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Geo-spatial analysis of urban development and sprawl over a decade (2013-2023) in Narayanganj district, Bangladesh

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Abstract

Globally, the speed of urbanization is transforming the landscape, reshaping economies, and challenging cities to develop sustainably while navigating environmental and social pressures. Narayanganj, the smallest district of Bangladesh and one of its oldest industrial hubs, has witnessed rapid urbanization in the past due to its proximity and richness in industries. This study aims to analyze the impact of a decade-long urban transformation by identifying areas suitable for development, quantifying urban sprawl using landscape metrics, and comparing actual urban expansion with designated suitable zones. Supervised land use classification was carried out using high-resolution Landsat imagery in 2013 and 2023. The spatial patterns of urban expansion were assessed using key indices. Through a multi-criteria analysis, a land suitability map was developed considering slope, soil type, proximity to roads, and existing land use. Findings reveal a 28% increase in urban area over the decade, with 25% aligning with suitable zones and 3% expanding into unsuitable areas. A high UEII value (1.49) indicates rapid and potentially unsustainable urban growth, while increased PD and LSI point to fragmented and irregular sprawl patterns. The spatial discrepancy between actual expansion and projected suitability emphasizes how urgently data-driven, sustainable urban planning is needed. This study supports policy interventions for more effective development in rapidly urbanizing areas.

Keywords: *Urban suitability, landscape metrics, urban sprawl.*

1 Introduction

Urbanization is a global phenomenon. As of 2018, 55% of the world's population lives in cities, and almost every country is urbanizing (Saini and Tiwari, 2020). The rapid rise of cities and urbanization has significantly impacted many aspects of society (Islam *et al.*, 2021). Bangladesh is a small country with a high population density, which leads to limited land availability. As more people migrate to urban centers, the need for residential housing, transportation, and services increases, which puts pressure on the available land and resources (Islam *et al.*, 2021). This haphazard and unplanned growth often results in the expansion of informal settlements, environmental degradation, and increased vulnerability to natural hazards such as flooding and heat islands (Misra and Sharma, 2015). Consequently, land-use suitability analysis is crucial for city planners and managers to determine the optimal spatial pattern for future use (Liu *et al.*, 2014). Furthermore, spatial metrics can help assess and quantify urban sprawl (Triantakonstantis and Stathakis, 2015). Spatial metrics have evolved as a popular technique for measuring urban morphologies and monitoring urban development (Debbage, Bereitschaft and Shepherd, 2017). Narayanganj, situated along the banks of the Shitalakshya and Meghna Rivers, its proximity to the central capital and the pervasive industrialization, which has fueled significant urbanization in the past decade (LGED). This study seeks to investigate the impact of this urbanization through a comprehensive geo-spatial analysis. The aim is to assess areas suitable for urban development, measure sprawl using key indices, and compare designated suitable areas with realized development. The goal is to provide critical insights for sustainable urban planning, examining the dynamic interplay between planned and unplanned growth.

2 Study Area

Narayanganj district is located at 23°34'N 90°27'E and 24°15'N 90°59'E. Shitalakshya flows to the east, whereas Buriganga flows to the south and west. The district has an area of 759.57 square kilometers. Narayanganj is the country's biggest river port. It is a significant trade and commercial hub. Nowadays, thousands of industries, such as garments, small and medium-sized enterprises, play a vital part in the national economy. Because of these

industrial developments, the district is urbanizing rapidly. The growth of industries has contributed significantly to the expansion of urban areas throughout the district.

2 Methodology

Narayanganj's land use land cover (LULC) and suitability for urban development were investigated, and two Landsat satellite images were used for the years 2013, 2023. The methodology involves creating thematic layers from georeferenced images, generating a land suitability map using factors affecting suitability, and identifying expanded urban areas. These areas are compared with suitable zones, and landscape metrics are used to quantify and analyze urban sprawl. The methodology used in this study is shown in the flowchart below:

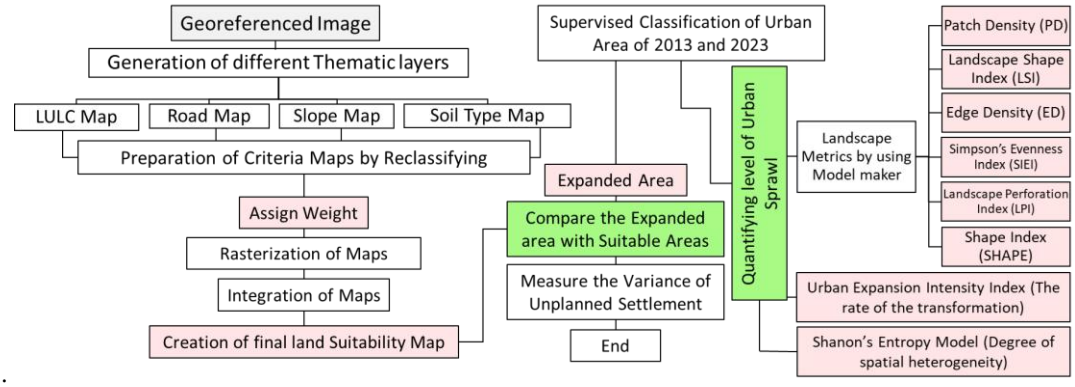

Figure 1. Methodology flowchart of the study.

3 Data Preparation and Processing

The study involved several stages of a geo-spatial analysis technique. At first, the classification of land use/land cover (LULC) for the years 2013 and 2023 using Landsat imagery was conducted. A supervised image classification method was conducted using a random forest algorithm (Figure 2). Accuracy assessment was then performed to evaluate the reliability of the classification result (Table 1)

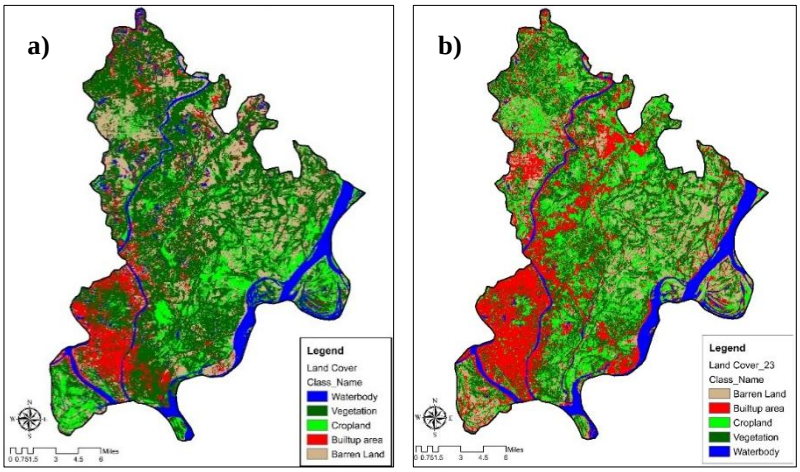

Figure 2. a) LULC map of Narayanganj district (2013), b) LULC map of Narayanganj district (2023).

Table 1. Accuracy metrics of classified Landsat images; "PA" and "UA" indicate producers' and users' accuracy.

Year (used sensor)	LULC Classes										Overall accuracy (%)
	Built-up Area		Vegetation		Cropland		Barren land		Waterbody		
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	
2013	83.33	89.74	75.02	95.45	90.48	76.01	86.67	72.22	90.24	86.05	85.14
2023	79.31	85.19	93.33	82.35	67.65	88.46	82.14	79.31	99.02	83.87	83.78

Several suitability factors were prepared to support urban suitability analysis (Table 2). These factors included LULC classification for 2013 itself, soil type, slope, and the proximity to roads (Figure 3).

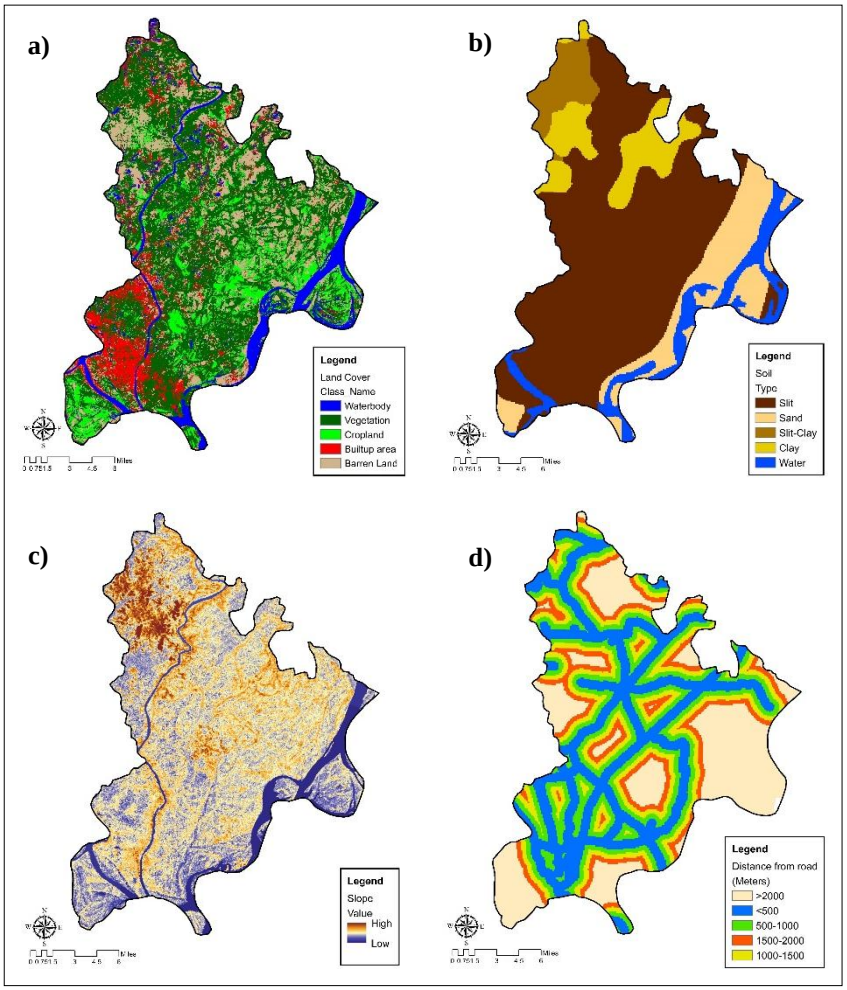

Figure 3. Map of suitability factors: a) LULC map (2013), b) Soil Type, c) Slope, and d) Proximity to roads.

Each factor was assigned a score based on a comprehensive literature review and provided a weight for the relevance of each factor to urban suitability.

Table 2. Ranking and scoring system of the suitability factors.

Rank / **Suitability Grade**	**Very high opportunity** **5**	**High opportunity** **4**	**Moderate opportunity** **3**	**Low opportunity** **2**	**Very low opportunity** **1**
Land-use type	Built-up area	Barren Land	Crop Land	Vegetation	Waterbody
Soil Type	Slit	Sand	Slit-Clay	Clay	Water
Slope (◦)	0.3-2	2-5	5-10	10-25	>25 or <0.3
Proximity to roads (m)	<500	500-1000	1000-1500	1500-2000	>2000

4. Results

4.1 Analysis of Expansion Composition

Using the factors, areas that are most suitable for urban development were identified within Narayanganj by combining the weighted factors through a multi-criteria evaluation (MCE). The suitable areas were classified into five categories. Among them, very high, high, and moderate suitability were considered appropriate for planned urban development. In this context, "planned" refers to the designation of suitable sites for the establishment of built-up areas, while other factors related to comprehensive development, such as infrastructure, social services, and environmental considerations etc., are excluded from the assessment.

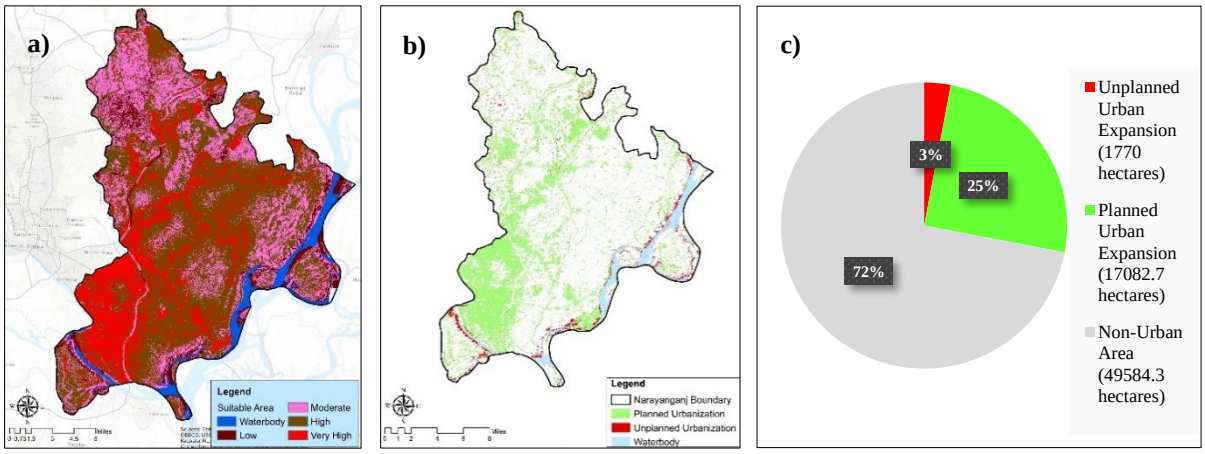

Figure 4. a) Map of suitable areas for built-up development, b) Map of planned vs. unplanned development and c) Urban expansion composition.

After identifying the suitable areas for development, a decade-long comparison was made between the development occurring from 2013 to 2023 and the suitability map to assess whether the development aligned with the designated suitable areas. The analysis revealed that 25% of the development occurred in areas deemed suitable, referred to as planned development. In contrast, 3% of the development occurred in areas identified as unsuitable, representing unplanned development. The rest of the land belongs to non-urban areas. Although the 3% may seem relatively small, it accounts for a significant 1,770 hectares of built-up area, which cannot be overlooked in the context of urban growth and land-use planning.

4.2 Identification of Urban Sprawl

After assessing the suitability of development areas, another dimension of planning was examined: urban sprawl. Urban sprawl is the unplanned expansion of urban areas into surrounding rural or natural lands, driven by market forces. Assessing sprawl is crucial to understanding its impact on land use, infrastructure, and the environment (Lei Wang, 2020). This analysis focused on how urban areas have expanded and in which direction from 2013 to 2023. The findings revealed that urbanization is predominantly progressing from south to north. This expansion trend can likely be attributed to the establishment of industries in the southern parts of the city, which has driven the growth of residential and commercial areas towards the north.

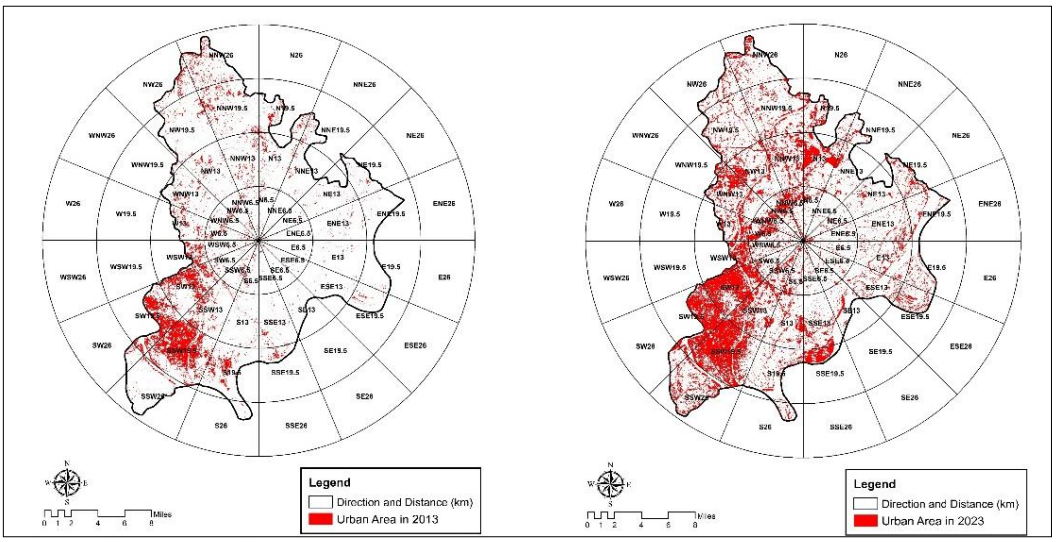

Figure 5. Direction of urban sprawl from 2013 to 2023.

4.3 Variation of Landscape Metrics

To quantify the level of urban sprawl, various landscape metrics were calculated (Table 3). These metrics were calculated using the FRAGSTATS (Spatial Pattern Analysis Program for Quantifying Landscape Structure). Each of these metrics evaluates and quantifies various aspects of urban sprawl, such as development fragmentation,

irregularity in urban growth, and the dispersion of settlements, which helps to understand the spatial patterns and dynamics of urban expansion.

Table 3. The metrics used and their descriptions.

Metrics	Equation Used	Outcome	Description
Patch Density (PD)	$\frac{N}{A}.(10000).(100)$	Increased	Fragmented and scattered development.
Landscape Shape Index (LSI)	$\frac{0.25E}{\sqrt{A}}$	Increased	Indicates irregularity in the urban area.
Edge Density (ED)	$\frac{E}{A}.(10000)$	Increased	Increased irregular formation of isolated urban patches.
Simpson's Evenness Index (SIEI)	$\frac{1-\sum_{i=1}^{m}P^2}{1-(\frac{1}{m})}$	Same	Distribution of land-use types or urban features has remained stable without significant shifts.
Largest Patch Index (LPI)	$\frac{MAX_{(aij)}}{A}.(100)$	Decreased	Urban patches in the study area become progressively smaller, and increased urban sprawl.
Shape Index (SHAPE)	$\frac{0.25P_{ij}}{\sqrt{a_{ij}}}$	Increased	Increased irregularity in the urban development.
Urban Expansion Intensity Index (UEII)	$\left\{\left(\frac{BLA_i^{t_2}}{BLA_i^{t_1}}\right)^{\frac{1}{t_2-t_1}}-1\right\}.(100)$	1.49	Indicates high-speed urbanization.
Shannon's Entropy Model (SEM)	$\sum_{i=1}^{n} p_i \log(\frac{1}{p_i})/\log(n)$	Increased	Settlements are more dispersed now.

After the analysis and comparison with standard values, the metrics quantify the level of urban sprawl in the study area. The results indicated that, while 25% of the development occurred in suitable areas and 3% in unsuitable areas, the urbanization process is fragmented and scattered. This fragmentation suggests irregular urban growth patterns, with an increased number of isolated urban patches. The distribution of land-use types has remained relatively stable, without significant shifts, while urban patches in the study area have become progressively smaller. These patterns point to rapid urban sprawl, characterized by irregularity, high-speed urbanization, and more dispersed settlements in the region.

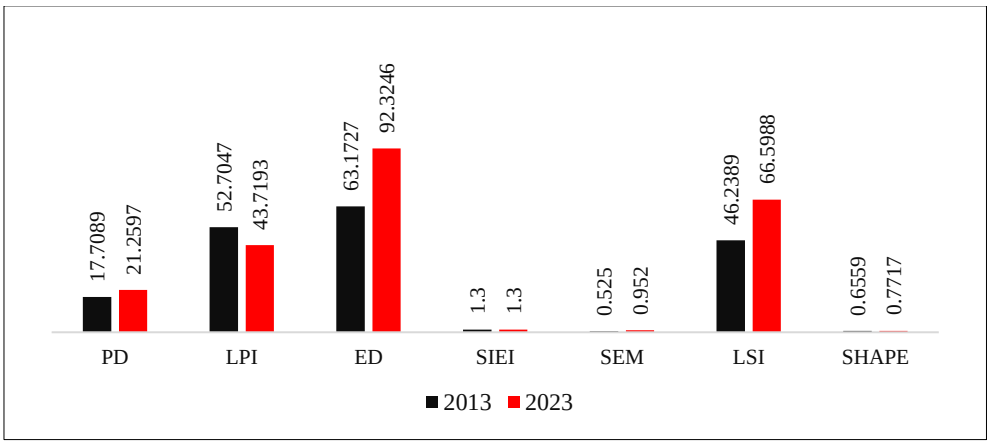

Figure 5. Variation of Landscape Metrics from 2013 to 2023.

5. Discussion

The spatial and quantitative data analysis show that the process of urban development of Narayanganj during the last decade is dynamic and complex. These findings indicate that urban growth has been fast and spatially imbalanced and is a combination of planned and unplanned development. The multi-criteria evaluation (MCE) established areas that could be expanded in urban areas where about 25 percent of the new growth between the years 2013 and 2023 was realized, indicating some compatibility with the development plans. Nonetheless, 3

percent of constructed development was in inappropriate locations, equaling almost 1770 hectares, which is an indication of the continuation of unplanned and unregulated urbanization - a common occurrence in rapidly expanding cities in the Global South (Lecomte, 2017).

The direction of the expansion, that is mostly southward, followed by northward, is due to the effect of the industrial setup in the southern side of Narayanganj. Industrial activities do tend to be growth poles, whereby residential and commercial land uses are attracted to the neighboring areas (Darwent, 1969). This growth has been driven by the market and not a slow process that is guided by planning; it is one of the factors that has led to the encroachment of the built-up areas into the peri-urban and rural landscapes. There is a tendency of such unchecked sprawl that can lead to degradation of agricultural and ecological lands, overloading of infrastructure, and inequitable distribution of services across space (Mishra, 2025). These results highlight a serious planning issue that the spatial control and coordination among urban development authorities is weak. Even what might appear like a minor percentage of unplanned development will have a huge long-term implication on land management and environmental sustainability. The paper, therefore, accentuates the dire necessity of the incorporation of the spatial suitability evaluations into urban development policies and the imposition of more rigid zoning rules. The negative impact of low-density and fragmented expansion can be stifled by encouraging compact and transit-oriented building policies (Li and Li, 2025).

To conclude, although Narayanganj has a significant potential for structured urbanization, the current trend of unplanned and disjointed development is an indication of the need to have policy intervention. The key to building a sustainable and resilient urban development is to strengthen urban governance, combine geospatial tools in monitoring, and ensure that space planning frameworks are applied.

6 Conclusion

The rapid urbanization of Narayanganj, driven by industrial growth and its proximity to Dhaka, has resulted in significant changes in land use. Over the past decade, the urban area expanded with a majority of growth occurring in designated suitable zones. However, a concerning 3% of this expansion occurred in unsuitable areas, highlighting a gap in adherence to urban planning guidelines. Despite the overall increase in urban land, landscape metrics indicate that this expansion has been irregular and fragmented, suggesting a need for improved urban planning. The findings underscore the importance of balancing industrial development with sustainable urban growth, utilizing data-driven approaches to inform future urbanization and mitigate adverse environmental and social impacts. Moving forward, stricter enforcement of zoning regulations and a more comprehensive approach to land suitability analysis are essential to foster resilient, well-planned urban growth in Narayanganj.

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