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International Journal of Current Research
Vol. 17, Issue, 12, pp.35573-35579, December, 2025
DOI: https://doi.org/10.24941/ijcr.49905.12.2025

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

URBAN SPRAWL AND URBAN EXPANSION USING SHANNON'S ENTROPY AND ITS IMPACT ON CHANGING CLIMATE: A CASE STUDY OF KANNUR CITY, KANNUR

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ARTICLE INFO

Article History:
Received 17th September, 2025
Received in revised form
18th October, 2025
Accepted 14th November, 2025
Published online 30th December, 2025

Keywords:

Urban sprawl, Shannon's Entropy, Landscape Expansion Index (LEI), LULC and Remote Sensing and GIS.

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ABSTRACT

This study conducts an urban sprawl in the urban area of Kannur city, Kannur, Kerala, over the years 2016 and 2024. The primary objective is to assess the extent and pattern of urban growth in these rapidly expanding urban areas. The analysis is based on land use and built-up area changes, utilising key indices such as Shannon's Entropy and the Landscape Expansion Index (LEI). Satellite imagery and GIS tools were utilised to extract land-use/land-cover data, and statistical methods were employed to assess the degree of urban sprawl. Shannon's Entropy is used to quantify urban sprawl by measuring the distribution of built-up areas, while the LEI assess the expansion of urbanisation and the proportion of urban land relative to the total area. The findings reveal varying degrees of urban sprawl in urban areas of Kannur, particularly in peripheral regions, driven by socio-economic factors and infrastructural developments. Also exhibits significant sprawl, largely concentrated in residential areas. The study underscores the importance of spatial planning and sustainable land management to mitigate the negative consequences of unplanned urbanisation. This research contributes valuable insights into regional disparities in urbanisation patterns and offers a framework for future urban planning efforts.

Citation: Sreerama Naik, S.R. and Feba Jose Jasmine, 2025. "Urban Sprawl and Urban Expansion Using Shannon's Entropy and Its Impact on Changing Climate: A Case Study of Kannur City, Kannur". ***International Journal of Current Research, 17, (12), 35573-35579.***

INTRODUCTION

rban sprawl refers to the uncontrolled expansion of urban areas into previously non-urban or rural spaces, often characterised by low-density, automobile-dependent development (Antipova, 2018; Krishnaveni&Anilkumar, 2020; Li, 2020). The phenomenon has significant implications for land use, environmental degradation, and socioeconomic patterns (Belaïd, 2025). The study of urban sprawl is crucial for urban planners and policymakers to understand the spatial dynamics of cities and implement sustainable growth strategies (Artmann *et al*., 2018).Various methods and indices have been developed to analyse and quantify urban sprawl, including land use analysis, built-up area analysis, Shannon's Entropy, and Landscape Expansion Index (Deka *et al*., 2012; Barman *et al*., 2024). These tools collectively provide a comprehensive understanding of urban expansion, particularly in understanding and quantifying changes in landscape patterns over time, direction, and sustainability of such growth (Tian *et al*., 2022a). Land use and land cover analysis are foundational components in understanding urban sprawl (Viana *et al*., 2019). The classification of land into various categories, such as residential, commercial, agricultural, and forest land, helps researchers assess the changing patterns of how land is being utilised (Martínez, 2012). Traditionally, satellite imagery and Geographic Information Systems (GIS) are used to classify and monitor land use changes over time (Jat *et al*., 2008). Urban sprawl is often indicated by a significant increase in built-up areas, which refers to the portion of land covered by buildings and infrastructure. As cities grow, the proportion of built-up areas expands, often at the expense of natural landscapes like forests, wetlands, and farmlands (Agriculture Organisation of the United Nations. Soil Resources, 1993). The increase in built-up areas without corresponding increases in population density suggests sprawling growth, as opposed to compact urban development (Alonso *et al*., 1974). Shannon Entropy, borrowed from information theory, is widely applied in the study of urban sprawl to quantify the degree of spatial dispersion or randomness in urban land use (Ahuja *et al*., 2022). It measures the degree of disorder in the spatial arrangement of urban areas, allowing researchers to assess whether urban growth is occurring in a concentrated or dispersed manner (Sudhira *et al*., 2004). The mathematical formulation of Shannon Entropy involves the division of urban areas into grids or zones and the computation of the entropy value based on the distribution of built-up areas across these zones (Mishra *et al*., 2025). The entropy value ranges from 0 to 1, where 0 indicates highly concentrated, compact urban growth, and 1 indicates a highly dispersed, sprawling urban expansion. The higher the entropy value, the more dispersed the urban growth is, which is often a sign of urban sprawl (Yeh& Li, 2001; Bhatta *et al*., 2010). Shannon entropy helps quantify how concentrated or dispersed urban growth is across different zones, providing insights into patterns of compactness and sprawl (Mohabey, 2024). The Landscape Expansion Index (LEI) is a metric used to analyse and categorise how landscapes change over time, particularly in the context of urban growth. Unlike traditional landscape metrics that simply describe spatial patterns at a single point in time, the LEI focuses on the process of change between different periods. The LEI is calculated by analysing the relationship between newly developed patches and existing landscape features within a defined buffer zone. By quantifying these different types of expansion, the LEI provides valuable insights into the dynamics of landscape change, helping urban planners and policymakers to understand the patterns and processes of urban growth and their impact on the environment (Herold *et al*., 2005). Urbanisation intensifies pressure on local hydrological and ecological systems, increasing runoff, imperviousness, and vulnerability to climate impacts (Huong, 2013). Rapid urban growth can also lead to measurable increases in local temperatures, with studies showing that urbanization can contribute to warming of mean surface temperature, altering microclimates and exacerbating heat-related stress on populations and ecosystems (e.g., southeast China experienced 0.05°C per decade warming attributable to urban expansion) (Zhou *et al*., 2004). Such rapid urban expansion is expected to further amplify environmental pressures, including increased surface temperatures, altered hydrological cycles, and greater vulnerability of ecosystems to climate impacts (Zhou *et al*., 2019). This extensive urban expansion has also intensified pressure on local ecosystems, altered land-use patterns, and contributed to environmental challenges such as loss of cultivated lands, increased impervious surfaces, and changes in microclimates (Liu *et al*., 2021). Global economic, demographic, and ecological landscapes have been significantly altered by urbanisation and climate change, resulting in issues like biodiversity loss, urban heat islands (UHIs), and resource inefficiency (Maity *et al*., 2025). Due to the growth of impervious surfaces and decreased vegetation cover, urbanisation exacerbates local temperature increases, and climate change makes heat stress worse by causing global warming. Urban heat islands can occasionally contribute up to 5°C more warming than local temperatures, according to a systematic review by Chapman *et al*. (2017) that emphasises the interaction between urbanisation and climate change. By 2050, urban growth may double the temperature increases brought on by climate change alone, according to case studies like Sydney's anticipated urban expansion. This is because urban environments have a higher heat capacity and less evaporation (Argüeso *et al*., 2014). Significant reductions in vegetated areas and elevated land surface temperatures have resulted from India's fast urbanisation of ecosystems such as wetlands and the Western Ghats (Sumith *et al*., 2022; Wakode, 2016).

As cities like Kannur continue to grow, the pressure on water resources keeps increasing, especially with climate change making rainfall less predictable (Shahanas, 2022). To use water wisely, it is important to consider how water and energy systems are interconnected, understand the trade-offs of using greenery and landscaping for cooling, and recognize how city growth affects the environment. Making good decisions for the future requires planning under uncertainty and ensuring that scientific knowledge and policy work together (Gober, 2010).Remote sensing technologies and Geographic Information Systems (GIS) have become effective instruments for examining urban growth trends, allowing planners to get ready for new challenges. These dynamics are best illustrated by Bengaluru, a city renowned for its economic prosperity and opportunities (Ramachandra *et al*., 2023). Ground truthing confirms studies that show growing entropy values in Bengaluru, indicating dispersed development and spatial shifts in growth centres. The usefulness of these tools in understanding land use changes and predicting expansion trends for well-informed regional planning is highlighted by this analysis (Verma *et al*., 2017).

High degrees of sprawl have been a defining feature of Tripoli's urban growth. Trends in the direction and patterns of urban growth were identified using historical satellite data and Shannon's entropy, highlighting the importance of these analyses for urban planning and forecasting future urbanisation scenarios (Abubakr *et al*., 2015; Alsharif *et al*., 2015). Studies conducted in West Bengal's Barrackpore subdivision also show that urban growth results in condensed urban areas. The ecological impact of urban sprawl is highlighted by recent trends that show aggregation into large urban patches, whereas earlier decades were characterised by landscape fragmentation. The results validate the distributed character of urbanisation and its consequences for sustainable development plans (Das *et al*., 2021). Due to socioeconomic and policy factors, Addis Ababa has seen a rapid urban expansion at the expense of agricultural and forest land. Research using GIS, remote sensing, and Shannon's entropy reveals a notable trend toward deforestation and dispersed urban growth, requiring significant policy changes to lessen ecological effects (Deribew, 2020). Further exposing spatial heterogeneity in urban growth patterns are urban studies that employ landscape metrics, such as the Landscape Expansion Index (LEI). The Multi-order Landscape Expansion Index (MLEI), which captured the shift from dispersed outlying clusters to more structured urban forms, offered insights into the dynamics of urban expansion in Wuhan. According to Jiao (2015), this method provides a strong framework for comprehending spatial structures and creating policies for urban expansion. Similar to this, research conducted in Addis Ababa using LEI showed zonal and directional variability in urban growth, exposing trade-offs between the loss of green space and urban expansion. The results highlight the necessity of sustainable planning techniques to prevent environmental deterioration and guarantee resilient urban growth (Woldesemayat *et al*., 2021).

Dataand Methodology

Data Collection: The primary data source for this study is satellite imagery, which provides consistent and reliable data on land use and built-up areas over time. Multi-temporal satellite images were acquired for the years 2016 and 2024 (the most recent year available). Sentinel 2A images were used, which are widely available for land use studies. The data has a spatial resolution of 10 meters, sufficient for detecting changes in urban growth and land use at the municipal level.

METHODOLOGY

The methodology of this study is divided into several stages, including image processing, land use classification, and the application of urban sprawl indices to analyse the data.

Land Use Classification: Using the pre-processed satellite images, land use classification was carried out for the years 2016 and 2024. A supervised classification algorithm was applied using the maximum likelihood classifier in ArcGIS.

Shannon Entropy Analysis: Shannon Entropy was used to quantify the degree of urban sprawl and spatial dispersion of built-up areas in Kannur City. Entropy measures the randomness or disorder of urban growth, with higher values indicating more dispersed and unplanned development.

The formula for Shannon Entropy is:

$H_{n})$ is

$$H_n = -\sum_{i=1}^{n} P_i log_e$$

Where:

- H = Shannon Entropy
- Pi = Proportion of the built-up area in the i-th zone to the total built-up area
- n = Number of zones

The City were divided into concentric zones centred on the urban core, and the built-up area in each zone was calculated. By comparing entropy values for 2016 and 2024, the study evaluates the spatial spread of urban development.

Landscape Expansion Index

$$\mathrm{LEI} = 100 \times \frac{A_o}{A_o + A_v}$$

The Landscape Expansion Index (LEI) is a metric used to analyse and quantify changes in landscape patterns over time, particularly in the context of urban expansion.

The basic LEI formula is:

Where:

- LEI is the Landscape Expansion Index
- Ao is the intersection between the buffer zone and the occupied category (existing urban area)
- Av is the intersection between the buffer zone and the vacant category (non-urban area)

Study Area: Kannur City, located in the southern Indian state of Kerala, is a historically significant area with a rich tapestry of cultural, geographical, and socio-economic features, making it a valuable study area for researchers. Kannur has been a prominent trading centre since ancient times, with connections to the spice trade and interactions with various foreign powers, including the Portuguese, Dutch, and British.

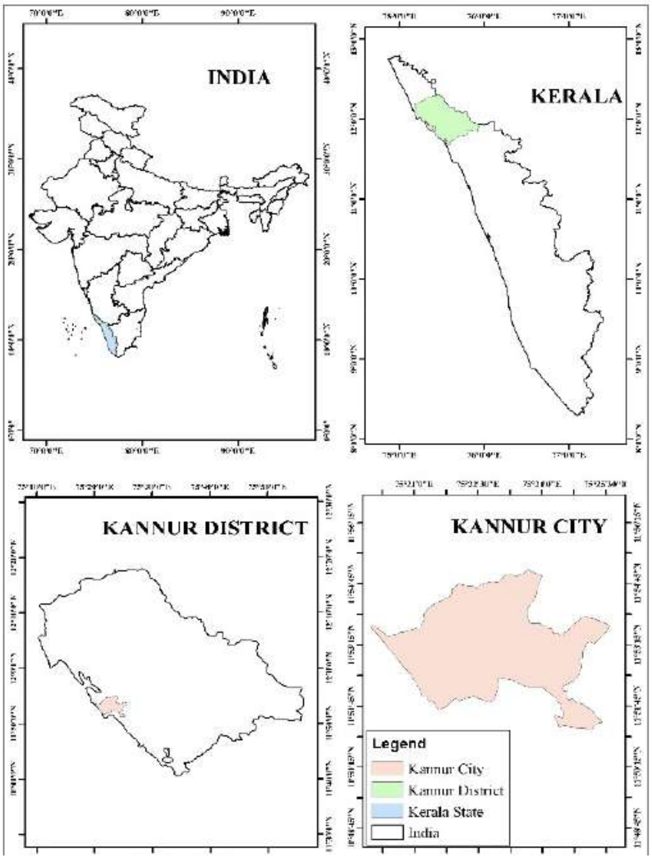

Fig. No. 1. Location map of the study region

The city is a melting pot of various cultures and religions, with a strong presence of Hinduism, Islam, and Christianity. Kannur city is located between 11° 52' 28.12" N latitude and 75° 22' 13" E longitude. With a total geographic area of 34.3467 square kilometres. The city has a total population of approximately 232,486 according to the 2011 census. Kannur's geography encompasses coastal areas, plains, and hills, providing opportunities for research in fields like environmental science, geography, and urban planning. The city's coastal location also makes it relevant for studies on marine ecosystems and coastal erosion.

RESULT AND DISCUSSION

Road Network and Basic Infrastructure: The spatial organisation of a city is essentially determined by its transportation network and the spread of basic infrastructure. This study analyses the road network and the points of infrastructure in Kannur City. The density and distribution of these features are crucial for understanding the patterns of development of the city and the provision of essential

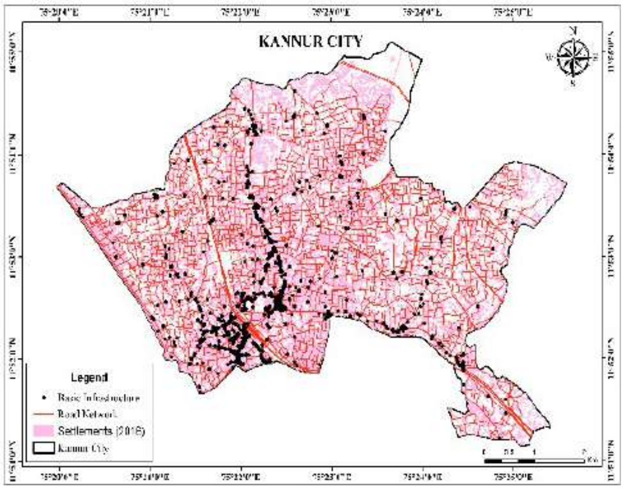

Fig. No. 2. Kannur City in 2016

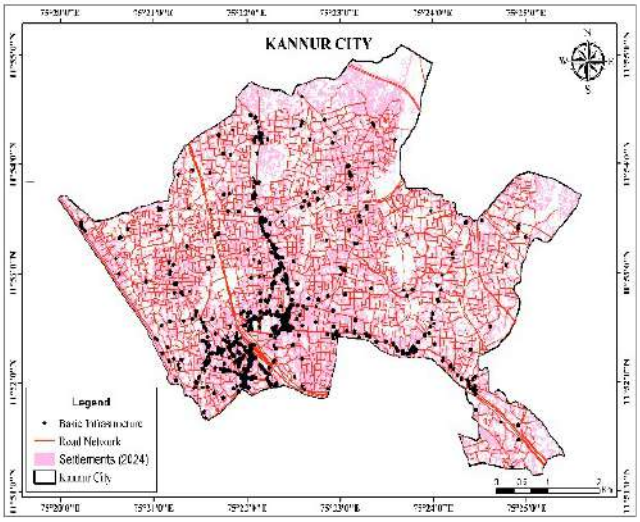

Fig. No. 3. Kannur City in 2024

services. The road network is one of the most important indicators of urbanisation and development levels. The higher the density of these lines, the more developed or urbanised the area is. On the other hand, areas with fewer or no red lines are less developed or rural. This pattern tends to reflect a general tendency of the roads' proliferation in highly populated areas, active commercial activity, and overall development. The density and connectivity of the road network affect accessibility, transport efficiency, and overall functionality in the urban environment. Thus, an analysis of the road network gives a deeper understanding of the city's spatial structure and internal connectivity. Basic Infrastructure: Enabling Urban Functionality.

Scattered black dots across the map represent points of basic infrastructure. These points probably include a variety of essential facilities that support the city's functioning and the well-being of its residents. Public Buildings represents the vital public services such as schools, hospitals, government offices, and community centres. The distribution of these buildings reflects the provision of social services and administrative functions throughout the city. Utility Infrastructure are related to utilities, for example, power stations, water treatment plants, and telecommunication facilities. Transportation Hubs includes key transportation facilities such as bus stops, train stations, and potentially other transport terminals. Distribution and density of road network infrastructure points can be important in providing insight into the spatial organization of the city as well as provision of essential services. It is through this very information that urban planning and policy formulation can be made in targeting improved infrastructural connectivity and access to services for every citizen in a society.

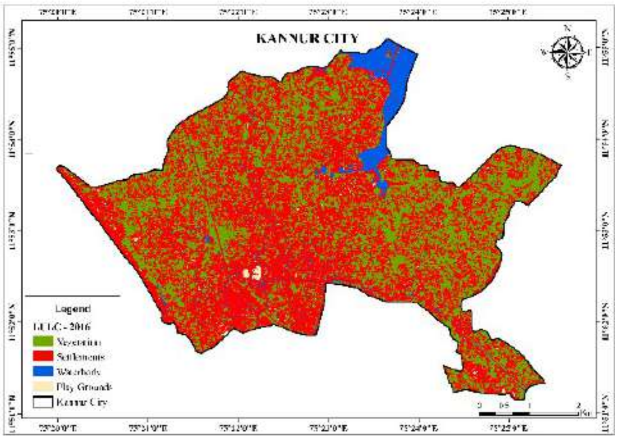

Fig. No. 4. LULC in 2016

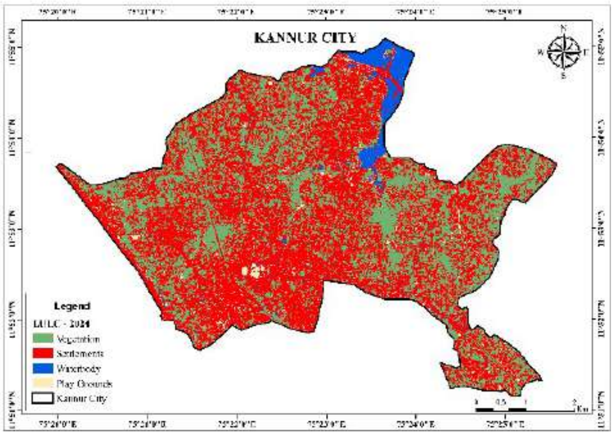

Fig. No. 5. LULC in 2024

Land use and Land cover: The most striking feature is the extensive pink area, indicating that settlements dominate the land cover of Kannur City. This suggests a densely populated urban area with significant infrastructure development. While settlements are dominant, there are still notable patches of vegetation. The Land use and Land cover maps indicate the changes in landform utilisation in the urban area of Kannur city from the year 2016 to 2024. The entire change in type of land use in the urban area of Kannur is noticed to be 34.3121 km2. The maximum change is found in the attribute of settlements, which reflected a positive growth with a change in area of 14.9751 km2 from the year 2016 followed by the vegetation type, which had reflected a change of 9.405 sq. km. Around 3.7091 sq.km. of area changed from vegetation areas to settlements and 3.4286sqkm changed from settlements to vegetation. Around 0.1358 km2 area changed from playground to settlement and 0.4850 sq.km. of area changed from waterbody to settlements. From 2016 to 2024 the area under settlements and vegetation has significantly increased and 3.4286 sq. km. of area changed from vegetation to settlements, about 13.3157sqkm has changed from vegetation to other classes 0.2596 sq. km. area changed from playground to other attributes 19.0914 sq. km. was changed in settlements. 1.6454 was changed from water body. The urban area of Kannur is showing a growing pattern.

Table No. 1. Land Use Land Cover Change Detection

Change Detection (2016 to 2024)	Area Change (Sq. Km.)
Play Grounds-Settlements	0.1358
Play Grounds-Vegetation	0.0066
Play Grounds-Waterbody	0.0023
Settlements-Play Grounds	0.5592
Settlements-Vegetation	3.4286
Settlements-Waterbody	0.1285
Vegetation-Play Grounds	0.1726
Vegetation-Settlements	3.7091
Vegetation-Waterbody	0.0286
Waterbody-Play Grounds	0.0166
Waterbody-Settlements	0.4850
Waterbody-Vegetation	0.0890
Grand Total	**34.3121**

Rainfall

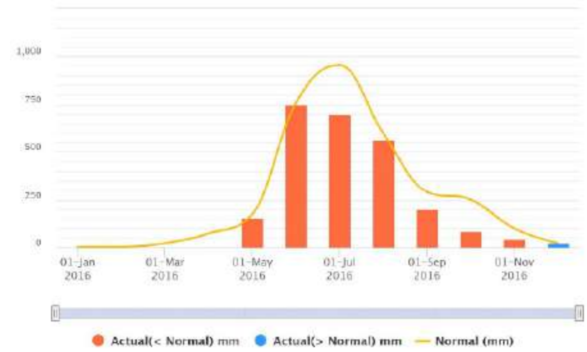

Fig. No. 6. Rainfall Distribution 2016

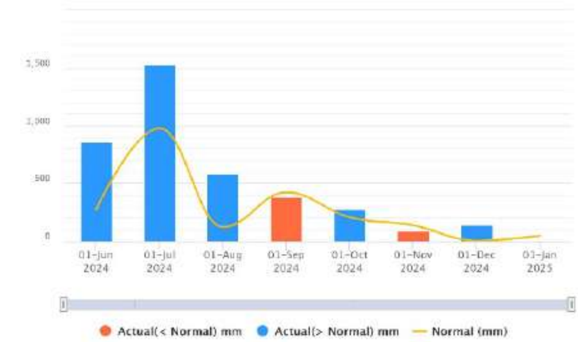

Fig. No. 7. Rainfall Distribution 2024

The graph provides a visual representation of rainfall data for the years 2016 and 2024. It shows the actual rainfall received each month compared to the normal rainfall for that month. These bars represent months where the actual rainfall was significantly lower than the average or "normal" rainfall for that month. The height of the bar indicates the difference between the actual and normal rainfall in millimetres.

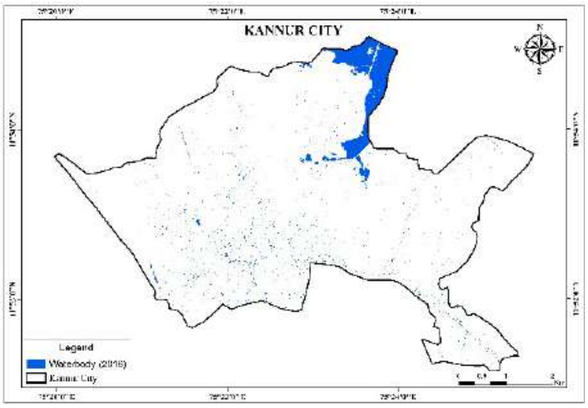

Fig. No. 8. Water Bodies 2016

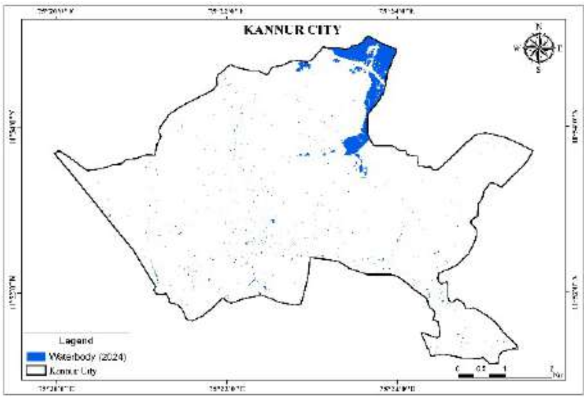

Fig. No. 9. Water Bodies 2024

Kannur City has been found to show a very unequal distribution of its water bodies. A high and consistent concentration of water features occurs in the northeast sector of the city. A comparison between the 2016 and 2024 maps reveals important changes: Although the significant concentration of water bodies in the northeast remains, with the larger water body and associated features remaining prominent, the scattered distribution of smaller water bodies throughout the rest of the city appears less pronounced in 2024. This may indicate a reduction in the number or size of these smaller features over the eight years. Some ponds or streams that were previously used to be conspicuous may have dwindled to non-existent.

Vegetation

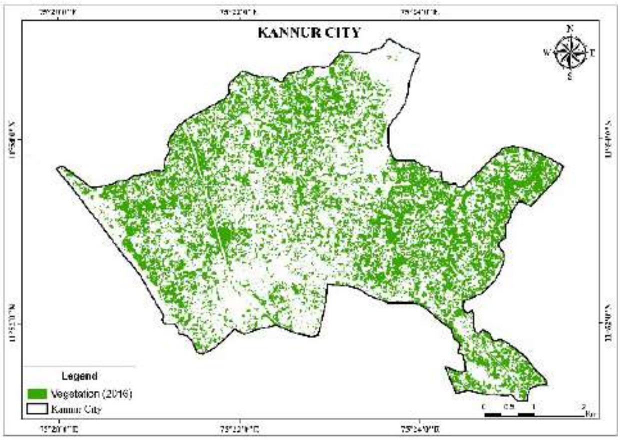

Fig. No. 10. Vegetation Cover in 2016

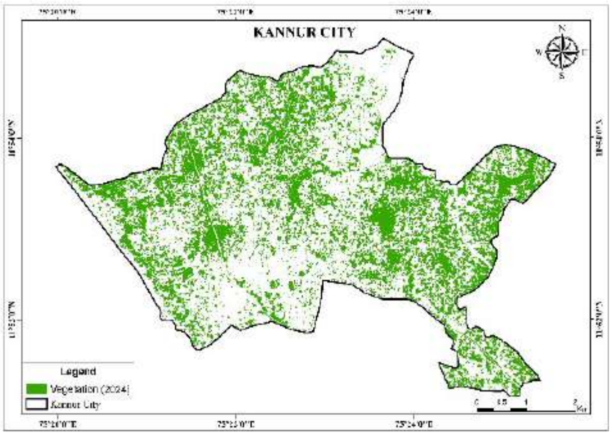

Fig. No. 11. Vegetation Cover in 2024

Concentrated patches (darker green) were observed in 2016 and 2024, mainly on the western and eastern sides of the city. Such patches probably are forests, parks, or important green spaces. A large part depicts dispersed vegetation (lighter green), which suggests scattered trees, gardens, or agricultural land within the urban matrix. Central parts show very small amounts of vegetation (white/very light green), probably associated with highly dense built-up urban or industrial areas. Some linear vegetation patterns indicate riparian or roadside vegetation potentially serving as ecological corridors.

Shannon Entropy: The analysis reveals a heterogeneous spatial distribution of settlements in Kannur City. High Shannon entropy values indicate a high degree of settlement diversity, suggesting a dispersed pattern with numerous settlements scattered across the study area. Conversely, low Shannon entropy values indicate a low degree of settlement diversity, suggesting a concentrated pattern with a few large settlements. The study identifies several clusters of settlements in2016, mainly in the central and eastern parts of the city. These clusters coincide with major urban infrastructure, such as roads, railway lines, and commercial areas. This suggests a strong

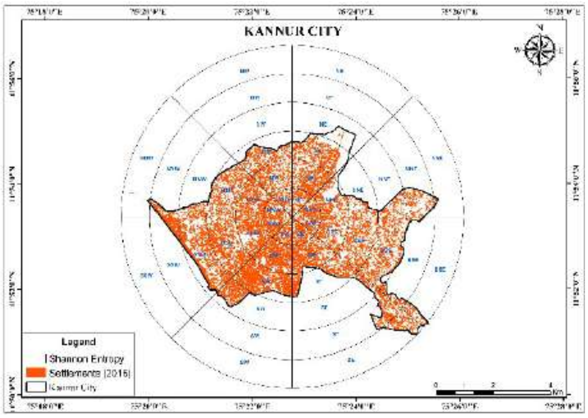

Fig. No. 12Shannon Entropy in 2016

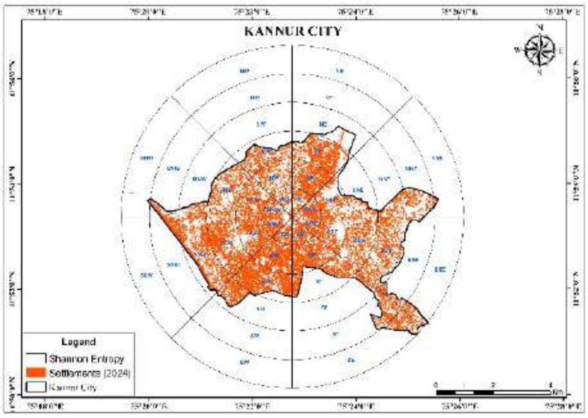

Fig. No. 13Shannon Entropy in 2024

Table No. 2. Urban Sprawl direction of Shannon Entropy

2016			
Sl. No	Direction	Area (Sq. Km.)	Area (%)
1	NE	1.757303	9.20
2	NNE	1.543279	8.08
3	NNW	2.234563	11.70
4	NW	1.399924	7.33
5	SE	2.497941	13.08
6	SSE	2.945422	15.42
7	SSW	3.750972	19.64
8	SW	2.971703	15.56

2024			
Sl. No	Direction	Area (Sq. Km.)	Area (%)
1	NE	2.096327	10.85
2	NNE	1.621481	8.40
3	NNW	2.092488	10.83
4	NW	1.301491	6.74
5	SE	2.597851	13.45
6	SSE	2.953651	15.29
7	SSW	3.732382	19.32
8	SW	2.918304	15.11

correlation between the location of settlements and the availability of infrastructure. In 2024 analysis, Shannon Entropy shows remarkable spatial variations in settlement distribution throughout Kannur City. Central areas are characterized with relatively low entropy values, representing a denser, more clustered pattern of development. Higher entropy values characterize peripheral areas, meaning a more dispersed pattern. All this information will be vital in the context of urban planning and infrastructure development.

Landscape Expansion Index

The map shows Kannur City, India, as classified by the Land Expansion Index (LEI). The index probably distinguishes between

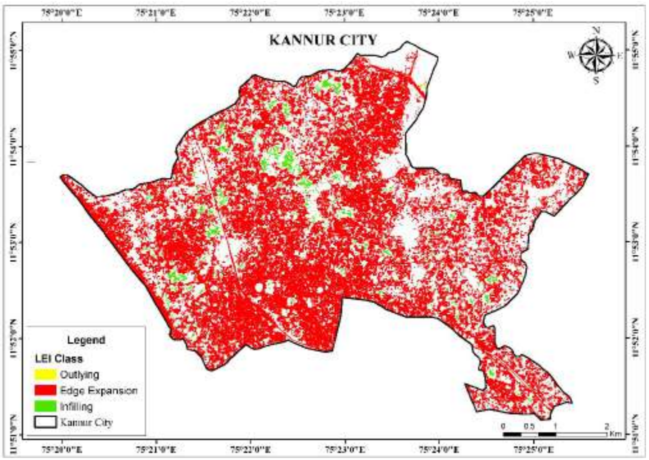

Fig. No. 14 Landscape Expansion Index

three types of urban growth: "Outlying" (new development on the periphery), "Edge Expansion" (growth along the existing urban edge), and "Infilling" (development within already built-up areas). Understanding these patterns is essential for sustainable urban planning.

Outlying: Outlying development is represented by yellow patches on the map. They appear sparsely distributed, mainly to the north and east of the main urban core. This would indicate that Kannur City is experiencing some peripheral growth, but it does not appear to be the dominant form of expansion. The limited extent of outlying areas may be because of geographical restrictions, patterns of land ownership, or regulation.

EdgeExpansion: The map clearly indicates that edge expansion is the major mode of urbanisation in Kannur City. Red colour shows continuous band forming a larger portion surrounding the older core, thus implying an uninterrupted growth in all directions of the city. It therefore depicts a common phenomenon of urbanisation wherein the development primarily happens at the periphery. Implications and Research Questions: Edge expansion, while a natural part of urban growth, needs careful management to avoid negative consequences.

Infilling: The map indicates dispersed green patches in the red areas, meaning infilling is taking place to some extent in Kannur City. The green patches are relatively small and dispersed, indicating that infilling is not a major factor in the city's urban growth. There may be pockets of redevelopment or densification within existing neighbourhoods, but the overall contribution of infilling to urban expansion appears limited.

CONCLUSION

This study has comprehensively analysed settlement patterns and urban expansion dynamics in Kannur City by using a combination of spatial analysis techniques, such as Shannon Entropy and Land Expansion Index (LEI) classification. It has presented differential settlement clusters around central and eastern parts of the city and highly correlated with existing infrastructure like roads, railways, and commercial zones, as observed from the 2016 data. By 2024, the Shannon Entropy analysis had revealed important spatial variations in the distribution of settlement. Central regions had low entropy values, suggesting a dense and clustered pattern of development, whereas peripheral regions were characterized by high entropy, signifying a dispersed pattern. This change is testimony to the continuing process of urban expansion and the impact it had on the city's spatial structure. The LEI classification further refined the nature of this expansion. This expansion created a ribbon of continuous banding around the older urban core, indicating continuous growth in all directions. Such growth pattern puts great emphasis on managing peripheral growth with caution, thus avoiding undesirable side effects brought about by the development of an urban sprawl. Outlying development was indeed noted, but mostly in the north and east, and to a limited extent, indicating it is not a major urban growth driver in Kannur yet. This could be due to geographical constraints, land ownership patterns, or regulatory measures. Infilling was indeed present but played a relatively minor role in the expansion of the city, with small and dispersed green patches indicating a lack of redevelopment or densification within existing neighbourhoods. The combined insights from the Shannon Entropy and LEI analyses provide valuable information for urban planning and infrastructure development in Kannur City. Identification of dense central clusters, dispersed peripheral growth, and the dominance of edge expansion forms the basis of key areas of intervention. Proper edge expansion management, encouragement of infilling to make optimal use of the existing urban land, and judicious development of infrastructure to serve both existing and future settlement patterns are some of the effective urban planning strategies that need to be emphasized. This broad understanding of the dynamics of an urban area will be essential in creating sustainable and balanced growth for Kannur City.

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