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Assessment of Urban Expansion in the Jorhat Municipality Area using Geospatial Techniques

Pixi Gogoi[1] and Princi Gogoi[2]

[1]Department of Geography and Disaster Management, Tripura University, Tripura 799 022, India
[2]Department of Geography, Bikali College, Assam, India

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ABSTRACT

This study investigates the phenomenon of urban sprawl, particularly focusing on Jorhat, the second-largest city in Assam, India, which has experienced significant growth and expansion. Urban sprawl, defined as the unplanned expansion of a city into surrounding regions, is characterized by the outward growth of residential, commercial, and industrial infrastructure, leading to the conversion of agricultural or natural spaces into urban land. This expansion results in increased land use, the development of low-density communities, and significant challenges including traffic congestion, environmental degradation, and inefficient land use. Jorhat has witnessed exponential population growth and urban expansion, with the urban area increasing from 4.95 sq. km in 1961 to 72.58 sq. km in 2001. This rapid development has led to environmental issues such as pollution, water logging, and traffic congestion, particularly in sub-urban areas where encroachment has resulted in habitat loss and community fragmentation. The existing research on Jorhat has primarily focused on broader landscape transformations, with a gap in studies specifically analysing urban growth dynamics within the district. This study aims to bridge this gap by evaluating the extent of urban area expansion in Jorhat district, utilizing GIS and RS to quantify urban sprawl through parameters such as land cover changes and urban area expansion. By providing a detailed analysis of Jorhat's urban growth, this research contributes to the understanding of urban sprawl's impacts and offers valuable insights for informed decision-making in urban planning and sustainability efforts. The findings underscore the need for integrated planning and management strategies to address the challenges of urban sprawl, aiming to achieve a balance between development and environmental conservation.

Key words: *Urban sprawl, UEII, Shannon's entropy, Landscape metrics.*

Introduction

Urban sprawl refers to the unplanned, expansion of a city or metropolitan area into surrounding regions this phenomenon is characterized by the continuous outward growth of development, typically resulting in the spread of residential, commercial, and industrial infrastructure (Hasnine and Rukhsana, 2020). Urban sprawl leads to the increased use of land, the expansion of sub-urban areas, and the development of low-density communities (Maier, *et al.*, 2006). As cities grow outward, they consume rural land for housing, infrastructure, and commercial development. This expansion leads to the conversion of agricultural or natural spaces into urban land, altering the rural land use patterns and posing significant challenges, including increased traffic congestion as people commute longer distances, leading to environmental issues and decreased air quality, inefficient land use (Surya *et al.*, 2021). Additionally, the

([1] Research Scholar, [2]Assistant Professor) environmental strain, habitat loss, and increased demand for resources associated with sprawl raise sustainability concerns for the long-term well-being of urban areas (Hatab *et al*., 2022). The root causes of urban sprawl are multifaceted but often stem from factors such as economic incentives, population growth, and accessibility and urban infrastructure (Saini and Tiwari, 2020).

Geographic Information Systems (GIS) and Remote Sensing (RS) are crucial tools for understanding and managing urban growth and land use changes (Dhaoui, 2018). By utilizing GIS and Remote Sensing, we can monitor and analyse how cities evolve over time in terms of spatial patterns and temporal dynamics (Chettry, 2022; Chettry and Surawar, 2021). These technologies provide effective means for controlling and evaluating urban expansion, helping planners make informed decisions and contribute significantly to sustainable urban development by offering insights into the impact of growth on the environment and infrastructure through mapping and measuring changes (Hammad *et al.,* 2018). By integrating GIS and RS various statistical techniques and parameters have emerged to quantify and measure urban sprawl. Parameters such as the expansion of urban areas, changes in land cover, Shannon diversity index and landscape metrics can be precisely assessed using GIS and RS data (Manesha, *et al.,* 2021). These statistical measures play a crucial role in providing planners and policymakers with valuable insights for informed decision-making in the management and control of urban sprawl.

Jorhat, positioned as the second-largest city within the vibrant state of Assam, India, serves as the pivotal administrative hub for Jorhat District. This city stands out as a beacon of rapid development, experiencing exponential growth both in terms of population surge marking a remarkable 44.92% of population growth between the years 2001 and 2011. The urban expanse itself saw a significant transformation, initially covering a mere 4.95 sq. km, including 15.85 sq. km of revenue town in 1961. This area expanded substantially, reaching 72.58 sq. km in 2001, vividly illustrating the city's rapid growth and expansive development (Bhuyan and Husain, 2013). In the context of Jorhat municipality, the existing body of research predominantly centers on assessing broader landscape transformations rather than delving into the intricacies of urban growth dynamics. Consequently, there is a notable gap in studies that specifically measure and analyse the extent of urban area expansion within the temporal context in Jorhat district. Moreover, the study area is facing heightened pollution levels,water logging, strained waste management systems, and traffic congestion because of unplanned urban expansion. Suburban areas, in particular, face encroachment, leading to habitat loss and community fragmentation. Hence, this study is conducted to effectively addressing these issues through evaluation of urban expansion to inform sustainable solutions and urban planning initiatives.

Materials and Methods

Study area

Jorhat, located in the eastern region of Assam along the southern bank of the Brahmaputra River, holds the prestigious designation of a Class I Urban Agglomeration (UA) town, affirming its status as an advanced urban centre (according to the Jorhat Municipal Board, Assam). Geographically, it spans from 26°43'10 N to 26°46´50 N latitude and 94°09'28 E to 94°14'50 E longitude. The town's average elevation is 116 meters above mean sea level (Choudhury and Dutta, 2017). Jorhat's landscape is characterized by a flat plain and experiences a humid climate. The municipality covers an area of 9.20 sq. km, with a population of 98,000 (Census of India, 2011), distributed across 19 wards. Jorhat is a well-connected hub, accessible through rail, road, and airport services, facilitating easy connectivity with other parts of the nation. The town boasts a commendable literacy rate of 90.01% and a sex ratio of 951 (Census of India, 2011). The population density is notable at 2100 individuals per sq. km. Jorhat has been a focal point for economic activities in Upper Assam since the Ahom period. With a rich historical background, the study area is undergoing multi-dimensional development across various phases, solidifying its significance and contributing to its growth.

Database

The research employed Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) for 2002 and 2022 respectively. These Satellite imageries were collected from the United States Geology Survey (USGS) to depict landscape change and urban expansion patterns. Using Supervised classification through Maximum Likelihood Algorithm the

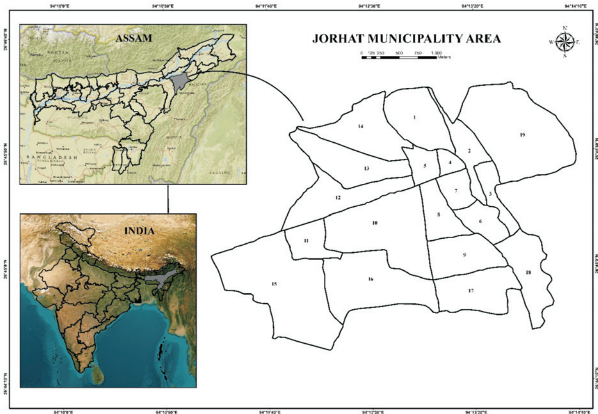

Fig. 1. Location Map of the Study Area

study area was divided into three Land Use and Land Cover (LULC) categories: (I) Urban expansion areas, (II) Non-urban expansion areas, and (III) Water Bodies, providing a comprehensive assessment of the spatial dynamics over the specified time frame. Here in this study, we used the kappa coefficient method to assess the accuracy level of our LULC change analysis part with the aid of both Google Earth and ground truthing.

Assessment of Urban Sprawl

Urban Expansion Intensity Index

The computation of the Urban Expansion Intensity Index (UEII) is crucial as it offers a quantitative measure of the rate and spatio-temporal urban expansion. Additionally, this method provides valuable insights into the pace or intensity and pattern of urban growth, aiding in informed decision-making for sustainable urban planning. Equation (1) depicts the formula to calculate UEII (Barman *et al.,* 2024; Guo *et al.,* 2024).

$$UEII_{it}= \left[\frac{ULA_{i,b}-ULA_{i,a}}{t}\right]/TLA_i \times 100 \quad .. (1)$$

Where $UEII_{it}$ is the annual average urban expansion intensity index of (i^{th}) zone in time period (t), and are the quantity of built-up area at time periods a and b respectively and is the total area of (i^{th}) spatial zone.

Shannon's Entropy Model

Shannon's entropy model is employed in urban sprawl studies to quantify the degree of disorder or heterogeneity in land cover distribution within a given area. This model allows researchers to capture and quantify the changes in landscape, providing valuable insights into the spatial dynamics of urban sprawl over time (Das and Angadi, 2021). Through the application of Equation (2) the absolute entropy is determined (Barman *et al.*, 2024).

$$H_n = \sum_i^n P_i \log_e \left(\frac{1}{P_i}\right) \quad .. (2)$$

Where is the proportion of the variable (built-up area) in the zone and n is the total number of zones.

Absolute entropy, ranging from 0 to log (n), is a measure of randomness in the context of urban expansion. A value closer to 0 indicates a more ordered and homogeneous distribution of land covers, suggesting a well-organized urban landscape. On the other hand, a value closer to log(n) signifies higher disorder and heterogeneity, indicating a more fragmented and dispersed pattern of urban expansion. Equation 3 depicts the formula to calculate relative entropy value.

$$H_n = \sum_i^n P_i \log_e \left(\frac{1}{P_i}\right)/\log_e(n) \quad .. (3)$$

Relative entropy, ranging from 0 to 1, indicates the level of disorder in land cover distribution during urban expansion. Closer to 0 suggests organized growth, while values near 1 signify dispersed expansion. The evolving rate of urban sprawl is determined using Equation (4).

$$H_n = H_n(t_2)-H_n(t_1) \quad .. (4)$$

Whereis the relative entropy at time (t_1) and $H_n(t_2)$ is the relative entropy at time (t_2).

Landscape metrics

Landscape metrics play a crucial role in computing urban sprawl or expansion by providing quantitative measures that capture the spatial configuration and composition of land cover changes and are commonly used to assess the extent and pattern of urban growth. These metrics offer insights into the fragmentation, connectivity, and overall structure of landscapes affected by sprawl. The details of the metrics used in the study are described in Table 4 (Bozkurt and Basaraner, 2024).

Results

Computing the Kappa coefficient in land use and land cover classification provides a quantitative measure of the accuracy and reliability of classification results. It helps assess the agreement between observed and classified data, offering a robust way to evaluate the performance of classification models and improve the overall reliability of land cover mapping. The categorized image and the ground truth image are 100 percent identical if the kappa coefficient is 1. Hence, the classification is more accurate the greater the kappa coefficient. Our study in the year 1990 and 2020 has yielded a Kappa coefficient of 0.86 and 1 which is categorised to the agreement of Very Good. Table 2 and 3 depicts the kappa coefficient assessment results of 1990 and 2020 respectively. Figure 2 illustrates the spatial representations of urban expansion from 1990 to 2020.

Urban expansion intensity

The result indicating that Jorhat municipality has an Urban Expansion Intensity Index (UEII) of 1.107, which signifies high urban expansion speed, offers valuable insight into the urbanization dynamics within this region. The UEII is a quantitative measure that reflects the rate at which urban areas are expanding, taking into account factors such as the increase in built-up areas and the conversion of non-urban land into urban uses over a specific time period. A UEII value greater than 1 suggests that the urban area is expanding at a rate faster than the population growth, indicating an intensive urban sprawl.

Shannon's Entropy

The towns were categorized into four zones, delin-

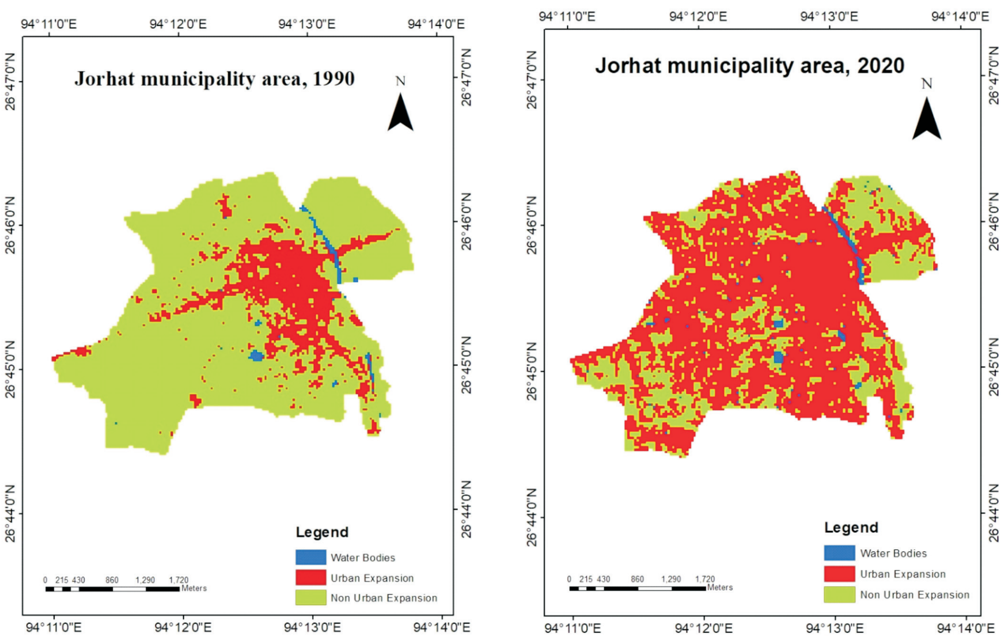

Fig. 2. Urban Expansion of Jorhat Municipality area in 1990 and 2020

Table 1. Accuracy Assessment of 1990

1990	Producer' Accuracy %	User Accuracy %	Kappa Index	Agreement
Water Bodies	100	93	86.30	Very good
Urban Expansion	96	83		
Non- urban Expansion	81	100		

Table 2. Accuracy Assessment of 2020

2020	Producer's Accuracy %	User Accuracy %	Kappa Index	Agreement
Water Bodies	100	100	100	Very good
Urban Expansion	100	100		
Non-urban Expansion	100	100		

eated by buffer circles created at 1000meter intervals around the city center. This classification enables a detailed analysis of the degree of disorder or heterogeneity in land cover distribution within different spatial zones around each town.

The analysis affirms that the absolute entropy value is higher than the midpoint of log e (n). The relative entropy values observed in 1990 and 2020 are also closer to 1, indicating a continued and accelerated trend of unchecked scattered urban sprawl. This underscores the urgency to implement a sustainable urban management plan to regulate and guide future urban growth. The findings underscore the critical need for strategic interventions to curb uncontrolled expansion, emphasizing the importance of sustainable development practices to maintain a balanced urban landscape in Jorhat municipality. Table 3 presents the Shannon's Entropy values, spanning the years 1990 to 2020.

Landscape metrics

In the context of urban expansion, landscape metrics serve as vital tools for analysing and understanding the spatial dynamics and ecological impacts of growing urban areas. These metrics help quantify changes in urban landscapes, such as increases in impervious surfaces, fragmentation of natural habitats, and the alteration of land use patterns (Bozkurt and Basaraner, 2024). By applying landscape metrics, we have assessed the extent and intensity of urban sprawl, identified critical areas of ecological concern within urbanizing regions, and evaluated the connectivity or isolation of green spaces within urban matrices. The importance of studying landscape metrics in urban expansion lies in their ability to inform sustainable urban planning and conservation strategies (Chandan *et al.*, 2017). Moreover, understanding the landscape structure through metrics enables the prediction and management of ecological impacts associated with urban expansion, such as habitat loss, reduced biodiversity, and increased runoff and pollution. This knowledge is crucial for developing integrated urban planning approaches that incorporate green infrastructure, compact urban growth, and the conservation of natural areas, aiming to achieve a sustainable coexistence between urban development and the natural environment. In this study, the results depict theEdge Density (ED) and Patch Density (PD) have increased from 1990 to 2020 which refers to a higher concentration of edges and patches between different land cover types within a landscape. This indicates a more fragmented and complex urban pattern and irregular formation of isolate urban patches, where urban development interfaces with various land uses. The increased Edge Density suggests a greater degree of spatial heterogeneity, reflecting the expansion of urban areas into different land cover types. The decreased Largest Patch Index (LPI) suggests a more dispersed and fragmented urban pattern, characteristic of increased urban sprawl where larger continuous urban areas are replaced by smaller and disconnected patches. The Largest Shape Index (LSI) is a measure of shape complexity, and the increased

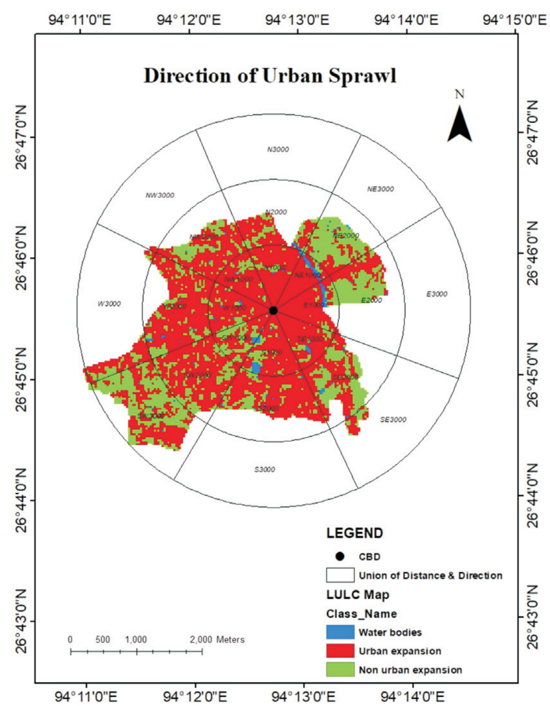

Fig. 3. Direction of urban sprawl of Jorhat Municipality area from 1990-2020

Table 3. Shannon's Entropy values for the year 1990 and 2020

Town	Year	Shannon's entropy model		Change rate
		Absolute	Relative	
Jorhat	1990	0.995352	0.9060085	0.2678757
	2020	0.701060	0.6381328	

value from 1990 to 2020 signifies a departure from compact, well-defined urban structures toward a more dispersed and irregular layout, characteristic of urban sprawl. Table 4 shows the different landscape metrics depicting the expansion of urban.

Direction of urban sprawl

A direction of urban sprawl diagram visually represents the spatial dynamics of growth, providing insights into the directional pattern of development within the study area. Here, the direction of urban sprawl is depicted towards the northwest. Understanding the direction of urban sprawl aids in formulating targeted strategies for sustainable urban development and managing the impact on the surrounding environment.

Discussion

The temporal analysis of urban sprawl within Jorhat Municipality over a thirty-year period from 1990 to 2020 unveils significant shifts in the landscape composition, underscoring the multifaceted nature of urbanization processes. This period has witnessed a pronounced expansion of built-up areas, reflecting an evolving urban fabric that accommodates the growing demands of its population. The transformation is marked by an increased footprint of residential, commercial, and infrastructural developments, painting a picture of a municipality in the throes of rapid urbanization. The spatial dynamics of land cover change within this timeframe reveal a clear trajectory towards intensified urban development. Initially gradual, the pace of urban sprawl accelerated notably in the last decade, highlighting a period of heightened economic activity and development initiatives. This trend is symptomatic of a broader movement towards urban growth, mirroring global patterns of migration from rural to urban areas in search of better livelihoods and opportunities. However, the blossoming of Jorhat's urban landscape is not without its challenges. The surge in built-up areas has ushered in a host of issues related to infrastructure adequacy, environmental sustainability, and the quality of urban life. The expansion has strained existing infrastructure, necessitating upgrades and expansions to meet the new demands. Environmental considerations, too, have come to the forefront, with the need to mitigate the effects of urban sprawl on natural habitats, biodiversity, and

Table 4. Detailed explanation of different landscape metrics

Category	Metrics	Description	Interpretation
Shape irregularity	Edge Density ED = $\frac{E}{A}$ (10,000)	It quantifies the total length of edges between different land cover types per unit area.	Low ED:uniform and continuous surface High ED:composed of edges, signifying maximum fragmentation.
	Landscape Shape Index LSI= $\frac{0.25\,E}{\sqrt{A}}$	It assesses the complexity of patch shapes within the landscape	Low LSI: landscape with simple, regular shapes. High LSI:highly irregular and complex landscape with intricate shapes.
Fragmentation	Patch Density PD = $\frac{N}{A}$ (10,000) (100)	It measures the number of patches per unit area in a landscape.	Low value: homogenous landscape; high value: fragmented landscape.
Other	Largest Patch Index LPI = $\frac{MAX_{(aij)}}{A}$ (100)	It measures the proportion of the landscape occupied by the largest contiguous patch	If LPI=0, no dominant patch in the landscape And LPI=100, single, dominant patch covers the entire area.

Table 5. Value of Different Landscape metrics of 1990-2020

Landscape metrics	PD	LPI	ED	LSI
1990	14.8866	78.8277	64.1986	0.6981
2020	33.397	V30.5826	133.157	12.3318

climate change becoming increasingly apparent. This study's focus on Jorhat Municipality, while providing critical insights, also underscores the necessity for a broader examination of urban sprawl. Future research endeavours should aim at scaling these observations, applying similar analytical rigor to larger geographical extents. This would enable a more comprehensive understanding of urbanization patterns and their ramifications, facilitating the development of holistic urban planning and management strategies. In light of these findings, there is an urgent call for the adoption of strategic urban planning and sustainable development practices in Jorhat Municipality. The trends observed necessitate a proactive approach to urban expansion, one that carefully balances developmental aspirations with environmental stewardship. Policymakers and urban planners are thus presented with an opportunity to harness these insights in formulating and implementing strategies that prioritize resilience and sustainability. The path forward involves crafting urban environments that are not only conducive to economic prosperity but also sustainable, liveable, and responsive to the environmental imperatives of our times. This study contributes a valuable perspective to the discourse on urban development, offering a foundation upon which future research and policy interventions can build to foster sustainable urban growth in Jorhat and beyond.

Conflict-of-interest statement

The authors have no conflict of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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