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Land Use Dynamics and Challenges in Smart Cities: A Temporal and Spatial Perspective

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Abstract

Cities are experiencing unprecedented expansion due to globalisation, posing a serious threat to their existence. Urbanisation is a global phenomenon that results in disorganised growth and imbalances in cityscapes. Smart city planning aims to enhance the quality of life, citizen participation, e-governance and environmental sustainability. The temporal land use analysis depicts that the Coimbatore region had only 35.63% urban spaces, reaching 79.54% by 2023

at the cost of other land uses. Srinagar city depicts the conversion of its fertile farming lands owing to the expansion of urban areas from 1995 to 2023. The per-urban area of Srinagar witnessed 35.65% urban cover due to city expansion. The landscape metrics analysis shows that cities are becoming fragmented due to urban growth. The number of patches shows that the cities are becoming compact, whereas the outskirts are becoming increasingly fragmented. It necessitates sustainable planning measures, which are the need of the hour to curtail environmental degradation and uphold clean air, water, and a suitable environment for all.

Keywords: Urbanisation; Sprawl; Smart City; Landscape Dynamics; Smart City Mission

Introduction

Cities are the dynamic convergence of people, culture, and economic pursuits. Cities are vibrant geographical spaces accommodating diverse people who live, earn livelihoods, exchange upgraded health facilities, have access to education and other services, and lead a quality of life. Cities would accommodate 70% of the global population by 2050, accounting for 6.3 billion people out of 9 billion people (Esch et al., 2017). Many people are migrating to the cities for better opportunities and livelihoods. This trend depicts a higher impact on resource exploitation and abrupt land transformation to accommodate the expansion of cities. The rural areas used to accommodate twice the population of cities in 1950, but remarkably, this reversed by 2008, with enormous urban expansion (Davis, 2015). Cities serve as historical centres of economic development, whereas peri-urban areas evolve alongside replacing natural cover with paved surfaces, competing with and complementing urban functions. The uncontrolled urbanisation results in sprawl by triggering inequalities in the natural environment and structure of the cities. The city growth in the form of sprawl is accompanied by three spatial transformations, i.e., denser urban cores, the emergence of unstructured edge cities, and rapid suburban spread (Ramachandra et al., 2012; 2019). Land use land cover changes (LULC) are dynamic and unsustainable, which impacts natural forest cover, agricultural lands, natural resources, ecosystem services, etc., necessitating the analysis of the quantitative changes in spatial patterns for planned interventions (Newbold et al., 2015; Ye et al., 2020; Bharath & Ramachandra, 2021; Abdollahi et al., 2023). The unchecked growth in the population and the

related global urbanisation are posing more significant challenges for a sustainable future. However, the actual dimension of city transformation due to urban expansion is still not completely understood. Hence, to safeguard sustainable urban development, it is vital to scrutinise the factors prompting city growth, their effects, and appropriate strategies. One key aspect is employing precise, up-to-date spatial data on human settlements.

The smart cities program has been conceived by the regional development authorities to augment the improving infrastructure, amenities, and overall urban well-being by using technology to create sustainable, inclusive, and economically advanced cities across the globe. The major component of a smart city project should focus on quality of life along with innovative design principles. Urban design should focus on the following primary components: redesigning existing infrastructure for sustainable resource use, conservation through technology and enriching the existing quality of urban form. This requires a thorough redesign for smart cities integrating the transdisciplinary (theoretical, methodological and technological) developments in urban informatics. Pfeiffer and Cloutier (2016) highlighted key factors inducing happiness in cities and neighbourhoods, emphasising elements such as open, natural, green spaces and urban design promoting social interaction and safety. Smart city planning is essential in advancing the United Nations (UN) Sustainable Development Goals (SDGs), which were proposed in 2015 and focus on sustainable urban infrastructure, affordable housing, climate-resilient cities, and environmental conservation. Specifically, SDG 11 provides an overview of sustainable cities and communities (SDG 11) to promote sustainability and reduce environmental impacts. People and nature should be integrated as part of smart city planning and development, but ignoring these prime features can result in imbalances.

The Smart City Mission, launched by the Indian Union Government in 2015 and led by the Ministry of Housing and Urban Affairs (MOHUA), aimed to develop 100 selected cities nationwide into smart cities. Unrestrained urban population growth pushes the existing city boundary towards the countryside to support the augmented growth, often manifesting as sprawl. Urban sprawl develops along city fringes, forming new irregular edges along transport routes, frequently characterised by inadequate infrastructure. The smart city program intends to understand the current growth pattern and sprawl and appropriately plan the landscape by

integrating innovative tools and technologies. The union government had stringent policy and selection criteria based on the state nomination, diverse evaluation metrics and regional balancing factors. The cities were chosen based on the existing infrastructure, ability to gain finance projects, citizen activism, and governance. The smart city mission has undertaken 8.040 projects, accounting for 164667 crore rupees worth of upgrading or restructuring infrastructure across 100 cities (Smart City Mission: https://smartcities.gov.in/). The current research aims to evaluate temporal land use changes and to analyse the positive or negative transformations across the selected smart cities portraying diverse landscapes. The work also examines the impact of urbanisation on peri-urban landscape regions by exploring the various landscape metrics.

Study Area:

Smart urban planning has been proposed to address challenges like traffic congestion, pollution, and inadequate public services, thereby improving living standards for citizens. Coimbatore and Srinagar cities saw significant infrastructure upgrades as part of the smart city program. These cities were chosen as they depict diverse agroclimatic zones of India. Coimbatore city is part of the Southern Plateau and Hills zone, located in the foothills of the Western Ghats. It is recognised as Tamil Nadu's second-largest urban agglomeration and holds the position of the 16th largest in India. The city contributes $45 billion to the gross domestic product (GDP) with a population of 2.1 million. It has four special economic zones (SEZ): ELCOT SEZ, KGISL SEZ, SPAN Venture SEZ, and Aspen SEZ. Srinagar city has a beautiful, charming environment in the Western Himalayan agro-climatic zone. The city has 1.8 million people contributing significantly to the GDP of the union territory (Jammu and Kashmir - J&K accounting for $2.3 billion). Srinagar has witnessed accelerated growth in its population due to migration and economic activities.

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Method:

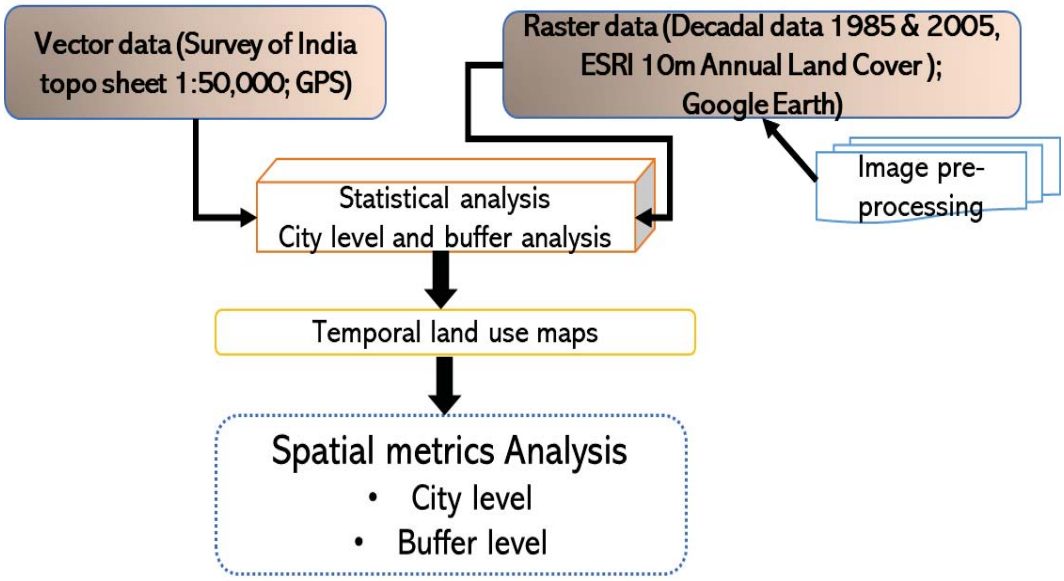

Figure 1. The method followed in the study

The method employed for the study is depicted in Figure 1. The RS data used in the study include Landsat TM & IRS LISS III (1985, 2005) data with 100 m spatial resolution downloaded from ORNL DAAC (Roy et al., 2015), Sentinel-2A data from 2017-2023 with 10 m spatial resolution downloaded from ESRI landcover archive (Karra et al., 2021) and validated with Google Earth (http://earth.google.com). The RS data is verified for geometrical and radiometric consistency, and the image pre-processing techniques are performed to maintain consistency. The Landsat data has been rescaled to 10 m resolution to maintain consistency. The ancillary dataset is collected to assist in interpreting different land use types from RS images. Survey of India (SOI) topographical maps of scale 1:50,000 and 1:250,000 procured from SOI. The spatial metrics, known as landscape metrics, assist in analysing the structure and quality of the landscape. Table 1 outlines the prioritised spatial metrics for analysing spatiotemporal urbanisation trends and their significance (Herold et al., 2005; Uuemaa et al., 2009; Kaminski et al., 2023).

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Table 1. Significance of the spatial metrics analysed.

Sl No	Metric	Method	Metric range	Significance/Description
1	Number of Built-up Patches	$NP = number$ NP accounts for the number of built-up patches in the study region.	NP>0, boundless	NP denotes fragmentation in the urban landscape, with a rise in values resulting in more significant fragmentation.
2	Patch Density (PD)	F(Study Area) = (Number of built-up patches/ Landscape Area) * 1000000	PD>0, without limit	PD is calculated on a land use map using a four-neighbour algorithm, where higher PD values indicate an increased number of patches within a given landscape area.
3	The mean Euclidean nearest-neighbour distance (ENN_MN)	ENNMN =mean*(*ENN*[*patchij*])* where ENN[patchij] is each patch's Euclidean nearest neighbour distance.	ENN_MN > 0	ENN_MN is an aggregation measure that evaluates the proximity of the nearest neighbouring patches within a similar class by analysing edge effects and landscape complexity.

Results:

The temporal land use analysis depicts the Coimbatore region had only 35.63% urban spaces, which has reached 79.54% by 2023 at the cost of other land uses. The greater extent of open lands and agricultural regions were transformed into buildings. Expanding SEZs and increasing small-scale built-up areas resulted in increased paved areas in the buffer region. The buffer region covers 45.64% of the built-up area by 2023, causing an imbalance in the landscape. The agricultural area shows a loss of 16% in its cover, followed by a 13% loss in barren areas. Srinagar City depicts the alteration of fertile farming lands due to the expansion of urban areas

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from 1995 to 2023. The Core city had 31.55% urban area, which has increased to 48.6% by 2023 due to large-scale land transformation. The land use assessment uncovers that one of the massive and unstructured urban centres has emerged in the fragile Himalayan ecosystem. During the last thirty years, this haphazard growth has resulted in a disproportionate distribution of buildings devoid of basic civic amenities, socio-economic issues and environmental pollution. The increase in population in the valley is extremely abrupt, and it overwhelms the city's capability to provide critical urban services (Nengroo et al., 2017). The mushroom growth of unauthorised colonies is noticed in the valley and mountains, resulting in an increase of 17% in urban areas. The buffer analysis further confirms that traditionally, Srinagar city was anchoring growth limited to the core. At the same time, the abrupt increase in population and migration resulted in peri-urban growth in the past three decades. Variations in population trends within the city and its environs have led to socio-economic instability and numerous associated problems.

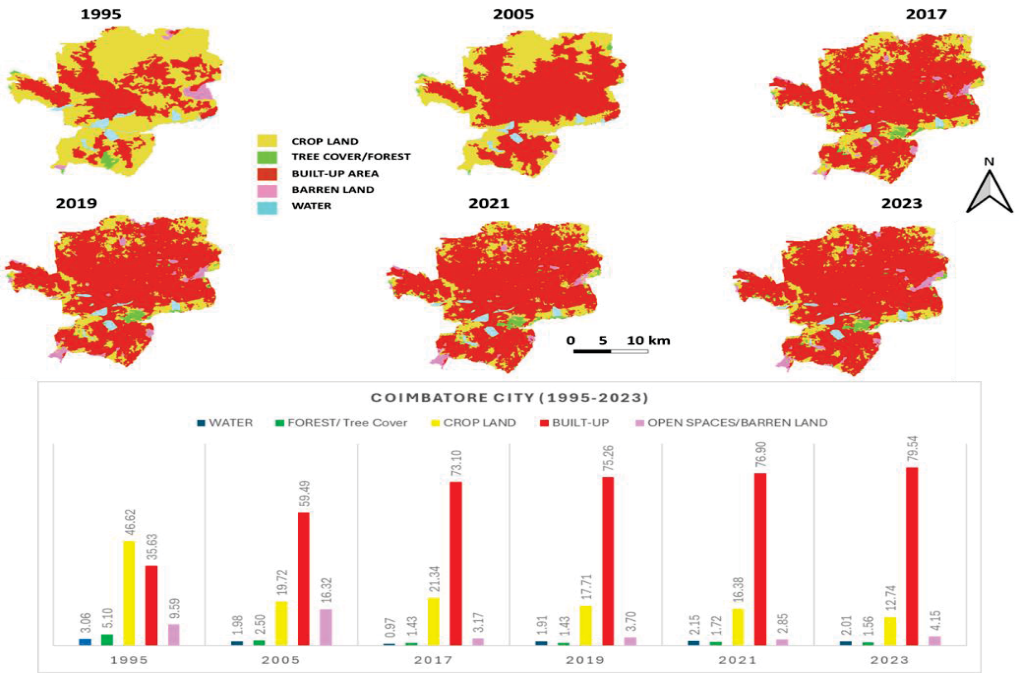

Figure 2. Temporal land use of Coimbatore smart city from 1995-2023

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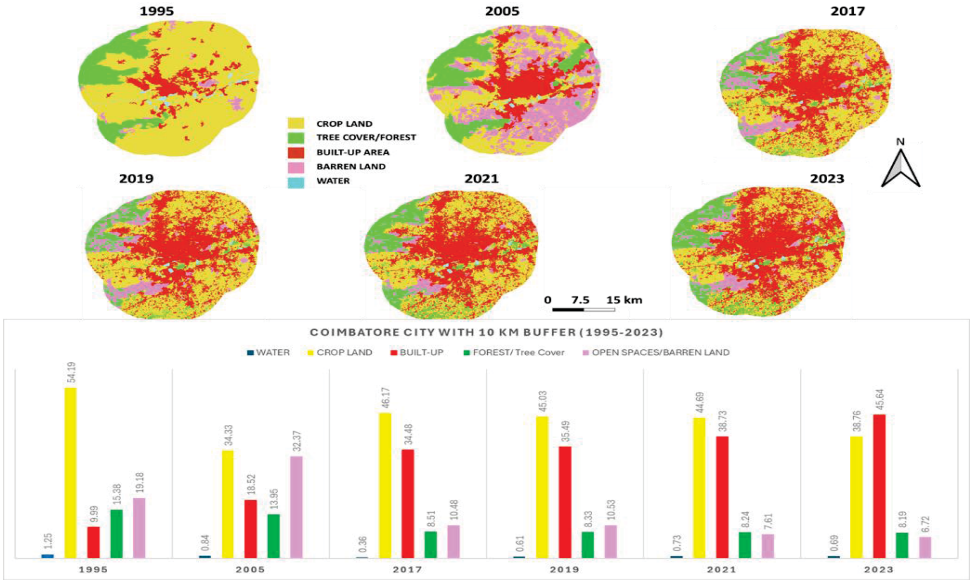

Figure 3. Temporal land use of Coimbatore with a 10 km buffer area

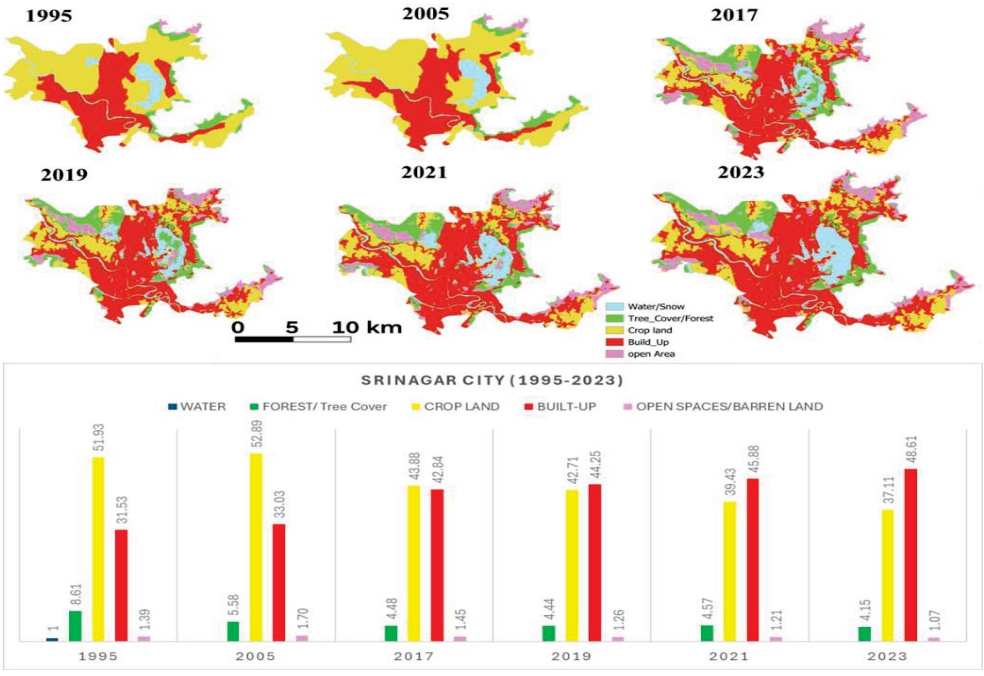

Figure 4. Temporal land use of Srinagar smart city from 1995-2023

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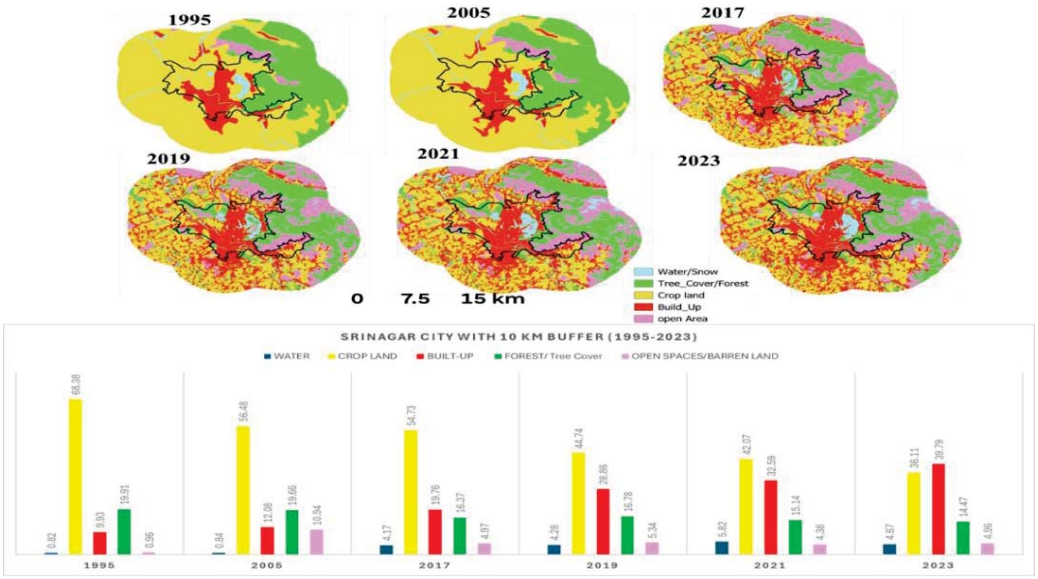
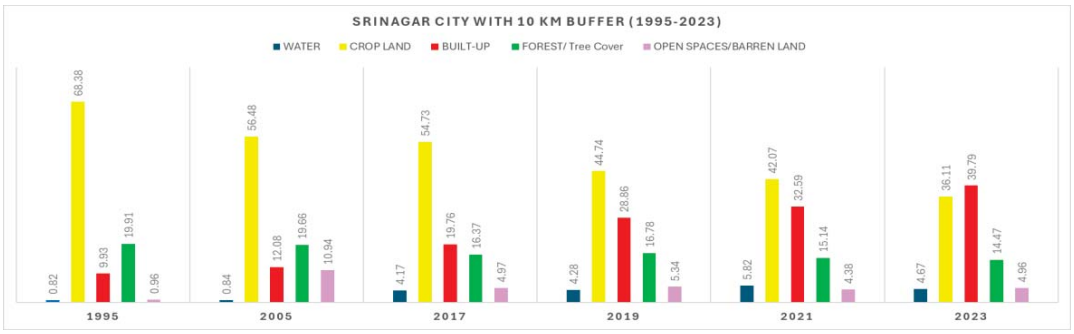


Figure 5. Temporal land use of Srinagar with 10 km buffer area



Spatial metrics are fundamental for effectively capturing landscape diversity and spatial heterogeneity in urban environments. The number of built-up patches (NP) is an important indicator of fragmentation; the more significant the number, the more fragmentation there is. The NP metric shows that Coimbatore had many patches in 1995, but the city has become more compact due to the growth and infilling process. The buffer region depicts the increase in patches, resulting in more fragmentation in the landscape owing to new built-up patches in the peri/outer-city areas. The same trend is noticed in Srinagar and its peri-urban areas, which are more fragmented urban structures. The peri-urban region significantly shows an increase in patches over the study period. PD depict the compact growth across the cities, whereas the

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buffer region shows more fragmented growth. The ENN_MN shows the reduction in the distance between urban patches in the city areas, whereas the buffer region shows increased neighbour distances due to fragmented patches. The shape of the peri-urban is complex due to more patches with disconnected edges. The natural cover of the city and its buffer region are experiencing pressures from urban expansion across the study areas. This necessitates the cautious expansion of the region and maintaining the balance of land uses. There is a serious need to integrate green infrastructure, efficient public transport, and renewable energy systems across the city and its peri-urban areas to promote sustainability and reduce environmental impacts. Preserving urban biodiversity, improving air quality, and implementing sustainable waste management systems must be strengthened along with economic resilience through effective zoning and urban policies.

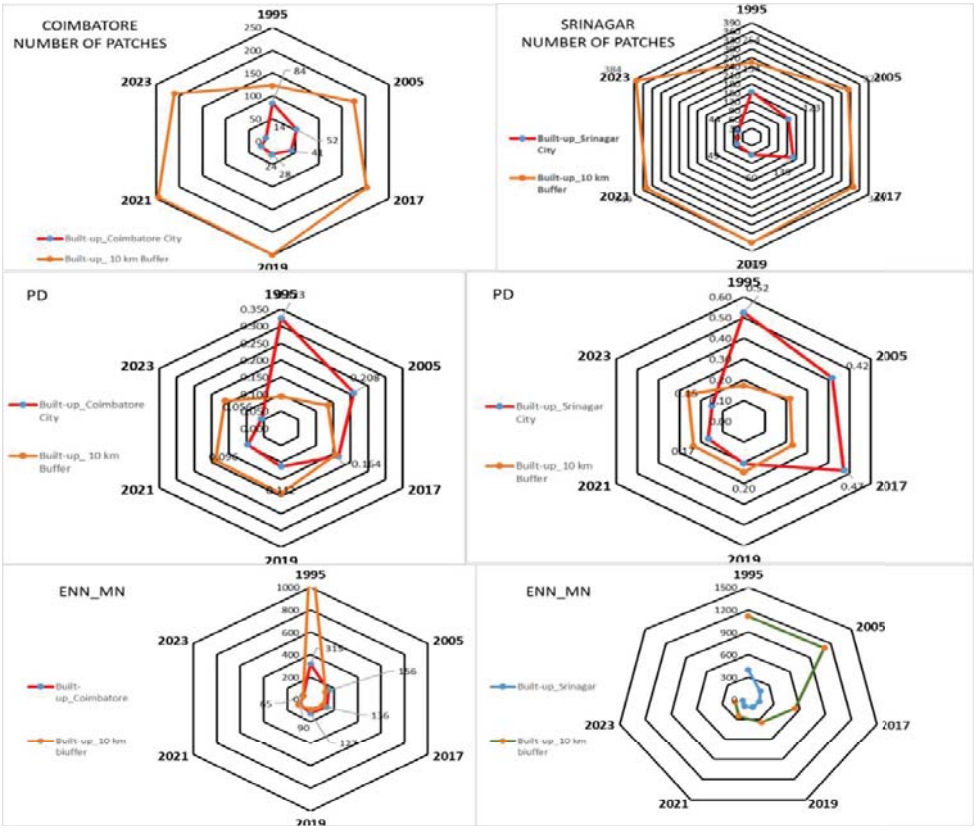

Figure 6. Landscape metrics analysed.

Conclusion:

The smart cities are significant contributors to India's GDP. The city's permanence lies in its people, diverse cultures, and vibrant economy. The smart city initiatives have enhanced better infrastructure, digital connectivity, and improved quality of life. The unplanned growth and peri-urban land transformation pose a serious challenge in managing regions. The spatio-temporal land use analysis shows the 44% and 17% increase in the built-up cover across Coimbatore and Srinagar cities due to rapid growth from 1995-2023. The peri-urban regions have witnessed a large conversion in their natural cover, as evidenced by buffer analysis. Due to migration and uncontrolled land transformation, the Srinagar buffer region has envisioned 35.65% growth in urban-to-rural transitional zones. Analysis of the urban-rural gradient at a temporal scale can aid decision-makers in efficiently balancing growth with ecological preservation. The city's developmental setting should be balanced to improve the quality of the ecosystem rather than focusing solely on creating unconventional economic hubs. Smart city planning under a unified, sustainable development framework perhaps integrates them more efficiently into the national and global economy.

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