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Spatio-temporal variation of urban sprawl in Tura town using the Shannon entropy model

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Abstract

Urbanization is driving substantial transformation of cities worldwide, with unmanaged expansion often resulting in urban sprawl and the loss of agricultural land, forests, and environmentally sensitive areas. Tura Town, headquarters of West Garo Hills District, has experienced steady urban growth over the past two decades, yet few studies have examined its expansion pattern. This study aims to analyse the spatio-temporal variation and assessing the degree and directional patterns of urban sprawl from 2006 to 2026 using Remote Sensing, GIS, and Shannon's Entropy Index. Landsat imagery was classified into LULC categories, with accuracy validated through a confusion matrix, achieving satisfactory results (77–81%). Built-up area increased from 10 km² to 17 km²—a 70% rise, with faster growth occurring during 2006–2016 (40%) than 2016–2026 (21.4%). Shannon's Entropy Index revealed the compactness or dispersal of growth, while buffer and directional analyses identified expansion patterns. The findings offer valuable insights for sustainable urban planning and land-use management in Tura Town.

Keyword: Urban sprawl, Urbanization, Land use/land cover (LULC), Remote Sensing, GIS, Shannon's Entropy Index, Built-up area, Tura Town, Spatio-temporal analysis, Sustainable urban planning

1. Introduction

Urbanization is one of the most influential processes transforming the physical and socio-economic landscape of cities across the world. As urban populations continue to increase, cities expand beyond their traditional boundaries to accommodate the growing demand for housing, transportation, commercial activities, and public infrastructure. Although urban growth contributes significantly to economic development and improved living standards, uncontrolled expansion often results in urban sprawl, leading to the loss of agricultural land, forests, and environmentally sensitive areas (United Nations, 2019). The rapid

expansion of built-up areas has therefore become an important concern for planners and policymakers seeking to balance development with environmental sustainability.

Urban sprawl generally refers to the outward expansion of urban areas into surrounding rural or undeveloped land in a dispersed and often unplanned manner. It is characterized by low-density development, fragmented land use, and increasing dependence on transportation networks (Ewing, 1997). Such growth patterns can have significant environmental, economic, and social consequences, including habitat fragmentation, increased energy consumption, traffic congestion, pressure on public services, and changes in the natural landscape (Bruegmann, 2005). Understanding the nature and pattern of urban sprawl is therefore essential for promoting sustainable urban development and ensuring the efficient use of land resources.

In recent decades, advances in Remote Sensing (RS) and Geographic Information System (GIS) technologies have greatly improved the ability to monitor urban growth and land use changes. Satellite imagery provides consistent spatial information over long periods, enabling researchers to detect changes in land use and land cover with greater accuracy. GIS complements this by providing tools for spatial analysis, visualization, and decision-making. Together, these technologies have become indispensable for studying urban growth, evaluating land transformation, and supporting evidence-based planning (Jensen, 2015; Lillesand, Kiefer & Chipman, 2015).

Several spatial statistical techniques have also been widely adopted to analyse urban expansion. Shannon's Entropy Index is commonly used to measure the degree of dispersion or compactness of built-up areas, where higher entropy values indicate a more dispersed pattern of urban development (Yeh & Li, 2001). Similarly, the Mean Centre and Standard Deviational Ellipse (SDE) are effective tools for identifying the spatial distribution, directional trend, and movement of urban growth over time. These methods provide valuable insights into the direction and intensity of urban expansion and are increasingly applied in studies of urban sprawl.

Tura Town, the headquarters of West Garo Hills district in Meghalaya, is one of the most important urban centres in the Garo Hills region. It functions as the administrative, educational, commercial, and service centre for the surrounding rural areas. Over the last two decades, the town has experienced noticeable physical growth due to population increase, improved road connectivity, expansion of educational and healthcare facilities, commercial development, and changing socio-economic conditions. As urban activities have expanded, built-up areas have gradually replaced forests, agricultural land, and open spaces, resulting in significant changes in the urban landscape. Despite these changes, comprehensive studies examining the spatio-temporal growth and spatial pattern of Tura Town remain limited, highlighting the need for systematic investigation.

Nearly six decades ago, urban sprawl was described as a modern form of American suburbanization characterized by scattered and low-density development (Whyte, 1993). Since then, scholars have continued to debate its nature and impacts, and there is still no universally accepted definition of urban sprawl (Galster et al., 2001; Hamidi & Ewing, 2014; Wei & Ewing, 2018). Urban sprawl is generally associated with unplanned and low-density urban expansion along the outskirts of cities and metropolitan

regions (Harvey & Clark, 1965; Bruegmann, 2006). It is commonly understood as the rapid and uncontrolled outward growth of urban areas into peripheral zones (Brueckner, 2000).

Parent and Civco (2007) studied different dimensions of urban sprawl using spatial metrics. The study identified major characteristics of sprawl, including city expansion beyond walkable limits, declining urban density, suburbanization, fragmented open spaces, and changes in urban compactness. The research introduced several quantitative indicators to analyse urban spatial structure and demonstrated their application in understanding urban growth patterns. The study emphasized the importance of spatial metrics for monitoring and managing urban sprawl.

Tayyebi et al. (2011) assessed and modelled urban sprawl using Remote Sensing, Geographic Information Systems (GIS), Artificial Neural Networks (ANN), and the Adaptive Neuro-Fuzzy Inference System (ANFIS). The study found that Tehran experienced rapid and increasing urban sprawl between 1988 and 2010. Landsat satellite imagery and factors such as distance to roads, green spaces, elevation, and developed areas were used to analyse urban growth. The results showed that the ANFIS model performed better than the ANN model in predicting urban sprawl patterns, demonstrating the effectiveness of integrating geospatial technologies with artificial intelligence for urban growth modelling.

Pampoore-Thampi, Varde, and Yu (2014) used Geographic Information Systems (GIS), data mining algorithms, and ArcGIS tools to analyse urban sprawl patterns. They developed a Spatial Decision Support System (SDSS) to predict future urban expansion by integrating geospatial and demographic data. The study demonstrated that combining GIS with data mining techniques provides an effective framework for supporting sustainable urban planning and decision-making.

Boori et al. (2015) studied urban sprawl in Kuala Lumpur, Malaysia, using Remote Sensing and GIS techniques from 1989 to 2014. The study found that rapid urban expansion significantly increased built-up areas while reducing agricultural land and green spaces. Landsat satellite imagery and GIS-based buffer analysis were used to monitor spatial and temporal urban growth. The researchers concluded that population growth, industrialization, and economic development were the major drivers of urban sprawl and highlighted the importance of Remote Sensing and GIS for sustainable urban planning.

Fatema and Chakrabarty (2018) investigated urban sprawl and land use/land cover (LULC) changes in Sylhet City, Bangladesh, between 2001 and 2011 using Remote Sensing and Geographic Information Systems techniques. Using Landsat ETM+ imagery and Google Earth Pro, the study demonstrated how urban expansion driven by population growth could be effectively monitored and mapped through geospatial tools. The findings highlighted the usefulness of Remote Sensing and GIS in detecting land use changes and supporting sustainable urban planning.

Parent and Civco (2007) developed spatial metrics to measure different dimensions of urban sprawl using Geographic Information Systems (GIS). The study examined major characteristics of urban sprawl, including urban expansion beyond walkable limits, declining urban density, suburbanization, fragmentation of open spaces, and changes in urban compactness. The proposed metrics were demonstrated using the case study cities of Bangkok (Thailand) and Minneapolis (USA). The authors concluded that spatial metrics provide an effective framework for monitoring urban expansion and supporting sustainable urban planning.

Jat, Garg, and Khare (2007) examined urban sprawl in Ajmer, Rajasthan, from 1977 to 2002 using Remote Sensing (RS) and Geographic Information Systems (GIS). Their study revealed that land development increased at a much faster rate than population growth, indicating significant urban sprawl and major spatial changes within the city.

Tayyebi et al. (2011) assessed and modelled urban sprawl in the Tehran Metropolitan Area, Iran, using Remote Sensing (RS), Geographic Information Systems (GIS), Artificial Neural Networks (ANN), and the Adaptive Neuro-Fuzzy Inference System (ANFIS). The study found that both models effectively predicted future urban expansion, with ANFIS producing slightly higher prediction accuracy than ANN.

Tiwari, Saxena, and Katare (2012) discussed how rapid population growth and economic development in India and other developing countries have accelerated urban expansion and land use change, particularly in urban fringe and peri-urban areas. The study emphasized the growing importance of Remote Sensing and GIS for analysing spatio-temporal changes and supporting sustainable urban planning.

Pampoore-Thampi, Varde, and Yu (2014) developed a methodology for analysing and predicting urban sprawl using Geographic Information Systems (GIS), data mining algorithms, and ArcGIS tools. The study proposed a Spatial Decision Support System (SDSS) that integrated geospatial and demographic data to predict future urban expansion. The findings demonstrated that GIS and data mining techniques provide an effective framework for sustainable urban planning and decision-making.

Ahmad and Goparaju (2016) investigated urban expansion in Ranchi, Jharkhand, using Remote Sensing and Geographic Information Systems with Landsat data from 1976 to 2015. The study showed a steady increase in built-up areas following Ranchi's designation as the state capital, driven by infrastructure development, education, and economic growth. The authors emphasized the importance of geospatial analysis for sustainable urban planning.

Fatema and Chakrabarty (2018) investigated urban sprawl and land use/land cover (LULC) changes in Sylhet City, Bangladesh, between 2001 and 2011 using Remote Sensing and Geographic Information Systems. The study demonstrated that rapid population growth significantly increased built-up areas while reducing agricultural land and vegetation. The authors concluded that RS and GIS are effective tools for monitoring urban growth and supporting sustainable land-use planning.

Krishnaveni and Anilkumar (2020) examined urban sprawl in the Kozhikode Metropolitan Area, Kerala, between 1991 and 2018 using Remote Sensing and GIS techniques. Built-up areas were extracted using the Index Derived Built-up Index (IDBI), while Shannon's Entropy was employed to measure urban sprawl. The study revealed a significant increase in built-up areas due to rapid and uncontrolled urbanization and highlighted the usefulness of geospatial techniques for monitoring urban growth.

Roy and Kasemi (2021) analysed urban growth in Raiganj, West Bengal, from 1991 to 2019 using land use/land cover analysis and spatial techniques. The study found a rapid increase in built-up areas accompanied by a substantial decline in agricultural and vegetative land, indicating unsustainable urban expansion and increasing urban sprawl.

Chettry (2022) analysed land use/land cover change and urban sprawl in the Thiruvananthapuram Urban Agglomeration between 2001 and 2021 using Remote Sensing and GIS techniques. The study reported a significant increase in built-up areas and a decline in natural land cover. Shannon's Entropy indicated rapid peri-urban sprawl characterized by scattered and low-density development patterns. The findings highlighted the importance of geospatial technologies for sustainable urban planning.

Chettry (2022) also investigated urban growth in four medium-sized Indian cities—Lucknow, Bhubaneswar, Raipur, and Dehradun—from 1991 to 2021 using Remote Sensing and GIS. The study identified edge expansion as the dominant pattern of urban growth and emphasized the role of geoinformatics in monitoring urban expansion and supporting sustainable planning strategies.

Mehra and Swain (2025) analysed land use change and urban sprawl in Dharamshala, Himachal Pradesh, between 2016 and 2022 using Remote Sensing and GIS techniques. The study found a substantial increase in built-up areas and a decline in agricultural and protected lands due to tourism, population growth, and urban expansion. The authors concluded that uncontrolled urbanization in the Himalayan region may increase environmental degradation and ecological risks, highlighting the need for sustainable urban planning.

Singh and Purkayastha (2026) examined the effects of urban sprawl in the Imphal Urban Agglomeration, Manipur, using Landsat and Sentinel satellite data together with household surveys. Shannon's Entropy was applied to quantify urban sprawl. The study found that rapid urban expansion had significantly altered land use patterns and affected both native and migrant populations, emphasizing the importance of sustainable urban development and planning.

Kharpran and Purkayastha (2024) examined the urban growth of Shillong, Meghalaya, from a colonial hill station to a rapidly expanding urban centre. Using Remote Sensing (RS), Geographic Information Systems (GIS), and Shannon's Entropy, the study analysed urban sprawl between 1991 and 2021. The findings revealed a continuous increase in built-up areas and increasing urban dispersion, accompanied by the conversion of natural land into urban land. The study highlighted the environmental impacts of rapid urban expansion and emphasized the importance of geospatial techniques for monitoring urban growth and supporting sustainable urban planning.

Saikia, War, Umlong, and Nath (2024) investigated the impact of urbanization on land surface temperature (LST) and the urban heat island (UHI) effect in Shillong, Meghalaya. Using land use/land cover (LULC) analysis for the period 1993–2023, the study found a steady increase in built-up areas accompanied by a corresponding rise in land surface temperature across all land-cover classes, particularly in densely populated urban zones. The decline in vegetation and expansion of impervious surfaces was identified as the major factors contributing to the warming trend. The study concluded that continued urban expansion could intensify environmental stress and highlighted the importance of integrating geospatial technologies into sustainable urban planning and environmental management.

2. Statement of the Problem

Tura Town, the headquarters of West Garo Hills District in Meghalaya, has experienced steady urban growth over the past two decades due to increasing population, rural-to-urban migration, economic development, and the expansion of educational institutions, commercial establishments, and transportation

infrastructure. As the town has grown, built-up areas have gradually expanded beyond the traditional urban core into surrounding agricultural land, open spaces, and areas covered by natural vegetation. While this expansion has contributed to the economic and social development of the town, it has also resulted in significant changes in land use and land cover, raising concerns about the sustainable management of urban growth.

Despite Tura's importance as the largest urban centre in the Garo Hills region, there are limited studies that comprehensively examine its pattern of urban expansion using geospatial techniques. Understanding how the town has expanded, the direction of its growth, and the extent of urban sprawl is essential for effective land-use planning and future urban development. Therefore, this study analyses the spatial and temporal pattern of urban sprawl in Tura Town between 2006 and 2026 using Remote Sensing, Geographic Information Systems (GIS), and Shannon's Entropy Index. The findings are expected to provide valuable information for planners and policymakers to promote sustainable urban development, improve land-use management, and minimize the environmental impacts associated with rapid urban expansion.

3. Objective

To analyse the spatio-temporal variation of urban sprawl in Tura Town in the year of 2006, 2016, and 2026 and to assess the degree and directional pattern of urban sprawl in Tura Town.

4. Study Area

Tura Town, the headquarters of West Garo Hills District, is located in the western part of Meghalaya, India. It is the largest urban centre in the Garo Hills region and serves as an important administrative, educational, commercial, and cultural hub.

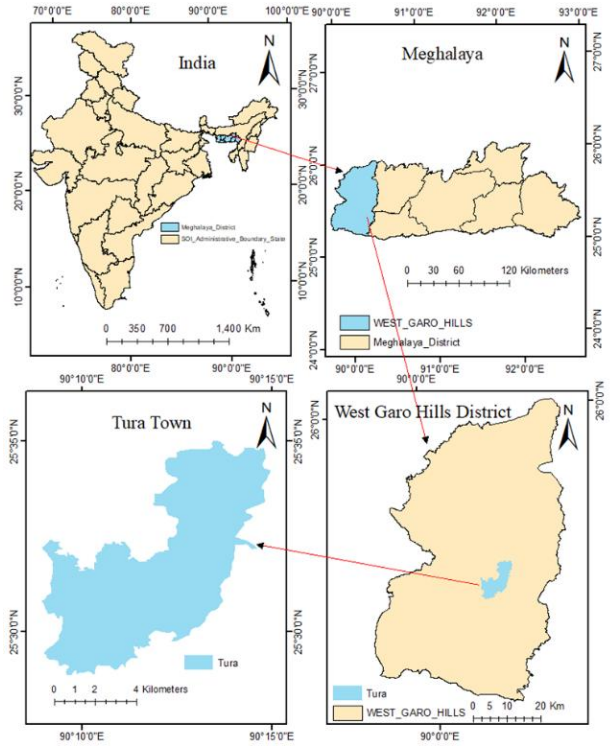


Fig.-1: Location Map of the Study Area

The town lies between approximately 25°30′N–25°35′N latitude and 90°10′E–90°15′E longitude. Tura is situated within West Garo Hills District, which forms part of the state of Meghalaya in north-eastern India. Due to its strategic location, Tura functions as the main service centre for the surrounding rural areas. The town has experienced rapid growth in recent years because of increasing population, rural-to-urban migration, expansion of educational institutions, government offices, healthcare facilities, and commercial activities. These developments have significantly contributed to the expansion of the urban area, making Tura an ideal study area for analysing urban sprawl.

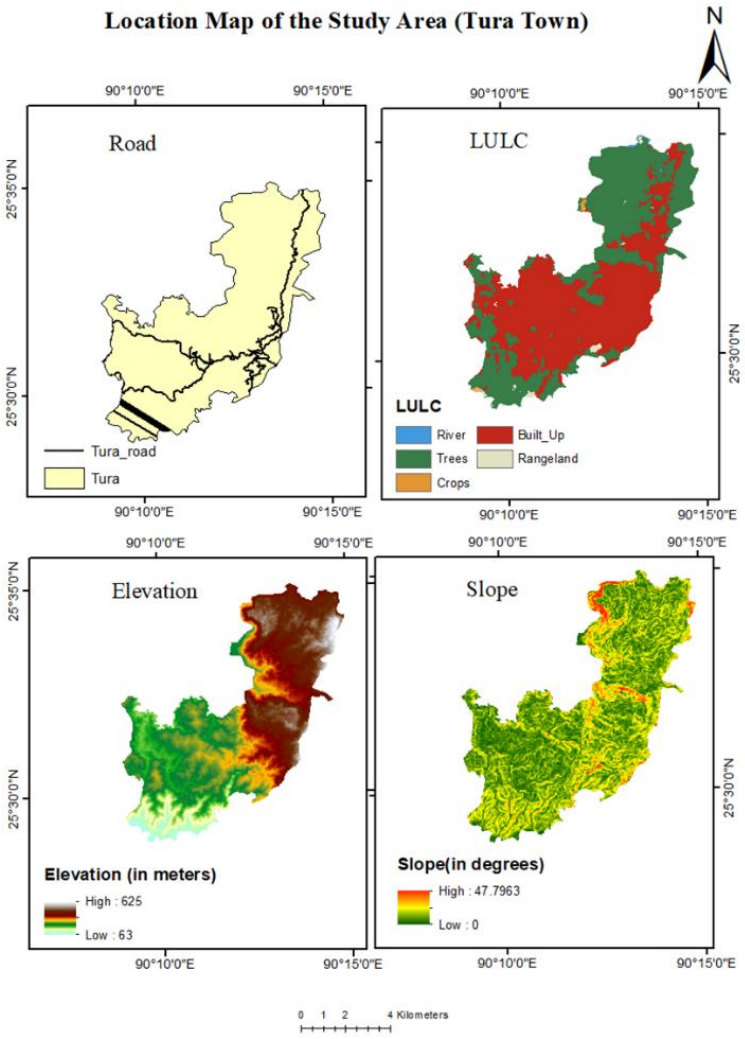


Fig.-1: Location Map of the Study Area (With Subset Map)

5. Data base and Methodology

The methodology adopted in this study consists of a series of systematic steps to analyse the spatial and temporal pattern of urban sprawl in Tura Town between 2006 and 2026. Remote Sensing, Geographic Information Systems (GIS), and Shannon's Entropy Index were integrated to assess changes in built-up areas and evaluate the nature of urban growth.

Table-Error! No text of specified style in document.**: Datasets Used in the Study**

Dataset	Description	Source
Landsat 5 TM	Satellite imagery for 2006 urban growth analysis	USGS Earth Explorer
Landsat 8 OLI/TIRS	Satellite imagery for 2016 and 2026 urban growth analysis	USGS Earth Explorer
Sentinel-2 LULC	Land Use/Land Cover classification	ESRI Sentinel-2 Land Cover
DEM (30 m)	Elevation and terrain information	USGS Earth Explorer
Road Network	Road and transportation network	BB Bike. Open street Map
Tura Boundary	Administrative boundary of the study area	Department of Urban Affairs, Governnent of Meghalaya (Tura Draft Master Plan 2015-35)

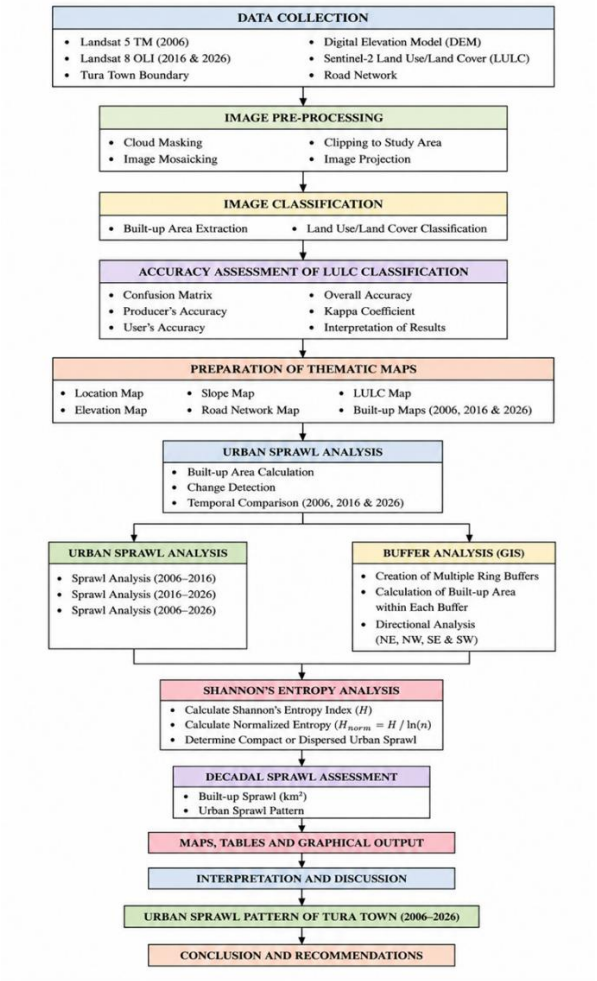


Fig.-3: Flow Chart of Methodology

6. Result and Discussion

Urban sprawl has become one of the most noticeable patterns of urban growth across the world, especially in developing countries where rapid population growth and economic development are transforming cities at an unprecedented pace. It refers to the outward expansion of urban areas into surrounding rural and agricultural lands in an unplanned, low-density, and fragmented manner. Such expansion often results in inefficient land use, increased pressure on natural resources, and various environmental challenges (Ewing, 1997; Galster et al., 2001). The main factors contributing to urban sprawl include population growth, industrialization, improved transportation networks, rising income levels, and the growing demand for residential, commercial, and industrial development (Bhatta, 2010).

Tura, the headquarters of West Garo Hills district in Meghalaya, is the largest urban centre in the Garo Hills region. Over the past two decades, the town has undergone significant physical expansion due to increasing population, rural-to-urban migration, economic activities, educational development, and improvements in transportation infrastructure. As a result, agricultural lands, open spaces, and natural vegetation have gradually been converted into built-up areas. This continuous expansion has increased the demand for housing, public services, and urban infrastructure, making it essential to understand the pattern and extent of urban growth for effective planning and sustainable urban management. Historical development also shows that Tura has gradually expanded into surrounding localities, reflecting its growing role as an administrative, educational, and commercial centre.

This study examines the spatial and temporal pattern of urban sprawl in Tura Town over a 20-year period using satellite imagery from 2006, 2016, and 2026. These years were selected at ten-year intervals to capture long-term changes in urban growth and land use/land cover (LULC). Comparing these three time periods makes it possible to identify changes in built-up areas, vegetation, agricultural land, water bodies, and other land-use categories. The analysis provides valuable insights into the direction, intensity, and pattern of urban expansion, thereby supporting sustainable urban planning and informed decision-making.

The built-up map for 2006 represents the initial stage of urban development considered in this study. It shows that urban growth was mainly concentrated in the central and south-eastern parts of Tura, which formed the town's primary urban core. In contrast, the northern, western, and outer peripheral areas remained largely undeveloped, with only a few scattered built-up patches. This distribution suggests that urbanization was still at an early stage, with most development confined to established residential, commercial, and administrative zones.

The spatial distribution of built-up land in 2006 was uneven across the town. The central and south-eastern areas exhibited the highest concentration of buildings, reflecting the presence of major commercial, residential, and institutional activities. In comparison, the western, northern, and south-western regions contained isolated and sparsely distributed built-up patches separated by vegetation and open land. This uneven pattern indicates that urban development was concentrated around the existing urban core rather than being evenly spread throughout the town.

Several factors contributed to the pattern of urban development observed in 2006:

- Population growth and the increasing demand for housing.
- Expansion of government offices and administrative services.
- Development of educational institutions and healthcare facilities.
- Growth of commercial and service activities within the town.

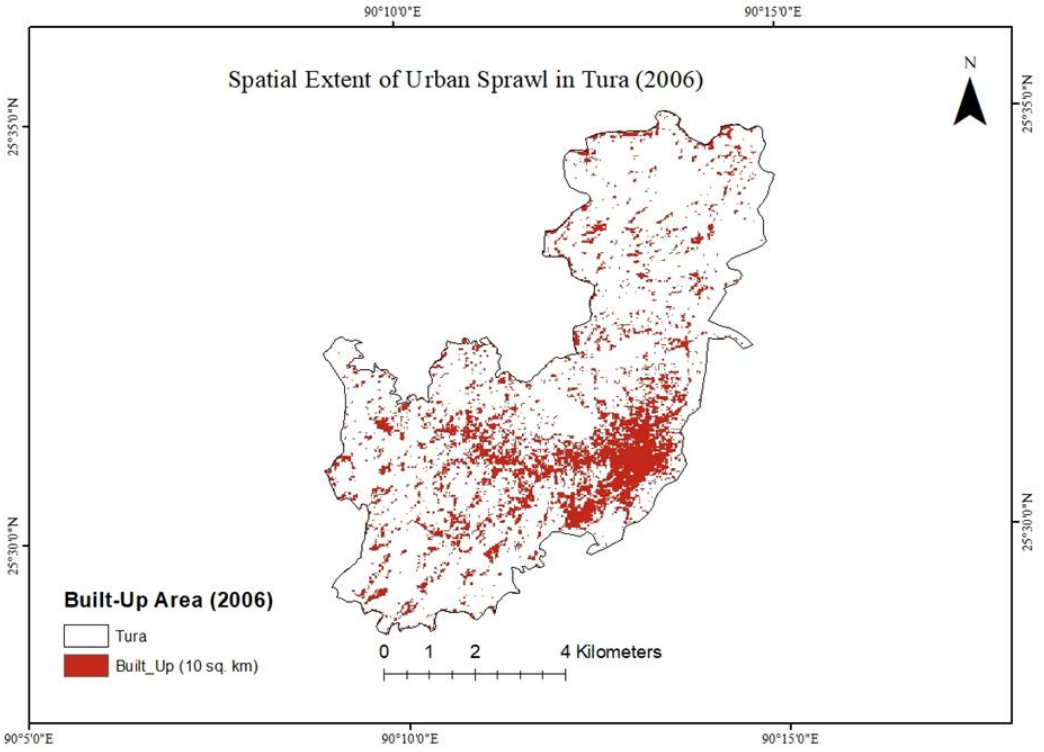


Fig.-Error! No text of specified style in document.**.2: Spatial Extent of Urban Sprawl in Tura (2006)**

- Improvement of road connectivity, encouraging development along transportation corridors.
- Rural-to-urban migration from surrounding villages in search of employment, education, and better public services.

Together, these factors supported the gradual outward expansion of the built-up area from the town centre toward surrounding locations.

Table-Error! No text of specified style in document.**.1: Confusion matrix table (2006**)

OID	Class Value	Built-up	Crops	Trees	Barren Ground	Total	U Accuracy	Kappa
0	Built-up	35	0	0	1	36	0.972222	0
1	Crops	0	21	3	2	26	0.807692	0
2	Trees	11	0	45	8	64	0.703125	0
3	Barren Ground	18	0	2	53	73	0.726027	0
4	Total	64	21	50	64	199	0	0
5	P_Accuracy	0.546875	1.000000	0.900000	0.828125	0	0.773869	0
6	Kappa	0	0	0	0	0	0	0.689913

The confusion matrix indicates that the land use/land cover (LULC) classification achieved an overall accuracy of 77.39% with a Kappa coefficient of 0.6899, indicating substantial agreement between the classified image and the reference data. This suggests that the classification is reasonably reliable for LULC mapping.

The Built-up class recorded the highest User's Accuracy (97.22%), indicating that nearly all pixels classified as built-up were correctly identified. However, its Producer's Accuracy was only 54.69%, showing that a considerable number of actual built-up areas were misclassified, primarily as trees and barren ground. This reflects a high omission error despite a low commission error.

The Crops class achieved a User's Accuracy of 80.77% and a Producer's Accuracy of 100.00%, indicating that all reference crop samples were correctly identified. Nevertheless, a few pixels classified as crops actually belonged to trees and barren ground, resulting in some commission errors.

The Trees class obtained a User's Accuracy of 70.31% and a Producer's Accuracy of 90.00%. Most reference tree samples were correctly classified, although some pixels labelled as trees were actually built-up areas and barren ground, indicating moderate confusion among these classes.

The Barren Ground class recorded a User's Accuracy of 72.60% and a Producer's Accuracy of 82.81%. While the majority of barren-ground reference samples were correctly identified, some barren-ground pixels were misclassified as built-up and trees, contributing to both omission and commission errors.

Overall, the classification demonstrates good performance, with crops showing the highest producer's accuracy and built-up exhibiting the highest user's accuracy. However, confusion between built-up areas, trees, and barren ground reduced the overall classification performance. The overall accuracy of 77.39% and the Kappa coefficient of 0.6899 indicate that the classification is sufficiently reliable for land use/land cover change analysis, although improvements in separating spectrally similar land-cover classes could further enhance accuracy

The built-up map of 2016 reveals a significant expansion of urban development in Tura compared with 2006. During this ten-year period, the town experienced considerable physical growth, with built-up areas extending beyond the original urban core into surrounding regions. The total built-up area increased from approximately 10 km² in 2006 to 14 km² in 2016, highlighting the rapid pace of urbanization. This growth reflects the increasing influence of demographic, economic, and infrastructural development on the town's spatial expansion.

The spatial distribution of built-up land in 2016 shows that the central and south-eastern parts of Tura continued to be the most densely developed areas. However, urban development also expanded towards the western, northern, and south-western parts of the town. Several new built-up patches emerged around the urban fringe, reducing the extent of open spaces that previously separated developed areas. Compared with 2006, the built-up areas became more widespread and interconnected, indicating a clear outward expansion of the urban landscape.

The growth pattern observed in 2016 reflects both urban densification and peripheral expansion. Within the existing urban core, vacant spaces were increasingly occupied, resulting in a more continuous and compact built-up pattern. At the same time, new residential, commercial, and institutional developments spread towards the outskirts, particularly along major road networks. This combination of infill development and outward expansion suggests that Tura was transitioning from a relatively compact urban form in 2006 to a more dispersed urban structure by 2016, marking a clear progression of urban sprawl.

Several factors contributed to the expansion of built-up areas between 2006 and 2016:

- Rapid population growth and increasing demand for housing.

- Expansion of educational institutions, healthcare facilities, and government offices.
- Growth of commercial and business activities.
- Improvement of transportation infrastructure and road connectivity.
- Rural-to-urban migration from surrounding villages in search of better employment, education, and public services.
- Rising demand for residential land and urban infrastructure.

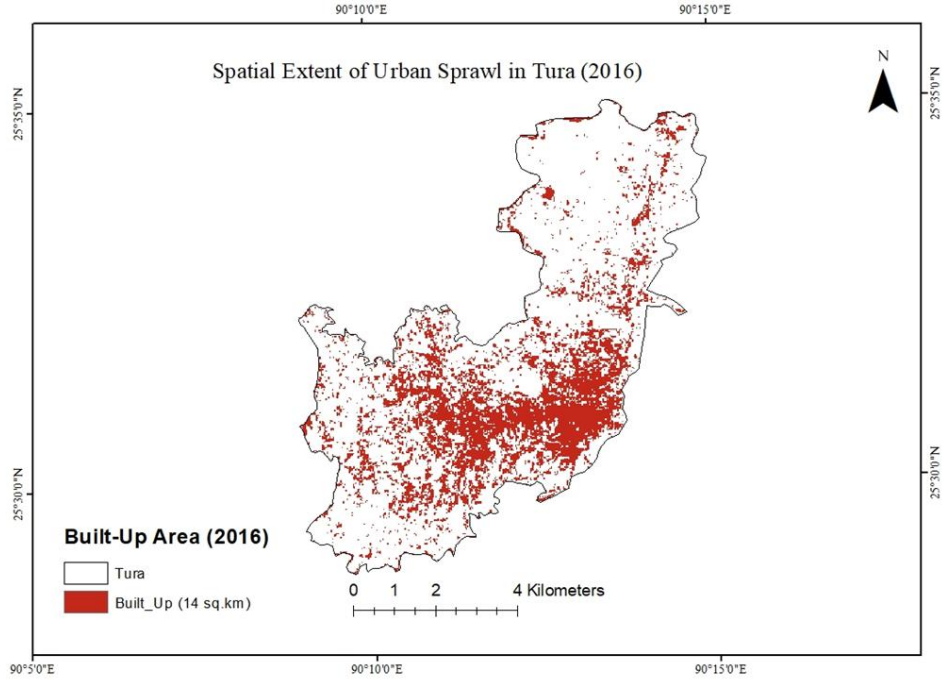


Fig.-Error! No text of specified style in document.**.3: Spatial Extent of Urban Sprawl in Tura (2016)**

Together, these factors accelerated the conversion of agricultural land, vegetation, and open spaces into built-up areas, resulting in the outward expansion of Tura's urban boundary. Compared with 2006, the 2016 urban landscape shows several notable changes:

- The built-up area increased from 10 km² to 14 km², indicating significant urban growth.
- The urban core became denser as vacant spaces were gradually developed.
- Peripheral development expanded considerably towards the western, northern, and south-western parts of the town.
- The pattern of growth shifted from predominantly compact development to a combination of compact growth and outward, dispersed expansion, reflecting the increasing influence of urban sprawl.
- The confusion matrix shows that the classified land use/land cover (LULC) map achieved an overall accuracy of 80.60% with a Kappa coefficient of 0.7418, indicating a substantial level of agreement between the classified image and the reference data. This suggests that the classification is reliable for land use/land cover analysis.

Table-Error! No text of specified style in document.**.2: Confusion matrix table (2016)**

OID	Class Value	Crops	Built-up	Barren Ground	Trees	Total	U Accuracy	Kappa
0	Crops	40	0	0	12	52	0.769231	0
1	Built-up	0	51	1	0	52	0.980769	0
2	Barren Ground	2	6	34	10	52	0.653846	0
3	Trees	3	5	0	37	45	0.822222	0
4	Total	45	62	35	59	201	0	0
5	P Accuracy	0.888889	0.822581	0.971429	0.627119	0	0.80597	0
6	Kappa	0	0	0	0	0	0	0.741815

The Built-up class recorded the highest User's Accuracy (98.08%), indicating that nearly all pixels classified as built-up were correctly identified. It also achieved a Producer's Accuracy of 82.26%, showing that most reference built-up areas were successfully mapped, with only a few being confused with barren ground.

The Crops class achieved a User's Accuracy of 76.92% and a Producer's Accuracy of 88.89%. This indicates that while most reference crop areas were correctly classified, some pixels identified as crops actually belonged to the trees class, resulting in moderate commission errors.

The Barren Ground class recorded a User's Accuracy of 65.38% but the highest Producer's Accuracy (97.14%). This means that nearly all reference barren-ground samples were correctly detected, although several pixels classified as barren ground were actually built-up areas or trees, leading to commission errors.

The Trees class obtained a User's Accuracy of 82.22% but the lowest Producer's Accuracy (62.71%) among all classes. This indicates that while most pixels classified as trees were correct, a considerable number of reference tree samples were misclassified as crops or barren ground, suggesting confusion between vegetation-related classes.

Overall, the classification demonstrates good performance, particularly for the Built-up and Crops classes. The relatively lower producer's accuracy for the Trees class indicates that further improvements in distinguishing vegetation from other land-cover types could enhance classification accuracy. The overall accuracy of 80.60% and the Kappa coefficient of 0.7418 confirm that the classification has a substantial level of reliability and is suitable for land use/land cover change analysis.

6.1 Urban Sprawl in Tura (2026)

The built-up map of 2026 indicates that urban sprawl in Tura has continued to intensify over the past two decades. The town has experienced steady physical expansion, with the built-up area increasing from approximately 10 km² in 2006 to 14 km² in 2016, and further to 17 km² in 2026. This sustained increase reflects the growing influence of population growth, economic development, and infrastructure expansion on the town's spatial development. Urban growth has extended well beyond the original urban core into surrounding peripheral areas, demonstrating a clear trend of outward expansion.

The spatial distribution of built-up land in 2026 is considerably more extensive than in the previous years. Although the central and south-eastern parts of Tura remain the most densely developed areas, substantial urban expansion is evident towards the western, northern, north-eastern, and south-western parts of the town. Many isolated built-up patches that were visible in 2006 and became more prominent in 2016 have

now merged through infill development, creating a larger and more continuous urban landscape. Despite this increased connectivity, scattered development remains evident along the urban fringe, indicating that the process of urban sprawl is still ongoing.

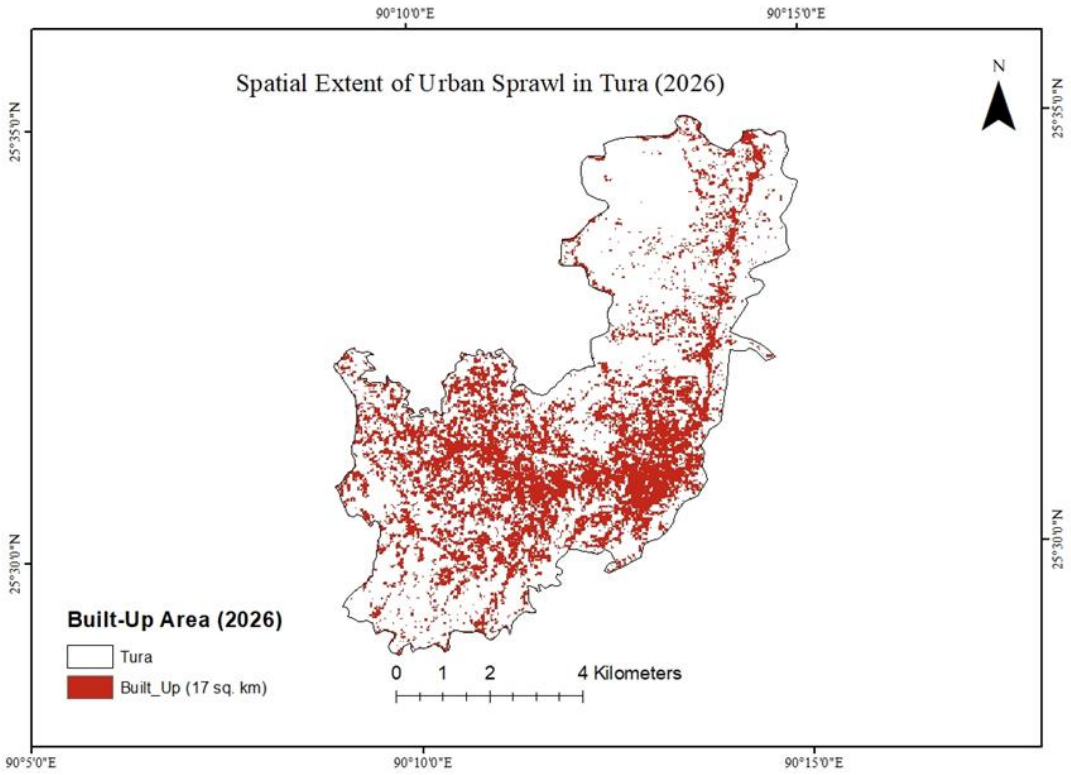


Fig.-Error! No text of specified style in document.**.4: Spatial Extent of Urban Sprawl in Tura (2026)**

The continued expansion of built-up areas between 2016 and 2026 can be attributed to several interrelated factors:

- Continuous population growth and increasing demand for housing.
- Expansion of commercial and business activities.
- Growth of educational institutions, healthcare facilities, and government offices.
- Improvement of road networks and transportation infrastructure.
- Rural-to-urban migration from surrounding villages in search of better employment, education, and public services.
- Increasing demand for urban services and public infrastructure.
- Economic development and the conversion of agricultural land, vegetation, and open spaces into built-up areas.

Together, these factors have accelerated the outward expansion of Tura while also increasing the density of development within the existing urban core.

The accuracy assessment of the 2026 Land Use/Land Cover (LULC) classification produced an overall accuracy of 78.00%, indicating that the classified map is sufficiently reliable for analysing urban sprawl and land use changes in Tura Town. The Kappa coefficient of 0.674 indicates substantial agreement

between the classified image and the reference data, suggesting that the classification is considerably more accurate than would be expected by chance.

Table-Error! No text of specified style in document.**.3: Confusion matrix table (2026)**

OID	Class Value	Built-up	Trees	Crops	Bare ground	Total	U Accuracy	Kappa
0	Built-up	61	1	0	0	62	0.983871	0
1	Trees	8	66	10	0	84	0.785714	0
2	Crops	6	13	19	0	38	0.5	0
3	Bare ground	2	2	2	10	16	0.625	0
4	Total	77	82	31	10	200	0	0
5	P Accuracy	0.792208	0.804878	0.612903	1	0	0.78	0
6	Kappa	0	0	0	0	0	0	0.674074

Among the land use classes, the Built-up class achieved the highest User's Accuracy (98.39%), indicating that nearly all pixels classified as built-up were correctly identified with very little confusion with other land cover types. This high accuracy confirms that built-up areas were successfully delineated and can be confidently used for urban sprawl analysis.

The Trees class recorded a User's Accuracy of 78.57%, indicating good classification performance, although some tree-covered areas were misclassified as cropland or built-up land due to similarities in spectral reflectance.

The Crops class showed the lowest User's Accuracy (50.00%), suggesting considerable confusion with other land cover classes, particularly trees and built-up areas. This may be due to similar spectral signatures during the image acquisition period, making discrimination between vegetation and agricultural land more difficult.

The Bare ground class achieved a User's Accuracy of 62.50%, indicating moderate classification accuracy. Some bareground pixels were confused with cropland and built-up areas because exposed soil and sparsely vegetated surfaces often exhibit similar spectral characteristics.

The Producer's Accuracy values indicate that Bare ground was completely represented in the classification with a value of 100%, while Trees, Built-up, and Crops achieved Producer's Accuracy values of 80.49%, 79.22%, and 61.29%, respectively. The lower Producer's Accuracy for the Crops class indicates that a notable proportion of reference crop pixels were classified into other land cover categories.

Overall, the classification results demonstrate acceptable accuracy for LULC mapping. The high accuracy of the built-up class is particularly important for this study because the primary objective is to assess urban sprawl. Therefore, the classified maps provide a reliable basis for analysing the spatial and temporal expansion of built-up areas in Tura Town during the study period.

Table-Error! No text of specified style in document.**.4: Summary of Accuracy Assessment**

Parameter	Value
Overall Accuracy	78.00%
Kappa Coefficient	0.674
Highest User's Accuracy	Built-up (98.39%)
Lowest User's Accuracy	Crops (50.00%)
Highest Producer's Accuracy	Bare ground (100.00%)

The analysis of built-up area over the three study years reveals a clear trend of continuous urban expansion in Tura. The town has gradually evolved from a relatively compact urban centre into a more extensive and interconnected urban area.

Table-Error! No text of specified style in document.**.5: Overall Comparison Table**

Year	Built-up Area	Major Characteristics
2006	**10 km²**	Compact urban core with limited development concentrated in the central and south-eastern areas, while peripheral regions remained largely undeveloped with scattered built-up patches.
2016	**14 km²**	Significant outward expansion accompanied by densification of the urban core, with increasing development along major transportation corridors and noticeable growth in peripheral areas.
2026	**17 km²**	Extensive outward expansion, greater connectivity of built-up areas through infill development, and continued urban sprawl extending into the western, northern, north-eastern, and south-western parts of the town.

Overall, the built-up area increased by 7 km² between 2006 and 2026, representing approximately 70% growth over the study period. The observed pattern indicates a gradual transition from a compact urban form to a more dispersed and interconnected urban landscape.

Table-Error! No text of specified style in document.**.6: Decadal Growth of Built-up Area in Tura (2006–2026)**

Period	Built-up Area (km²)	Increase (km²)	Percentage Growth
2006	10	–	–
2016	14	+4	40.0%
2026	17	+3	21.4%
2006–2026	**10 → 17**	**+7**	**70.0%**

The decadal analysis demonstrates a steady increase in the built-up area of Tura throughout the 20-year study period, reflecting continuous urban growth and expansion. The results indicate that urban development occurred in both decades, although the rate of growth varied over time.

Between 2006 and 2016, the built-up area increased from 10 km² to 14 km², representing an addition of 4 km² or 40% growth. This decade recorded the highest rate of urban expansion during the study period. The

rapid increase can be attributed to population growth, rural-to-urban migration, expansion of residential neighbourhoods, commercial development, improvements in transportation infrastructure, and the establishment of educational and administrative facilities. Much of the development during this period occurred through outward expansion from the existing urban core, leading to the conversion of agricultural land, vegetation, and open spaces into built-up areas.

During 2016–2026, the built-up area further increased from 14 km² to 17 km², adding 3 km², which represents a 21.4% increase. Although urban expansion continued, the growth rate was lower than that recorded during the previous decade. This comparatively slower growth suggests that urban development increasingly occurred through a combination of infill development within existing built-up areas and more gradual expansion into peripheral regions. As a result, the urban landscape became more continuous and interconnected while still extending into previously undeveloped areas.

Overall, the built-up area expanded from 10 km² in 2006 to 17 km² in 2026, resulting in a net increase of 7 km², equivalent to an overall growth of 70%. These findings confirm that Tura has experienced sustained urbanization over the last two decades, with the most rapid phase of expansion occurring between 2006 and 2016. The continued increase in built-up land highlights the growing demand for housing, infrastructure, and public services, emphasizing the importance of sustainable land-use planning and effective urban management to support future development while minimizing environmental impacts.

The trend in built-up area can be effectively illustrated using a bar graph or line graph, with the study years (2006, 2016, and 2026) on the X-axis and built-up area (km²) on the Y-axis.

The graph will show a consistent upward trend in built-up area over the study period, with the steepest increase occurring between 2006 and 2016, followed by continued but relatively slower growth between 2016 and 2026.

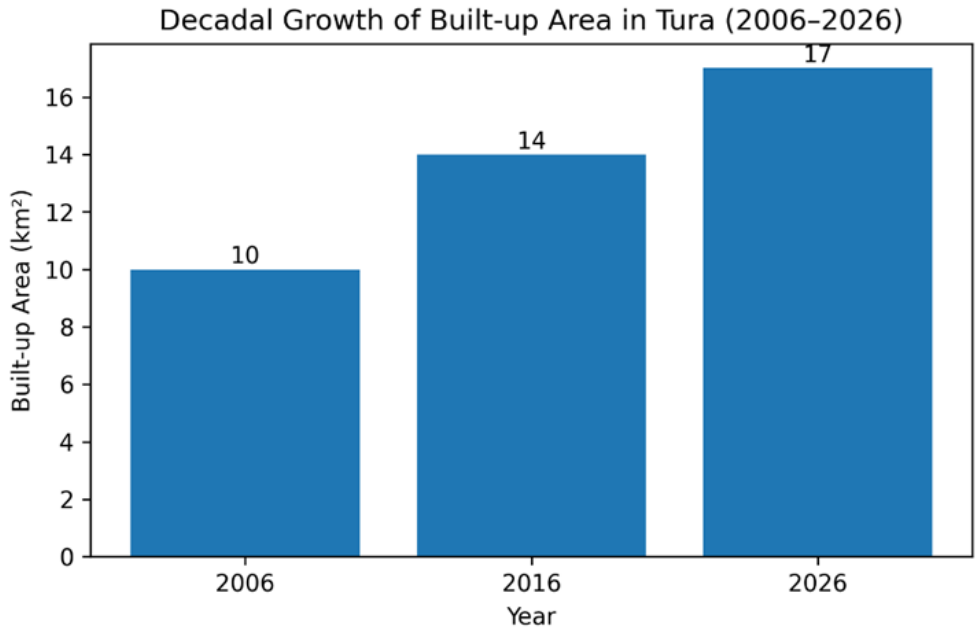


Fig.-Error! No text of specified style in document..**5: Decadal Growth of Built Area in Tura (2006-2026)**

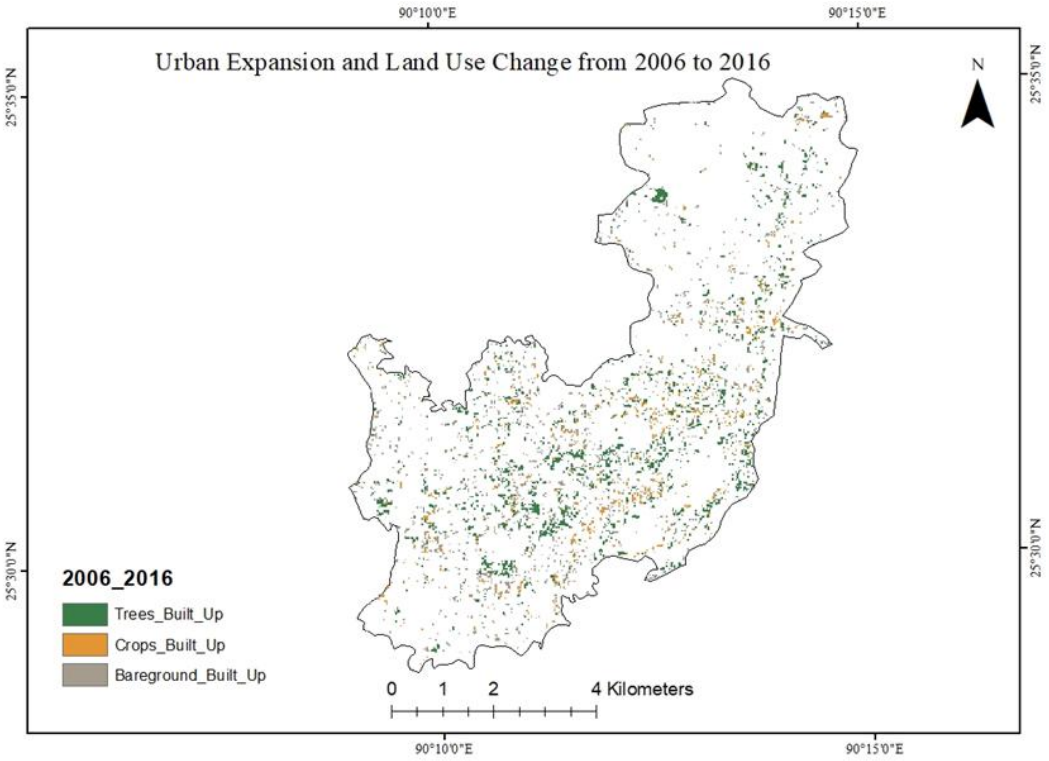


Fig.-Error! No text of specified style in document..**6: Urban Expansion and Land Use Change from 2006 to 2016**

Table-Error! No text of specified style in document..**7: Urban Sprawl Changes (2006-2016)**

Land Use Change (2006–2016)	**Total Area (sq km)**
Bareground → Built-up	**1.3374**
Crops → Built-up	**0.9747**
Trees → Built-up	**2.4876**
Grand Total	**4.7997**

6.2 Urban Sprawl Changes in Tura, Meghalaya (2006–2016)

The land use/land cover (LULC) change analysis for Tura, Meghalaya, between 2006 and 2016 indicates a noticeable expansion of built-up areas, reflecting the ongoing process of urban sprawl. A total of 4.7997 km² of land was converted into built-up areas during the study period, demonstrating increasing urban development.

Among the converted land-cover classes, forest (trees) experienced the highest loss, with 2.4876 km² transformed into built-up land. This indicates that urban growth in Tura expanded predominantly into

forested areas, which may be attributed to the increasing demand for residential housing, commercial establishments, public institutions, and transportation infrastructure associated with population growth and urban development.

Bare ground was the second-largest contributor to urban expansion, with 1.3374 km² converted into built-up areas. This suggests that vacant or undeveloped land provided additional space for new construction and infrastructure development, facilitating the outward expansion of the town.

The conversion of cropland to built-up areas accounted for 0.9747 km², indicating that agricultural land also experienced a decline as a result of urbanization. Although the converted area was smaller than that of forests and bare ground, it reflects the gradual encroachment of urban development onto productive agricultural land.

Overall, the findings reveal that urban sprawl in Tura between 2006 and 2016 occurred primarily at the expense of forest land, followed by bare ground and cropland. The substantial conversion of forests into built-up areas highlights increasing pressure on the region's natural ecosystems, while the reduction in agricultural land may have implications for local livelihoods and food production. These results underscore the need for sustainable urban planning and effective land-use management to balance future urban growth with the conservation of forest resources and agricultural land in Tura, Meghalaya.

6.3 Urban Sprawl Changes in Tura, Meghalaya (2016–2016)

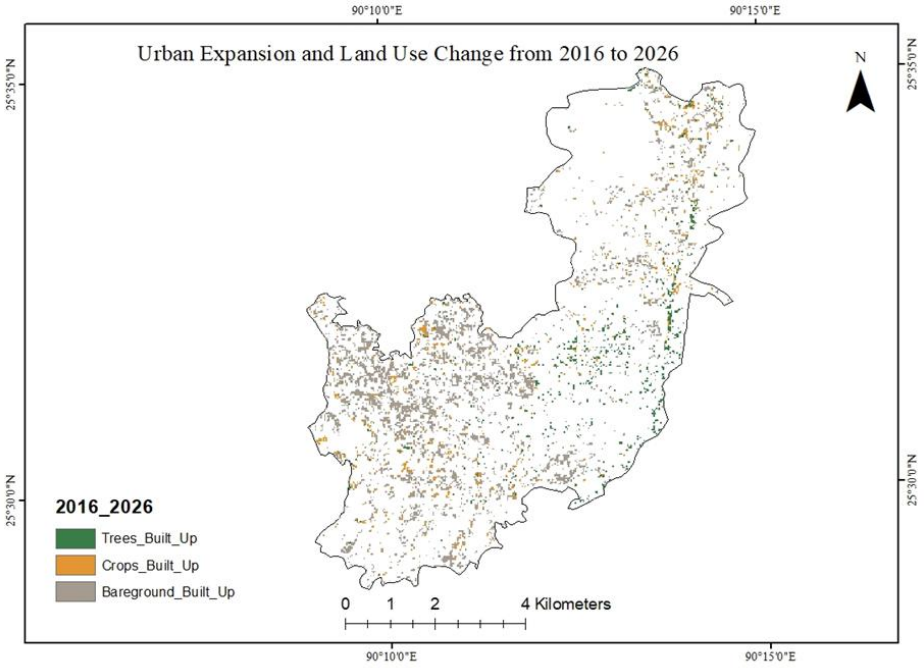


Fig.-Error! No text of specified style in document.**.7: Urban Expansion and Land Use Change from 2016 to 2026**

Table-Error! No text of specified style in document..**8: Urban Sprawl Changes (2016-2026)**

Land Use Change (2016–2026)	Total Area (km²)
Bare Ground → Built-up	4.6098
Trees → Built-up	1.0836
Crops → Built-up	1.1934
Grand Total	**6.8868**

The land use/land cover (LULC) change analysis for Tura, Meghalaya, between 2016 and 2026 indicates continued urban expansion, with 6.8868 km² of land converted into built-up areas. This increase reflects sustained urban growth associated with the expansion of residential neighbourhoods, commercial centres, public facilities, and transportation infrastructure.

The largest source of built-up expansion was bare ground, with 4.6098 km² converted into urban land. This suggests that much of the recent urban growth occurred on vacant or previously undeveloped land, indicating that available open spaces were increasingly utilized for new development.

The conversion of cropland to built-up areas totalled 1.1934 km², showing that agricultural land continued to be lost as urban areas expanded. This trend reflects increasing pressure on productive land resources and may have implications for agricultural activities around Tura.

Similarly, 1.0836 km² of forest (trees) was converted into built-up land. Although this conversion was smaller than that of bare ground and slightly lower than cropland, it indicates that urban expansion continued to encroach upon forested areas, contributing to the reduction of green cover and potentially affecting local biodiversity and ecosystem services.

Overall, the results indicate that urban sprawl in Tura during 2016–2026 occurred primarily through the conversion of bare ground into built-up areas, followed by cropland and forest land. The dominance of bare-ground conversion suggests that urban development increasingly utilized available open land; however, the continued loss of agricultural and forest areas highlights the need for sustainable urban planning and land-use management to support future development while conserving natural and productive landscapes.

6.4 Urban Sprawl Changes in Tura, Meghalaya (2006–2016)

Urban sprawl is a dynamic process characterized by the outward expansion of built-up areas into surrounding rural, agricultural, and natural landscapes. As cities grow, the spatial pattern of development may become either compact or dispersed, making it essential to quantify the nature and intensity of urban expansion over time. Spatial statistical techniques, combined with geospatial technologies, provide effective approaches for evaluating the magnitude, direction, and distribution of urban growth (Sudhira et al., 2004).

Among the various methods used to assess urban sprawl, Shannon's Entropy Index, originally developed by Shannon (1948), is one of the most widely applied measures for quantifying the degree of spatial dispersion of built-up areas. The entropy index measures the distribution of urban development across predefined spatial zones. Lower entropy values indicate that urban growth is concentrated and compact,

whereas values approaching the maximum entropy indicate dispersed and fragmented urban expansion, which is characteristic of urban sprawl (Yeh & Li, 2001; Sudhira et al., 2004).

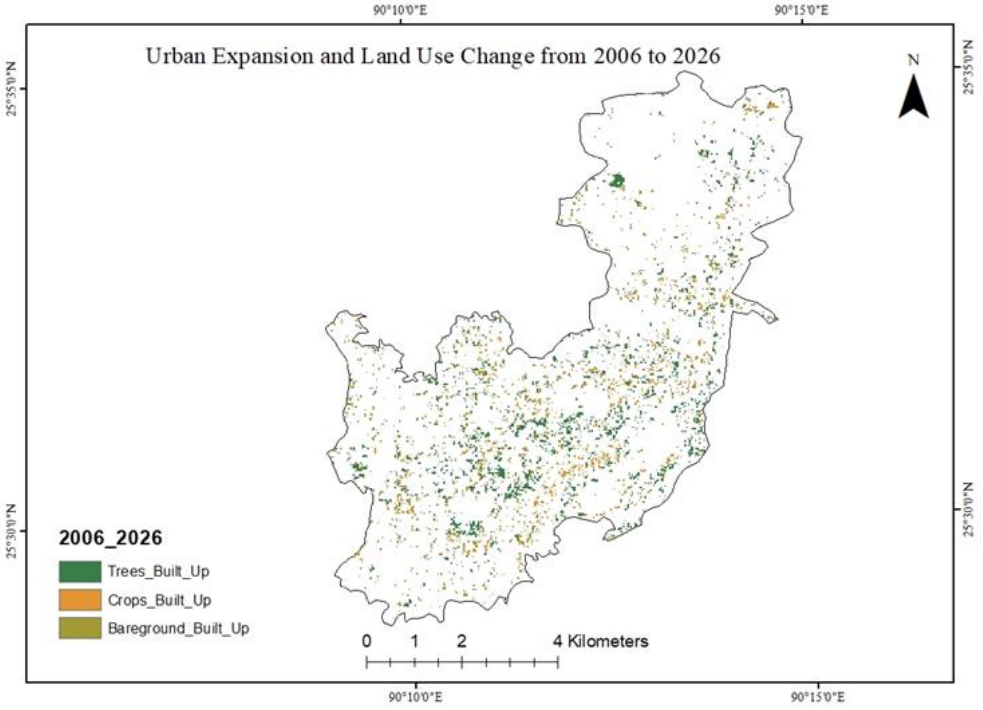


Fig.-Error! No text of specified style in document..**8: Urban Expansion and Land Use Change from 2006 to 2026**

Table-Error! No text of specified style in document..**9: Table Urban Sprawl Changes (2006-2026)**

Land Use Change (2006–2026)	**Total Area (km²)**
Bare Ground → Built-up	6.9795
Trees → Built-up	2.2968
Crops → Built-up	1.3590
Grand Total	**10.6353**

In this study, Shannon's Entropy was used to evaluate the spatio-temporal pattern of urban sprawl in Tura, Meghalaya, during the periods 2006–2016 and 2016–2026. The entropy analysis was complemented by spatial statistical techniques, including the Mean Center and Standard Deviational Ellipse (SDE), to identify the central tendency, directional orientation, and spatial dispersion of urban growth. Together, these methods provide a comprehensive understanding of the temporal evolution, spatial distribution, and directional characteristics of urban expansion in Tura over the two decades.

The built-up area in 2006 was primarily concentrated in the central part of Tura, forming a compact urban core. The highest density of built-up land occurred in the central and southeastern portions of the town, while the peripheral areas contained scattered settlements surrounded by forests, croplands, and bare

ground. This distribution indicates that urban development was largely confined to the existing municipal centre prior to significant outward expansion.

During the period from 2006 to 2016, urban sprawl expanded outward from the existing urban core through a combination of infill development and edge expansion. New built-up areas appeared in all directions; however, the most prominent growth occurred towards the east (E) and southeast (SE), followed by the northeast (NE) and south (S). Moderate expansion was observed in the west (W) and southwest (SW), whereas relatively limited development occurred towards the north (N) and northwest (NW). The standard deviational ellipse indicates that the overall orientation of urban growth followed a northwest–southeast (NW–SE) axis.

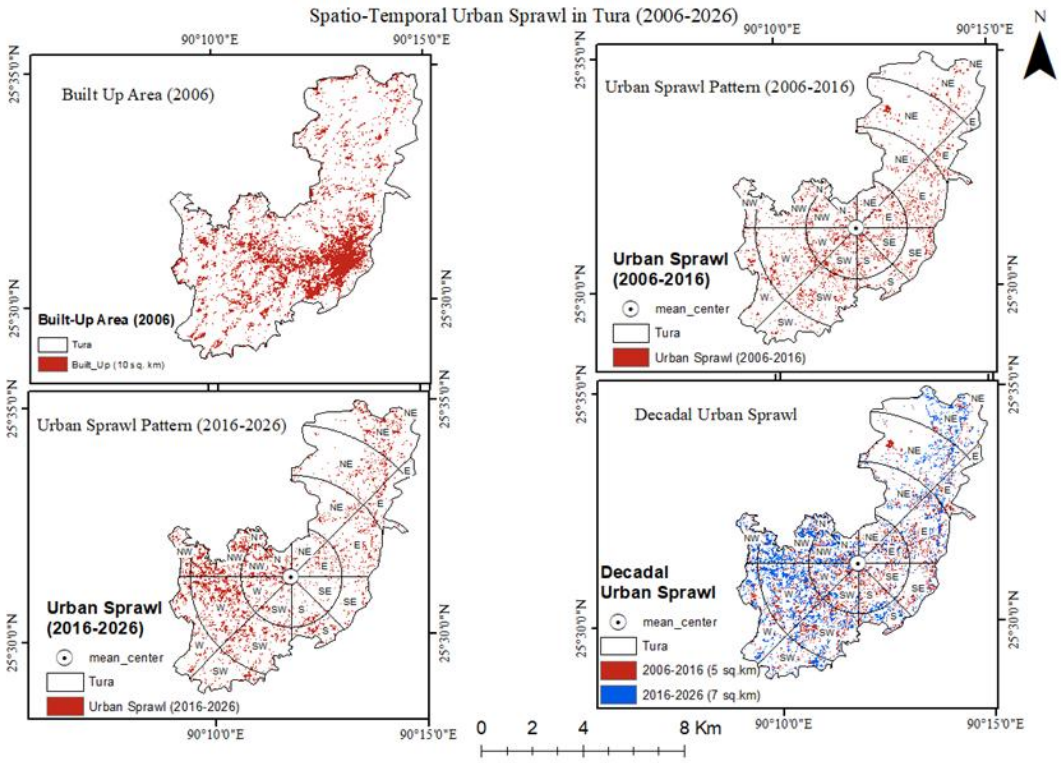


Fig.-Error! No text of specified style in document.**9: Spatio-Temporal Urban Sprawl in Tura (2006-2026)**

Between 2016 and 2026, urban expansion became more extensive and spatially dispersed. Compared with the previous decade, new built-up areas spread over a larger geographical extent, indicating accelerated urbanization. Expansion remained evident in the east (E) and southeast (SE) sectors while increasing substantially in the west (W), southwest (SW), and south (S). Growth also became more noticeable in the north (N) and northwest (NW), demonstrating that urban development had spread across almost the entire municipality. Despite the increased extent of urbanization, the standard deviational ellipse maintained a similar NW–SE orientation.

(2006–2016 vs. 2016–2026)

The comparative decadal analysis reveals that urban sprawl intensified during the second decade. While the 2006–2016 period was characterized by relatively concentrated development around the existing urban core, the 2016–2026 period exhibited a broader spatial distribution of new built-up areas. The decadal comparison map shows a higher density and wider distribution of urban growth during 2016–2026, indicating an increase in both the rate and spatial extent of urban expansion. The mean centre remained relatively stable between the two decades, suggesting that urban growth continued to radiate outward from the same urban core rather than shifting to a new development centre.

Urban expansion during 2006–2016 was concentrated around the existing urban core and spread into all directional zones. The southeast (SE) and east (E) sectors experienced the highest concentration of new built-up patches, indicating these were the dominant growth corridors during the first decade. Moderate expansion was observed in the northeast (NE), south (S), southwest (SW), and west (W) sectors, while the northwest (NW) and north (N) sectors exhibited relatively limited urban development. The standard deviational ellipse indicates that the overall orientation of urban growth followed a northwest–southeast (NW–SE) axis.

Between 2016 and 2026, urban growth became more extensive and spatially dispersed. Expansion continued in all directional zones, with the west (W), southwest (SW), south (S), southeast (SE), and east (E) sectors showing the greatest increase in built-up development. Compared with the previous decade, the northern (N) and northwestern (NW) sectors also experienced increased urban expansion, indicating that development had spread more uniformly across the municipality. Despite the wider distribution of urban growth, the standard deviational ellipse maintained a similar NW–SE orientation, suggesting that the principal direction of urban expansion remained consistent.

The comparison of the two decades reveals that urban sprawl intensified during 2016–2026. While 2006–2016 was characterized by relatively concentrated expansion around the urban core, the second decade exhibited a broader spatial distribution of new built-up areas across almost all directional zones. The mean center remained nearly unchanged between the two periods, indicating that the centre of urban development remained stable. However, the increased density of built-up patches in the western, southern, and southeastern sectors reflects the continued outward expansion of Tura's urban area.

Overall, the spatio-temporal analysis demonstrates that urban sprawl in Tura, Meghalaya, followed a predominantly radial expansion pattern originating from the existing urban core. The SE and E sectors remained important growth corridors throughout the study period, while the W, SW, and S sectors experienced substantial acceleration during 2016–2026. The persistent NW–SE orientation of the standard deviational ellipse indicates that the dominant spatial trend of urban growth remained stable over time, although the extent and dispersion of urban development increased considerably during the second decade.

6.5 Shannon's Entropy Analysis of Urban Sprawl in Tura (2006–2026)

Shannon's Entropy was used to examine the spatial pattern of urban growth in Tura, Meghalaya, for the years 2006, 2016, and 2026. The normalized entropy values obtained were 0.8801 for 2006, 0.8776 for 2016, and 0.8944 for 2026 (Table 4.X). Shannon's Entropy is widely used to measure the degree of urban dispersion, where values close to 0 indicate a compact pattern of development, while values approaching 1

represent a highly dispersed urban form. Therefore, the entropy values obtained in this study indicate that the built-up areas in Tura were spatially dispersed throughout the study period.

In 2006, the normalized entropy value of 0.8801 indicates that the built-up areas were already distributed across different parts of the municipality rather than being concentrated entirely within the town centre. Although the urban core remained the most developed part of Tura, scattered settlements were visible throughout the surrounding areas. This suggests that the urban structure was not completely compact and that some degree of urban dispersion had already taken place before the beginning of the study period.

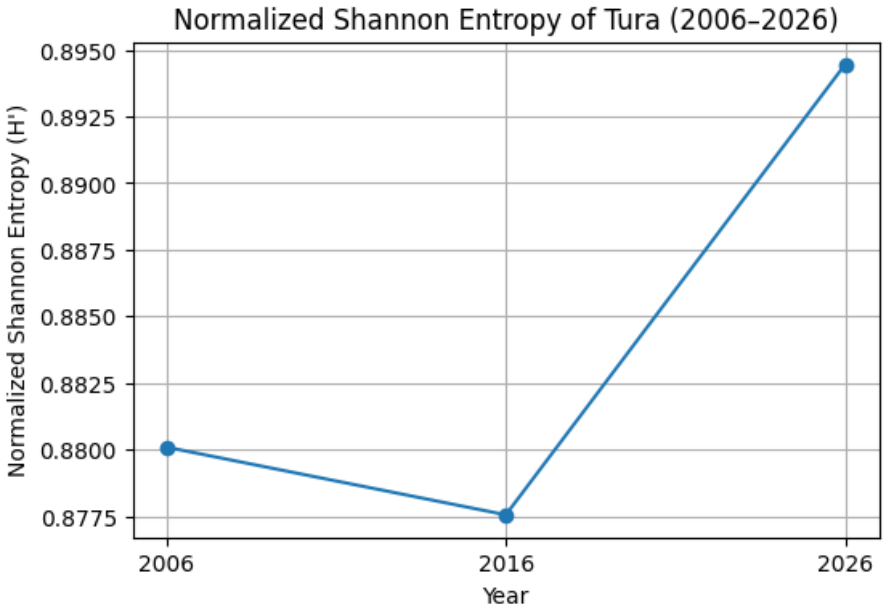


Fig.-Error! No text of specified style in document.**.10: Normalized Shannon Entropy Graph of Tura**

Table-Error! No text of specified style in document.**.10: Normalized Shannon's Entropy Values for Tura (2006–2026)**

Year	Normalized Shannon's Entropy (H')	Interpretation
2006	0.8801	Highly dispersed urban development
2016	0.8776	Highly dispersed urban development
2026	0.8944	Very highly dispersed urban development

The entropy value for 2016 was 0.8776, which is only slightly lower than that of 2006. The difference between the two years is very small, indicating that there was little change in the overall spatial distribution of built-up areas during the first decade. While urban development continued during this period, most of the expansion occurred close to the existing built-up areas through edge expansion and infill development.

As a result, the overall urban pattern remained relatively stable, with no significant increase in the level of urban dispersion.

A different trend is observed in 2026, when the normalized entropy value increased to 0.8944. This is the highest entropy value recorded during the study period and indicates that built-up development became more dispersed across the municipality. The increase suggests that urban growth extended further into peripheral areas instead of remaining concentrated around the existing urban centre. This pattern is consistent with the land use and land cover analysis, which showed the conversion of forest, cropland, and bare land into built-up areas, particularly during the 2016–2026 period.

When the three study years are compared, it is evident that the spatial pattern of urban development remained almost unchanged between 2006 and 2016, but became noticeably more dispersed by 2026. Although the change in entropy during the first decade was minimal, the increase observed in the second decade indicates that urban expansion accelerated and spread over a wider area. This suggests that recent urban growth in Tura has increasingly occurred in peripheral locations, leading to a more fragmented pattern of development.

Overall, the Shannon's Entropy analysis demonstrates that Tura maintained a relatively dispersed urban structure throughout the study period, with the highest level of urban dispersion occurring in 2026. The increase in entropy during the second decade confirms that urban sprawl intensified over time, with built-up areas expanding beyond the traditional urban core into surrounding landscapes. These findings support the results of the land use/land cover change analysis and the spatio-temporal urban sprawl assessment, both of which indicate a continued outward expansion of the urban area. The observed trend highlights the importance of sustainable land-use planning and urban management to accommodate future growth while reducing pressure on agricultural land, forests, and other environmentally sensitive areas.

The present study successfully employed Remote Sensing and Geographic Information System (GIS) techniques to analyse the land use/land cover (LULC) changes and urban sprawl in Tura Town for the years 2006, 2016, and 2026. Supervised image classification was carried out to classify the satellite images into different land use/land cover categories, including water, trees, flooded vegetation, cropland, built-up area, bare ground, and rangeland. These classified maps formed the foundation for analysing urban growth and spatial changes over the study period.

To evaluate the reliability of the classification, an accuracy assessment was performed for each study year using reference data obtained from satellite imagery and Google Earth. The overall classification accuracies were 77.39% for 2006, 80.60% for 2016, and 78.00% for 2026, indicating satisfactory classification performance. The corresponding Kappa coefficients also showed substantial agreement between the classified maps and the reference data, confirming that the classification results were sufficiently reliable for subsequent urban sprawl analysis.

Among the classified land use categories, the built-up class consistently recorded the highest user's accuracy, indicating that urban areas were accurately identified throughout the study period. Minor classification confusion was observed between cropland, bare ground, and tree cover because of their similar spectral characteristics; however, these limitations did not significantly influence the overall interpretation of urban expansion. The satisfactory classification accuracy demonstrates that the generated

LULC maps provide a dependable basis for analysing land use changes and assessing the spatial dynamics of urban sprawl in Tura Town.

The analysis of built-up areas revealed a continuous increase in urban development in Tura Town over the twenty-year study period. The built-up area expanded from 10 km² in 2006 to 14 km² in 2016 and further increased to 17 km² in 2026. This represents an overall increase of 7 km², equivalent to approximately 70% growth between 2006 and 2026.

The decadal analysis indicates that the most rapid urban expansion occurred during 2006–2016, when the built-up area increased by 4 km² (40%). During 2016–2026, urban development continued at a slower but steady rate, with an increase of 3 km² (21.4%). The results suggest that although the rate of expansion declined during the second decade, urban growth remained continuous due to increasing population, residential development, commercial activities, and infrastructure expansion.

The built-up areas initially remained concentrated around the existing urban centre but gradually expanded towards the surrounding peripheral regions. This outward expansion reflects the increasing demand for urban land and demonstrates the gradual transformation of Tura from a relatively compact settlement into a more spatially extensive urban area.

7. Land Use Change Detection

The land use change detection analysis revealed significant transformations in the urban landscape of Tura during the study period. Urban expansion primarily occurred through the conversion of natural and open land into built-up areas. During 2006–2016, forest land accounted for the largest proportion of land converted into built-up area, followed by bare ground and cropland. This indicates that the initial phase of urban growth occurred mainly through the expansion of settlements into forested regions surrounding the town.

During the second decade (2016–2026), bare ground became the dominant source of urban expansion, while cropland and forest land also continued to decline as urban development expanded further into the surrounding landscape. The increased conversion of bare ground suggests that previously cleared or vacant land became increasingly attractive for residential, commercial, and institutional development.

Overall, the change detection analysis indicates that 10.6353 km² of land was converted into built-up area between 2006 and 2026. These findings clearly demonstrate that urban development has substantially altered the land use pattern of Tura Town. The continuous conversion of forest and agricultural land into urban land highlights the need for effective land-use planning and environmental conservation to ensure sustainable urban development. The spatio-temporal analysis provided a detailed understanding of the direction and pattern of urban expansion in Tura Town. The findings indicate that urban growth occurred primarily through outward expansion from the existing urban core. During the period 2006–2016, the highest concentration of urban growth was observed towards the eastern and south-eastern sectors, while relatively moderate expansion occurred in the remaining directions.

Between 2016 and 2026, urban expansion became more widespread and extended towards the western, south-western, southern, northern, and north-western parts of the municipality. This indicates that urban development gradually spread across almost all directions as the availability of land near the town centre declined.

The Mean Center analysis revealed only minor shifts throughout the study period, suggesting that the geographical centre of urban development remained relatively stable despite the increasing extent of built-up areas. Similarly, the Standard Deviational Ellipse maintained a consistent northwest–southeast (NW–SE) orientation, indicating that the dominant direction of urban expansion remained unchanged. Together, these spatial statistical techniques demonstrate that urban growth in Tura has followed a stable directional pattern while continuously expanding into surrounding areas.

Shannon's Entropy analysis was used to quantify the degree of spatial dispersion of built-up areas and evaluate the level of urban sprawl in Tura Town. The normalized entropy values obtained for the three study years were 0.8801 (2006), 0.8776 (2016), and 0.8944 (2026).

The entropy values indicate that urban development remained highly dispersed throughout the study period. Although the values for 2006 and 2016 were very similar, suggesting a relatively stable pattern of urban distribution during the first decade, the increase in the entropy value in 2026 indicates that urban growth became more dispersed during the second decade. This reflects the gradual expansion of built-up areas into peripheral regions beyond the traditional urban core.

The entropy results are consistent with the findings of the built-up area analysis, land use change detection, and spatio-temporal analysis, all of which indicate that Tura has experienced increasing urban sprawl over the past two decades. The integration of Shannon's Entropy with Remote Sensing and GIS techniques provided a quantitative assessment of urban expansion and confirmed the transition from a relatively compact urban form to a more dispersed urban landscape.

Although the normalized entropy values for all three years are relatively high, the difference between 2006 (0.8801) and 2016 (0.8776) is negligible, suggesting that the spatial distribution of built-up land remained largely unchanged during the first decade. In contrast, the increase to 0.8944 in 2026 indicates that urban growth became more dispersed during the second decade. This finding agrees with the land use/land cover change analysis and the spatio-temporal urban sprawl maps, which showed increased conversion of forests, croplands, and bare land into built-up areas after 2016. Therefore, the entropy analysis confirms that urban sprawl in Tura became more pronounced during the period 2016–2026, reflecting an increasing tendency for development to spread beyond the existing urban core.

One of the major challenges was obtaining cloud-free satellite imagery for all the selected years, as Meghalaya experiences frequent cloud cover, particularly during the monsoon season. Although suitable images were selected, cloud contamination and atmospheric conditions may still have affected the quality of the satellite data. In addition, satellite images may contain noise caused by atmospheric effects, sensor limitations, or image acquisition conditions. Such noise can reduce image clarity and influence the identification and classification of certain land cover features.

Use of Landsat satellite imagery with a spatial resolution of 30 metres. While this resolution is appropriate for analysing urban sprawl at the town level, it may not accurately capture small buildings, narrow roads, or other fine-scale urban features. Consequently, some built-up areas may have been slightly underrepresented or mixed with neighbouring land cover classes.

The accuracy of the Land Use/Land Cover (LULC) classification is also influenced by the spatial resolution and quality of the satellite imagery. Although an accuracy assessment was carried out to validate the

classification results, some degree of misclassification among spectrally similar land cover classes may still exist. Similar spectral responses between certain land cover types and the presence of mixed pixels may have affected the classification accuracy in some locations.

The study relied mainly on freely available secondary datasets, including satellite imagery and other spatial data. Therefore, the quality of the results depends on the accuracy and availability of these datasets. In addition, historical field verification for the years 2006 and 2016 was not possible, limiting the validation of past land use conditions.

8. Conclusion

The spatio-temporal analysis of Tura Town from 2006 to 2026 demonstrates a profound physical transformation, shifting the region from a concentrated, compact urban core to a dispersed, sprawling landscape. Over this twenty-year duration, the total built-up footprint expanded significantly by 70%, escalating from 10 km² to 17 km². Methodological validation through robust accuracy assessments and Kappa coefficients confirms the reliability of these longitudinal findings, despite minor challenges regarding spectral confusion among vegetative and barren cover types.

The drivers of this physical expansion are deeply rooted in socio-economic and institutional catalysts, including rapid demographic growth, rural-to-urban migration, heightened housing demands, and the broader proliferation of commercial, educational, and administrative infrastructure. Spatially, this growth manifested through a dual dynamic: rapid initial peripheral expansion—predominantly encroaching upon forested domains and agricultural lands during the 2006–2016 decade—followed by a subsequent phase of increased spatial dispersion and land utilization, heavily targeting bare ground and open spaces between 2016 and 2026. While the directional trajectory of this urbanization has consistently adhered to a northwest–southeast (NW–SE) axis, the continuous outward push and subsequent coalescence of isolated urban patches highlight an accelerating pattern of unmanaged sprawl.

Ultimately, the empirical insights derived from this study underscore the urgent necessity for proactive, evidence-based urban planning in Tura. As the town continues to experience outward pressure and environmental resource conversion, municipal authorities and policymakers must implement robust land-use regulations. Balancing socio-economic development with environmental sustainability will be paramount in mitigating the ecological consequences of unplanned urban expansion and ensuring the long-term resilience of the region's urban ecosystems.

Conflict of Interest: *The author declares no conflict of interest.*

References

Ahmad, F., & Goparaju, L. (2016). *Analysis of urban sprawl dynamics using geospatial technology: A case study of Ranchi, Jharkhand, India*. *The Egyptian Journal of Remote Sensing and Space Sciences*, *20*(1), 91–102.

Anas, A., Arnott, R., & Small, K. A. (1998). Urban spatial structure. *Journal of Economic Literature*, *36*(3), 1426–1464.

Anderson, J. R. (1976). *A land use and land cover classification system for use with remote sensor data*. U.S. Geological Survey Professional Paper 964.

Angel, S., Sheppard, S. C., & Civco, D. L. (2005). *The dynamics of global urban expansion*. World Bank.

Batty, M. (2008). The size, scale, and shape of cities. *Science*, *319*(5864), 769–771.

Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: A review. *International Journal of Environmental Research*, *3*(4), 617–626.

Bhatta, B. (2010). *Analysis of urban growth and sprawl from remote sensing data*. Springer.

Bhatta, B. (2010). *Remote Sensing and GIS for Urban Planning*. Oxford University Press.

Boori, M. S., Voženílek, V., & Choudhary, K. (2015). Land use/cover disturbance due to tourism using remote sensing and GIS. *The Egyptian Journal of Remote Sensing and Space Sciences*, *18*(2), 243–251.

Brueckner, J. K. (2000). Urban sprawl: Diagnosis and remedies. *International Regional Science Review*, *23*(2), 160–171.

Bruegmann, R. (2005). *Sprawl: A Compact History*. University of Chicago Press.

Burrough, P. A., & McDonnell, R. A. (1998). *Principles of Geographical Information Systems*. Oxford University Press.

Burgess, E. W. (1925). The growth of the city. In R. E. Park, E. W. Burgess, & R. D. McKenzie (Eds.), *The City* (pp. 47–62). University of Chicago Press.

Campbell, J. B., & Wynne, R. H. (2011). *Introduction to Remote Sensing* (5th ed.). Guilford Press.

Chapin, F. S., & Kaiser, E. J. (1979). *Urban Land Use Planning* (3rd ed.). University of Illinois Press.

Chettry, V. (2022). *Urban sprawl analysis in medium-sized Indian cities using Remote Sensing and GIS*. *(Complete publication details before submission.)*

Clarke, K. C., Hoppen, S., & Gaydos, L. (1997). A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay Area. *Environment and Planning B: Planning and Design*, *24*(2), 247–261.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, *37*(1), 35–46.

Congalton, R. G., & Green, K. (2009). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices* (2nd ed.). CRC Press.

Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., & Lambin, E. (2004). Digital change detection methods in ecosystem monitoring. *International Journal of Remote Sensing*, *25*(9), 1565–1596.

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (5th ed.). Sage Publications.

Eastman, J. R. (2016). *TerrSet Geospatial Monitoring and Modeling System Manual*. Clark Labs.

Ewing, R. (1997). Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association*, *63*(1), 107–126.

Ewing, R., Pendall, R., & Chen, D. (2002). *Measuring Sprawl and Its Impact*. Smart Growth America.

Fatema, S., & Chakrabarty, A. (2018). *Urban sprawl and land use/land cover change analysis using Remote Sensing and GIS. (Complete publication details before submission.)*

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, *80*(1), 185–201.

Foody, G. M. (2004). Thematic map comparison: Evaluating the statistical significance of differences in classification accuracy. *Photogrammetric Engineering & Remote Sensing*, *70*(5), 627–633.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: Defining and measuring an elusive concept. *Housing Policy Debate*, *12*(4), 681–717.

Goodchild, M. F. (1992). Geographical information science. *International Journal of Geographical Information Systems*, *6*(1), 31–45.

Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010. *Landscape and Urban Planning*, *128*, 72–82.

Harvey, R. O., & Clark, W. A. V. (1965). The nature and economics of urban sprawl. *Land Economics*, *41*(1), 1–9.

Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth. *Remote Sensing of Environment*, *86*(3), 286–302.

Herold, M., Couclelis, H., & Clarke, K. C. (2005). The role of spatial metrics in the analysis and modeling of urban land use change. *Computers, Environment and Urban Systems*, *29*(4), 369–399.

Jat, M. K., Garg, P. K., & Khare, D. (2008). Monitoring and modelling of urban sprawl using Remote Sensing and GIS techniques. *International Journal of Applied Earth Observation and Geoinformation*, *10*(1), 26–43.

Jensen, J. R. (2015). *Introductory Digital Image Processing: A Remote Sensing Perspective* (4th ed.). Pearson.

Jensen, J. R. (2016). *Remote Sensing of the Environment: An Earth Resource Perspective* (2nd ed.). Pearson.

Kharpran, R., & Purkayastha, J. (2024). *Urban sprawl analysis of Shillong using Remote Sensing, GIS and Shannon's Entropy*. *(Complete publication details before submission.)*

Krishnaveni, M., & Anilkumar, K. S. (2020). *Urban sprawl analysis using IDBI and Shannon's Entropy*. *(Complete publication details before submission.)*

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change. *Annual Review of Environment and Resources*, *28*, 205–241.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2015). *Remote Sensing and Image Interpretation* (7th ed.). Wiley.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic Information Science and Systems* (4th ed.). Wiley.

Mather, P. M., & Koch, M. (2011). *Computer Processing of Remotely-Sensed Images* (4th ed.). Wiley.

Mehra, A., & Swain, S. (2025). *Urban sprawl analysis in Dharamshala using Remote Sensing and GIS*. *(Complete publication details before submission.)*

Mesev, V. (2003). *Remotely Sensed Cities*. Taylor & Francis.

Meyer, W. B., & Turner, B. L. (1994). *Changes in Land Use and Land Cover: A Global Perspective*. Cambridge University Press.

Mundia, C. N., & Aniya, M. (2005). Analysis of land use/cover changes and urban expansion of Nairobi City using remote sensing and GIS. *International Journal of Remote Sensing*, *26*(13), 2831–2849.

Parent, J., & Civco, D. L. (2007). Urban sprawl metrics: An analysis of global urban expansion using GIS.

Pampoore-Thampi, A., Varde, A. S., & Yu, H. (2014). Mining GIS data to predict urban sprawl. *Proceedings of the IEEE International Conference on Big Data*.

Roy, S., & Kasemi, M. (2021). *Urban growth analysis in Raiganj using land use/land cover and spatial techniques*. *(Complete publication details before submission.)*

Saikia, P., War, L., Umlong, R., & Nath, A. (2024). *Urbanization, land surface temperature and urban heat island effect in Shillong*. *(Complete publication details before submission.)*

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, *6*(8), e23777.

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030. *Proceedings of the National Academy of Sciences*, *109*(40), 16083–16088.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*(3), 379–423.

Singh, A., & Purkayastha, J. (2026). *Urban sprawl in Imphal Urban Agglomeration using Landsat, Sentinel and Shannon's Entropy*. *(Complete publication details before submission.)*

Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004). Urban sprawl: Metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation*, *5*(1), 29–39.

Taubenböck, H., Wegmann, M., Roth, A., Mehl, H., & Dech, S. (2009). Urbanization in India: Spatio-temporal analysis using remote sensing. *Computers, Environment and Urban Systems*, *33*(3), 179–188.

Tayyebi, A., Delavar, M. R., Pijanowski, B. C., Saeedi, S., & Tayyebi, A. H. (2011). A spatial logistic regression model for simulating land use patterns. *Landscape and Urban Planning*, *101*(3), 269–282.

Tiwari, A., Saxena, A., & Katare, S. (2012). *Urban expansion and land use change using Remote Sensing and GIS*. *(Complete publication details before submission.)*

Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science. *Proceedings of the National Academy of Sciences*, *104*(52), 20666–20671.

United Nations. (2019). *World Urbanization Prospects 2018: Highlights*. United Nations Department of Economic and Social Affairs.

Verburg, P. H., Schot, P. P., Dijst, M. J., & Veldkamp, A. (2004). Land use change modelling: Current practice and research priorities. *GeoJournal*, *61*(4), 309–324.

Wei, Y. D., & Ewing, R. (2018). Urban sprawl and sustainable development: A review. *Landscape and Urban Planning*, *177*, 1–12.

Whyte, W. H. (1993). *The Exploding Metropolis*. University of California Press.

Wilson, E. H., Hurd, J. D., Civco, D. L., Arnold, C., & Prisloe, M. (2003). Development of a geospatial model to quantify, describe and map urban growth. *Remote Sensing of Environment*, *86*(3), 275–285.

Wu, J. (2008). *Land Use Changes: Economic, Social and Environmental Impacts*. CRC Press.

Yeh, A. G. O., & Li, X. (1997). An integrated remote sensing and GIS approach in the monitoring and evaluation of rapid urban growth. *International Planning Studies*, *2*(2), 193–210.

Yeh, A. G. O., & Li, X. (2001). Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. *Photogrammetric Engineering & Remote Sensing*, *67*(1), 83–90.