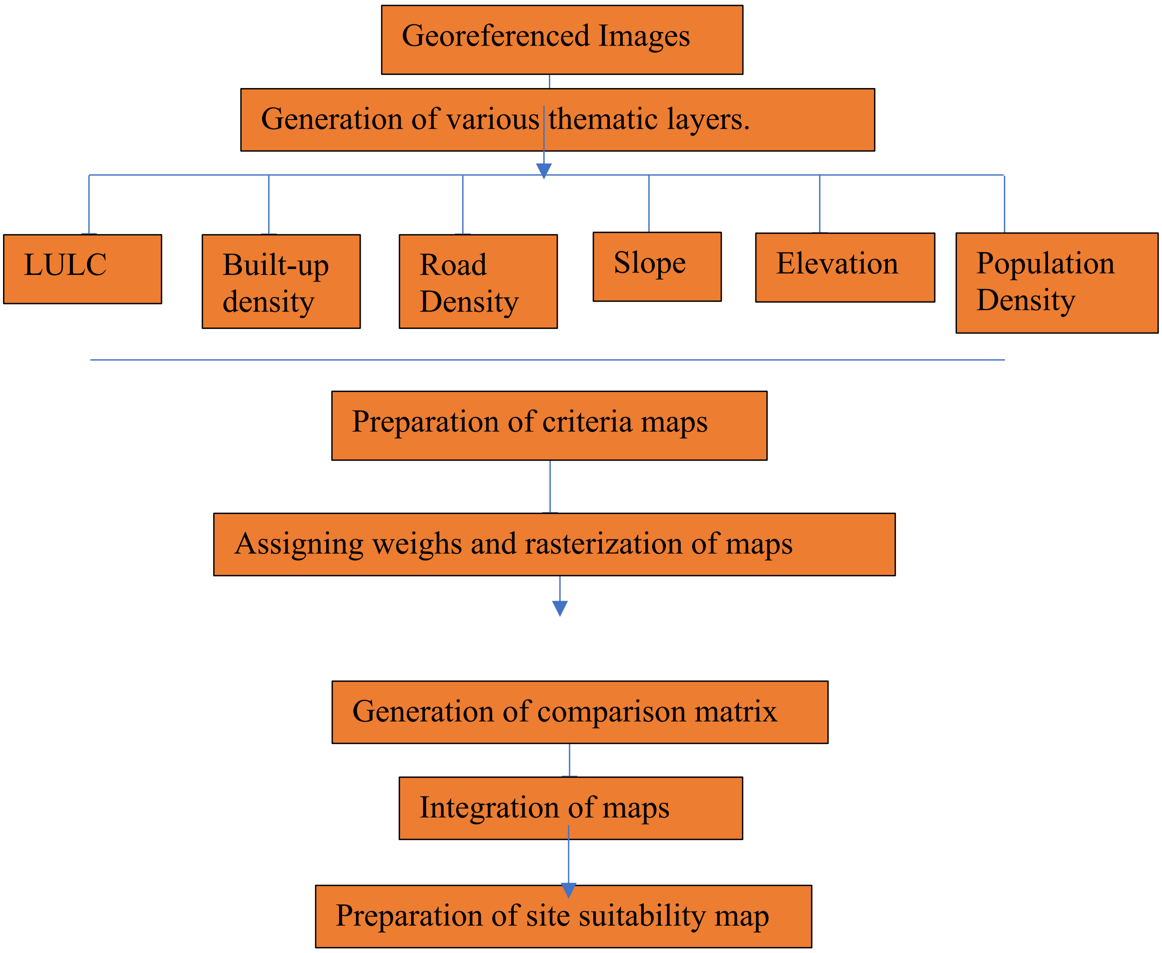


Figure 2: Methodology Site Suitability Analysis

The main goal to generate the site suitability map for urban expansion is the main goal of the study. Multiple criteria that influence the study are identified which includes slope, elevation, road density etc. Based on literature review, urban characteristics of Rohtak, and expert consultation, six key criteria were selected (Table 1). These factors capture the demographic, infrastructural, and physiographic determinants of urban expansion.

No.	Criterion	Data Source	Description	Suitability Relation
1	Population Density	Census of India (2011)	Indicates demographic concentration and demand pressure	Higher density → More suitable
2	Urban Density (Built-up/NDBI)	Landsat / Sentinel	Reflects existing urban footprint and compactness	Higher density → less suitable for further growth
3	Road Density	Haryana GIS Portal	Reflects accessibility and connectivity	Higher density → More suitable
4	Elevation	SRTM DEM	Influences construction cost and flood risk	Lower elevation → More suitable
5	Slope	Derived from DEM	Affects terrain stability and construction feasibility	Gentle slopes → More suitable
6	Land Characteristics	Land use map	Differentiates between agricultural, barren, or developed land	Non-forest, non-water areas → Suitable

Table 1: Criteria Used for AHP-Based Suitability Analysis

Each of these criteria was spatially represented as a raster layer and standardized to a common scale before applying the AHP weights.

Pairwise Comparison

A 6 × 6 pairwise comparison matrix was developed using Saaty's 1–9 scale to express relative importance among the six criteria. The weights were derived from expert consultations with urban planners, GIS specialists, and local authorities.

These are the resulting weights for the criteria based on pairwise comparisons:

Category		Priority	Rank	(+)	(-)
1.	**Road Density**	53.8%	1	24.4%	24.4%
2.	**Slope**	13.1%	2	1.9%	1.9%
3.	**Elevation**	13.1%	3	1.9%	1.9%
4.	**LULC**	13.6%	4	4.4%	4.4%
5.	**Built-up density**	3.1%	5	1.3%	1.3%
6.	**Population density**	3.2%	6	1.2%	1.2%

Table 2: Priority matrix

Number of comparisons = 15

Consistency Ratio CR = 4.4%

The resulting weights are based on the principal eigenvector of the decision matrix where Principal eigen value = 6.275

Eigenvector solution: 5 iterations, delta = 9.3E-8

	1	**2**	**3**	**4**	**5**	**6**
1	1	5.00	5.00	7.00	9.00	9.00
2	0.20	1	1.00	1.00	5.00	5.00
3	0.20	1.00	1	1.00	5.00	5.00
4	0.14	1.00	1.00	1	7.00	5.00
5	0.11	0.20	0.20	0.14	1	1.00
6	0.11	0.20	0.20	0.20	1.00	1

Table 3: Decision Matrix

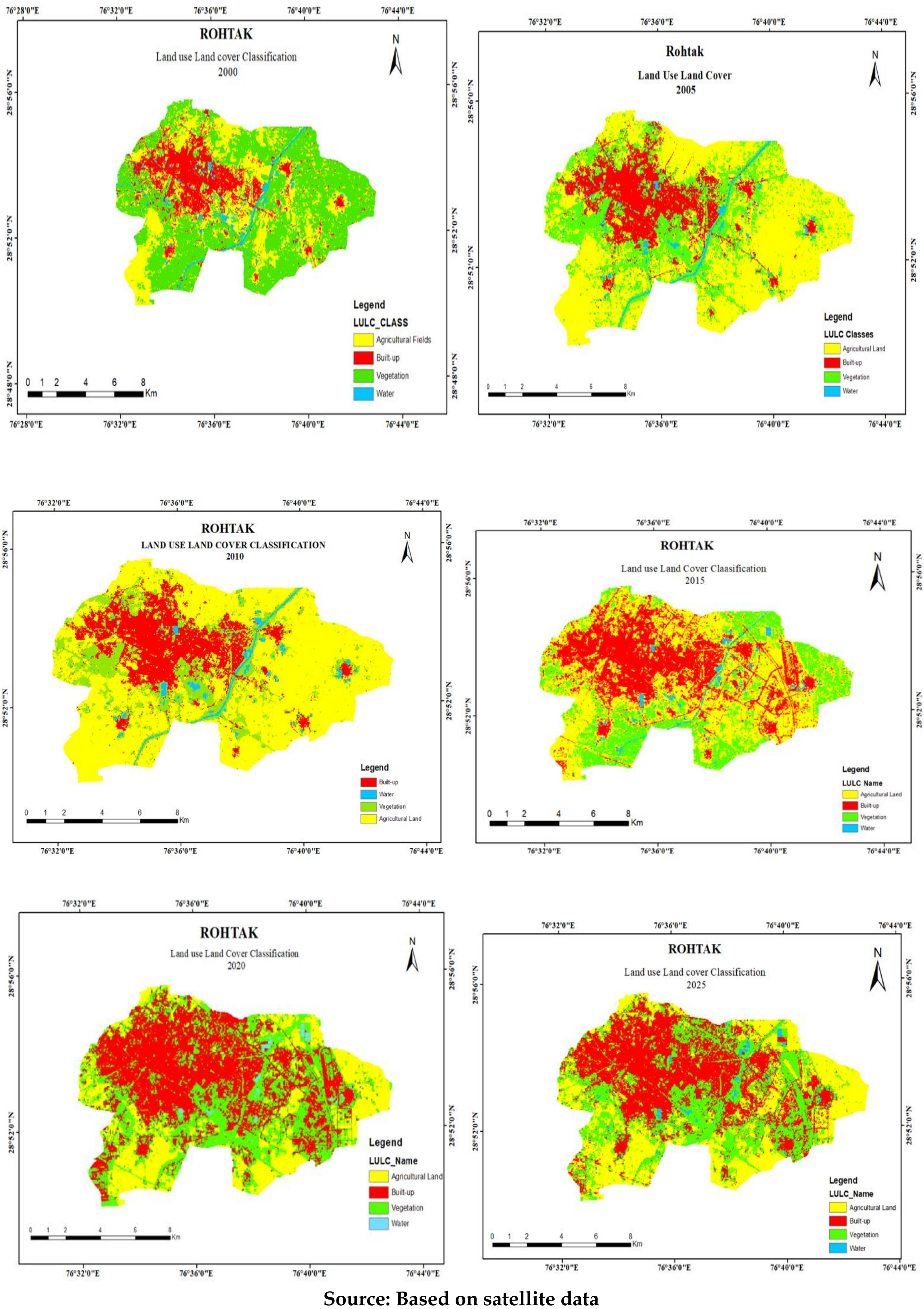
The integration of normalized spatial data layers with AHP-derived weights ensures objective and transparent decision-making. The final site suitability map provides a scientifically grounded spatial framework to support **sustainable urban planning**, helping policymakers balance growth demands with environmental constraints.

Results and Discussions

The temporal LULC analysis for Rohtak from 2000 to 2025, undertaken at five-year intervals, presents a marked transformation of the urban landscape, reflecting the dynamic growth processes and land transformation associated with urban expansion. The findings of study of land use land cover analysis clearly depict rapid urban expansion with declining agricultural and vegetated land.

The classified maps showcase four major land-cover classes: built-up land, agricultural land, vegetation, and water bodies. Visual comparison of the temporal maps reveals the change in land use presents a clear pattern of increasing urban area over the time span. There is noticeable outgrowth of built up from the core of the city in all directions which implies greater land conversion of agricultural or open lands to built-up for multiple purposes like transport corridors, residential complexes and industrial units.

2000-2005 is the early phase for urbanization where the built-up region remained relatively compact and scattered patches developed in urban fringe. The lately developed peripheral patches became more pronounced by 2010, indicating the emergence of peri-urban development zones and the official demarcation of residential complexes by Haryana Urban Development Authority (HUDA), presently identified as Haryana Shehri Vikas Pradhikaran (HSVP).



Source: Based on satellite data

Map 1-6: Land use Land cover mapping for Rohtak

	AREA (Km²)					
LULC CLASS	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Agricultural Land	34.04	65.16	72.04	54.94	28.22	32.65
Built-up	18.80	20.22	22.02	35.95	47.15	49.07
Vegetation	61.70	30.14	21.76	25.34	42.29	38.60
Water	3.98	2.98	2.70	2.26	0.86	1.19

Source: calculated by authors

Table 4: Area under different land use classes over years

With the rise in built-up areas in both density and spatial coverage, the increase in urban area is more pronounced between 2010-2015. The red patches depict outward growth of built-up towards the edges of the municipal boundary with area of about 50km² by 2025.The built-up is increasing contiguous implying the merger of scattered developments into a more continuous and cohesive urban landscape.

Similarly agricultural land dominant in 2000 declines by 2025. There is transformation of land to residential, commercial, and infrastructural spaces suggestive of increased demand and presence of strong land-market because of population growth and economic expansion. Vegetation cover displays dwindling and patchy pattern. During the early years green patches were constant however it succumbed to increasing urban pressure with scattered presence particularly near water channels, institutional campuses, or peripheral zones. It suggests the prioritization of infrastructural development over ecological balance. Water bodies are persistent and localized with minimal expansion which points out to pressures on existing urban water resources and drainage systems.

Overall, LULC demonstrate well defined transformation towards an increasingly urbanized environment from an agrarian landscape. The pattern illustrates blend of planned development, institutional growth which increased connectivity and enhanced urban amenities however expansion of unplanned settlements presents disparities in peripheral areas. The geographical immediacy of Rohtak to Delhi accelerated conversion as it serves as secondary urban node by supporting multiple regional economic activities.

LULC	**Overall Accuracy (%)**	**Kappa Coefficient**
2000	63.75%	0.52
2005	71.25%	0.62
2010	91.25%	0.88
2015	72.50%	0.64
2020	88.75%	0.85
2025	85 %	0.8

Table 5: Overall accuracy and Kappa Coefficient

The comparatively lower classification accuracy for earlier years in the LULC analysis is a major study limitation. This is mostly because Google Earth Engine is used to access historical satellite imagery, which frequently has poor spatial resolution, blurriness, and limited temporal availability. Precise class differentiation is hampered by such limitations. Additionally, validation reliability is impacted by the absence of high-quality ground truth data for previous periods. Since uniform classification methods were used for every year, this restriction is data-driven rather than methodological. The results successfully capture broad temporal trends in land-use change despite the decreased accuracy. By incorporating multi-source data fusion techniques or higher-resolution historical datasets, future research may increase accuracy.

	Accuracy Assessment - I					
LULC CLASS	**User Accuracy 2000 (%)**	**Producer accuracy 2000(%)**	**User Accuracy 2005(%)**	**Producer accuracy 2005(%)**	**User Accuracy 2010(%)**	**Producer accuracy 2010(%)**
Agricultural Land	45.83333333	55	57.14285714	80	100	95
Built-up	81.81818182	90	79.16666667	95	95	95
Vegetation	56	70	60	45	88.88888889	80
Water	100	45	100	65	82.60869565	95

	Accuracy Assessment- II					
LULC CLASS	**User Accuracy 2015 (%)**	**Producer accuracy 2015(%)**	**User Accuracy 2020(%)**	**Producer accuracy 2020(%)**	**User Accuracy 2025(%)**	**Producer accuracy 2025(%)**
Agricultural Land	55	55	94.44444444	85	97.22222222	77.77777778
Built-up	95.23809524	100	80	100	90	100
Vegetation	47.61904762	50	85.71428571	90	66.66666667	93.33333333
Water	94.44444444	85	100	80	100	68.88888889

Source: calculated by authors

Table 6-7: Accuracy assessment

CHANGE MATRIX					
	Agricultural Land	**Built-up**	**Vegetation**	**Water**	**Grand Total**
Agricultural Fields	**6.57**	13.72	13.56	0.15	33.99
Built-up	0.76	**15.77**	2.19	0.08	18.79
Vegetation	29.08	11.64	**20.53**	0.38	61.63
Water	0.18	0.92	2.29	**0.59**	3.98
Grand Total	**36.59**	**42.05**	**38.56**	**1.19**	**118.39**

Source: Calculated by Authors

Table 8: Land use change matrix

Overall, the analysis of conversion denotes **rapid, spatially concentrated, and infrastructure-driven in Rohtak**, with clear implications for land management. The advancements support economic development but simultaneously raises concerns for **loss of agricultural land and environmental sustainability**, reinforcing the need for controlled and planned urban expansion.

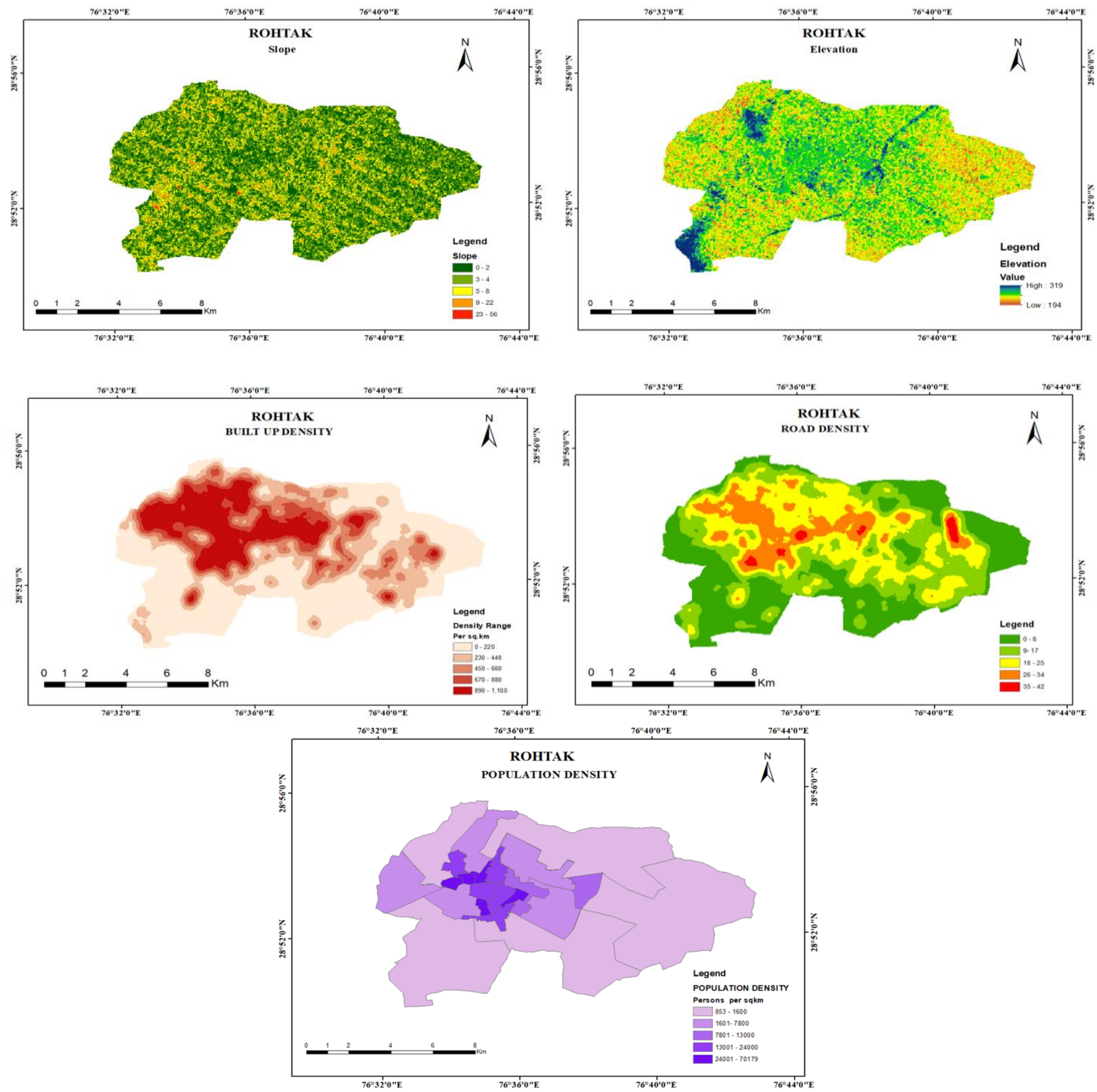
The urban site suitability analysis for Rohtak block was conducted using the **Analytic Hierarchy Process (AHP)** integrated with GIS-based spatial analysis. The pairwise comparison matrix was developed following Saaty's scale of relative importance, where each criterion was evaluated against the others in terms of its influence on urban development suitability. The normalized matrix generated the relative weights of each factor. The results indicated that **proximity to major roads emerged as the most influential factor**, followed by proximity to existing built-up areas, land use/land cover, slope, and elevation.

The AHP-weighted suitability analysis arranged the factors of urban expansion in a clear hierarchy. **Road density dominated the model (53.8%)**, as accessibility is the primary determinant of where urban development is feasible and likely to occur. Land use/land cover (~13.6%), slope (13.1%) and elevation (13.1%) together form the secondary band of control, presenting physical and environmental constraints on construction and service provision. **Built-up density (3.1%) and population density (3.2%)** were assigned relatively low weights, showing the model's emphasis on identifying future expansion opportunities rather than simply reinforcing existing urban cores

The high weight assigned to road density (53.8%) in the AHP framework is both methodologically justified and empirically grounded in Rohtak's urban context. Road density acts as a key indicator of accessibility and connectivity, which are primary drivers of urban expansion, particularly in non-metropolitan cities with infrastructure-led growth. Improved road networks reduce travel time, enhance mobility, and increase access to economic opportunities, making such areas more attractive for development.

This weighting is supported by observed spatial patterns, as Rohtak's growth is predominantly corridor-based along major transport routes such as the Delhi–Rohtak corridor and National Highway-9. LULC analysis (2000–2025) further confirms that built-up expansion has largely occurred in areas with higher accessibility, reinforcing the centrality of road infrastructure.

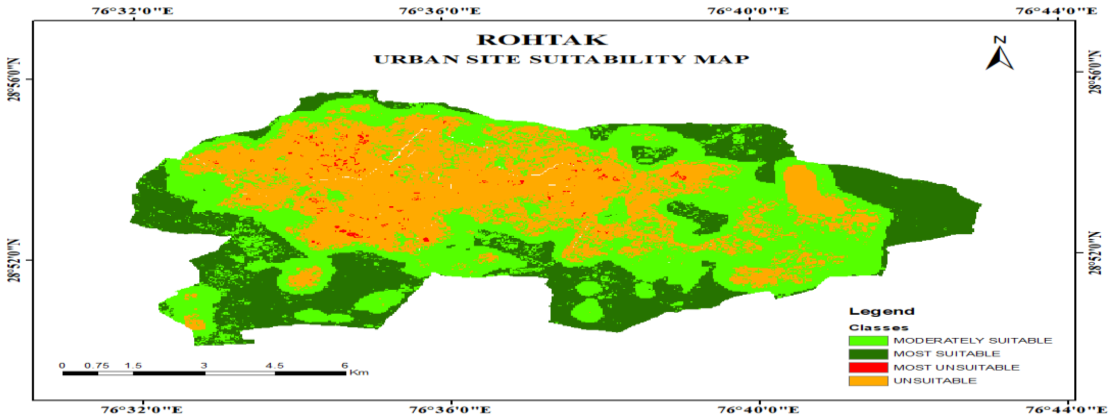
Additionally, areas with existing road networks offer greater feasibility for development due to lower infrastructural costs. Importantly, sustainability is not overlooked, as the model incorporates environmental constraints like water bodies and agricultural land. The low Consistency Ratio (4.4%) further validates the reliability of the weighting scheme, indicating that the emphasis on road density is contextually appropriate rather than biased.



Map 8-11: Variables for site suitability analysis

Spatially, **highly suitable zones** covering an area **31.70 km²** are along major transport corridors and adjacent to existing infrastructure; these corridors coincide with observed recent built-up growth, confirming that the model captures ongoing development dynamics.

Areas classified as **least suitable** are wetlands, drainage channels and productive agricultural parcels—locations where slope/elevation and LULC constraints reduce feasibility. The low weight given to population and built-up density indicates potential for planned, outward growth rather than densification; however, unchecked corridor-led expansion risks fragmenting agricultural land and increasing commuting distances



Map 12: Site suitability for urban growth

	SUITABILITY ZONE			
	Most Unsuitable	Unsuitable	Moderately suitable	Most Suitable
AREA (in km²)	0.552	40.23	44.06	31.70

Source: Calculated by Authors

Table 9: Area covered in each zone

The AHP findings indicate a two-part strategy for sustainability and environmental protection: directing development towards well-connected areas to optimize infrastructure use and preserving ecologically sensitive and agricultural regions deemed unsuitable for development. Incorporating land use, land cover, and topography into the ranking process helps prevent development in areas prone to flooding or erosion. Consequently, the model provides a geographically specific framework for prioritizing infrastructure investments, such as roads, sewerage, and public transit, and for limiting development in environmentally fragile locations.

Conclusion

This study presents an integrated AHP-GIS framework for evaluating urban growth suitability in Rohtak, yielding three significant findings. Road density emerged as the dominant factor, accounting for 53.8% of the total weight, underlining the central role of transportation infrastructure in urban expansion. High and moderately suitable zones are clustered along major transport corridors and adjacent to existing built-up areas, reflecting a pattern of corridor-based and contiguous urban growth. Furthermore, land use and land cover analysis conducted between 2000 and 2025 confirms a steady conversion of agricultural land into built-up areas, with most development occurring within zones pre-identified as highly suitable. This alignment validates the predictive strength of the model, supported by a Consistency Ratio of 4.4%.

From a planning viewpoint, these findings strongly advocate for aligning urban expansion with Transport-Oriented Development principles, while instituting protections for environmentally sensitive areas including water bodies, drainage channels, and productive agricultural land. Policymakers are encouraged to adopt zoning strategies that promote compact urban growth, regulate urban sprawl, and prioritize infrastructure-led development to ensure long-term ecological and spatial sustainability.

Despite these contributions, the study acknowledges several limitations. The AHP methodology depends on expert judgment, which introduces a degree of subjectivity, even where consistency thresholds are met. The use of static datasets restricts the model's ability to reflect dynamic factors such as population growth, shifting land markets, or evolving policy frameworks. The absence of socioeconomic variables also limits the overall comprehensiveness of the assessment.

Future research should address these gaps by incorporating high-resolution temporal data, socioeconomic indicators, and advanced techniques such as machine learning or hybrid multi-criteria models. The inclusion of scenario-based simulations and climate resilience parameters would further strengthen the framework's capacity to support sustainable, inclusive, and long-term urban planning in rapidly developing cities like Rohtak.

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