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Appraising the Degrees of Sprawl, Freedom and Goodness of Urban Growth Detection Using Geoinformatics Approach - A Study of Tumkur City in Karnataka State, India

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ABSTRACT

The urban expansion analysis plays a significant role in the physical, social, and environmental dimensions of the cities. The research was conducted to monitor the urban growth and urban sprawl analysis of Tumkur city from 2000 to 2020 using multispectral satellite data (Landsat-5, Landsat-7, Resourcesat-1, Landsat-8, Sentinel-2A). Various methods like urban-related indices (AUER, UEII, and NDBI), and statistical methods (Degree of Freedom, Shannon Entropy, and Degree of Goodness) were used in the present research work. The AUER (Annual Urban Expansion Rate) and UEII (Urban Expansion Intensity Index) study of urban indices reveal that the urban area has expanded from 24.94 km^2 to 60.59 km^2 due to the development of commercial buildings, single-use zones, and low-density areas. The analysis of NDBI (Normalised Difference Built-up Index) indicates that the expansion of urban infrastructure, industrial growth, and population increase cause significant damage to vegetation in the city center compared to other areas. The study of the Degree of Freedom and Shannon entropy indicates that high compactness appeared in the core, whereas other regions are experiencing significant expansion. The method of freedom of goodness (2000 = - 0.093 to 2020 = - 0.159) demonstrates that the currently unfavorable conditions of urban growth have appeared in Tumkur city and it leads to numerous adverse effects on present and future generations. This study will help urban planners and decision-makers maintain the proper land use planning to reduce urban sprawl and its associated consequences, allowing for sustainable urban development.

INTRODUCTION

Urban areas constitute less than 1 percent of the Earth's surface area. However, they contribute to 90 percent of the global economy, with 50 percent of the world's population residing in cities. Additionally, cities consume 65 percent of the planet's resources and are responsible for 70 percent of the greenhouse gases emitted into the atmosphere (Martinuzzi et al. 2007, Almeida et al. 2005). By the World Urbanization Prospects-2018, 95% of the population will be settled in towns in developing countries in the coming years. Urbanization is a societal and spatial process that affects human societies in many ways. This process leads to changes in human practices that impact urban communities negatively. Urbanization and urban growth are two main urban development phases that must be clearly outlined (Bhatta et al. 2010, Dadras et al. 2015). Urbanization refers to the increasing proportion of a population residing in urban areas, while urban growth pertains to the actual increase in population within urban areas. Urban growth is a key indicator of the development of urban areas and it is a comprehensive approach that involves various ideas.

Urban growth is influenced by a multitude of factors, including natural population growth, improvements in transportation and communication, the availability of facilities for education and recreation, urban planning policies, topographical factors, uneven spatial development, changes in living habits brought about by modernization and transformation, mining and investment, migration, commercialization, and industrialization, etc (Manna et al. 2024, Alam & Banerjee 2023).

The expansion of cities has many detrimental effects, such as the significant loss of biodiversity brought about by habitat destruction and fragmentation, pollution of air and water, soil contamination from waste disposal, heat island effect, improper waste management, higher rates of crime and violence due to socioeconomic inequities, and an increased risk of disease due to poor health practices and overpopulation (Nkeki 2016). Significant dangers from man-made and natural catastrophes can arise from unplanned and mismanaged urban expansion in cities. When properly planned and managed, urban growth can reduce poverty and inequality by improving employment opportunities and quality of life, including through better education and health. But when poorly planned, urbanization can lead to so many consequences like traffic congestion, higher crime rates, pollution, increased levels of inequality, economic inequality, and social exclusion. Urban expansion influences the increased demand for land and changes in a region's land use and cover areas (Yakub & Tiffin 2017). Proper analysis of urban development is crucial to examine its past records, as well as natural, geographical, societal, and financial influences.

Urbanization in India

India's urbanization rate initially decreased but then grew gradually in the 1920s (Mohan & Dasgupta 2004, Dadras et al. 2015). After a few decades, urbanization has become more significant in India, which accounts for just 2.5 percent of the world's total land area yet produces about 16 percent of its people. (UNEP 2001). Compared to a gain of 2.1% between 1991 and 2001, it has climbed from 27.7% to 31.1% between 2001 and 2011, a growth of 3.3% (Bhagat 2011). According to this analysis, India's urban population is expected to almost triple, to 600 million people, by 2031 (Raftery 2012). The nation's fast urbanization has drastically changed the urban environment, changing land use and cover and placing a great deal of strain on the nation's natural resources. Given the extent of urbanization, it shows that one must study those topics to maintain unfavorable living circumstances and local environmental issues that would plague Indian towns (Mohan et al. 2011, Saxena et al. 1997).

Proper land-use planning and comprehending the dynamics of growth and the effects of driving variables to manage urban development effectively is essential. Urban growth monitoring involves remotely observing an object or phenomenon at different times to study changes resulting from human modification of the environment (Hegazy & Kaloop 2015, Li et al. 2018). The urban growth analysis is helpful for local planning authorities to manage growth and development under the region's environmental or ecological carrying capacity and maintain sustainable urban development in cities (Das & Das 2019, Haregeweyn et al. 2012).

There are already many methods like the Geospatial method, Machine Learning Method, Statistical methods, Land use Prediction Models, and other different models used to monitor the urban land transition, urban studies, and urban growth in different study areas (Ramachandra et al. 2013, Mishra & Rai 2016, Rahman et al. 2017, Chen et al. 2020).

Present Study

The present study employed geospatial methods and statistical models to examine the urban area expansion of the study region over two decades. The use of GIS and RS methodologies has enabled the creation of various statistical scales and parameters to quantify urban sprawl and monitor urban growth (Bhatta et al. 2010). These technologies provide cost-effective and efficient ways to study the physical expressions and patterns of urban sprawl (Barnes et al. 2001). In recent years, remote sensing data and geographical information systems (GIS) techniques have been increasingly used to understand urban patterns and processes and simulate urban growth, urban land transition, and urban sprawl development (Patra et al. 2018, Wang & Munkhnasan et al. 2021, Fertner 2018, Ngolo et al. 2023, Mohan et al. 2020). Remote sensing provides reliable scientific tools for calculating the built-up area, using intertemporal satellite images, and studying the multispectral space. The GIS may use multi-agent data evaluation methods to analyze the data gathered by remote sensing with the embedded decision-making support features (Basu et al. 2023, Mohan et al. 2020, Mohan & Kandya 2015, Verma & Garg 2022). Various methods, including unsupervised and supervised classification (Kim 2016, Mohan & Kandya 2015, Ji et al. 2006), hybrid methods (Mas et al. 2017), and object-based detection methods were utilized to quantify, assess, mapping, and monitor urban growth in cities. Scholars have utilized a few important indices to monitor and analyze urban expansion in a given area. These indices include the Annual Urban Expansion Rate Index (AUERI), which measures the rate of urban expansion, and the Urban Expansion Intensity Index (UEII), which assesses the intensity of urban areas. Additionally, they use the Normalised Difference Built-up Index to analyze the built-up area. The scholar used statistical analysis like the person" 's Chi-square and 'Shannon's entropy' to analyze the disparity of urban growth in the study area (Dewa et al. 2022). The new "degree-of-goodness" method is applied to statistically monitor urban growth in the present study (Akshaya 2021).

Tumkur City, also known as Tumakuru City, is a growing urban entity in Karnataka, undergoing substantial expansion and development. The city has witnessed significant developments in many areas, including the economy, governance, culture, and education. Opportunities for infrastructure development, employment creation, and bettering the standard of living for locals are presented by this urbanization process. Tumkur city, on the other hand, has undergone a considerable rural-to-urban shift during the last few decades. Apart from that, most of Karnataka's studies on urban expansion have concentrated on the Bangalore metropolitan region rather than on Tumkur City which is very close to Bangalore (Ramachandra et al. 2019, Govind & Ramesh 2019, Raj et al. 2021, Shukla 2020, Kannan et al. 2021, Kanga 2022). Urban surface water quality, urban groundwater quality, sewage waste management, and urban solid waste management are the few research works conducted in the study area (Bhaskar & Nagendrappa 2008, Kumara & Belagali 2010, Manjunath et al. 2020). Furthermore, as far as we know, studies have yet to use the most recent spatial data and statistical methods to investigate the spatiotemporal assessment, urban land transition, urban sprawl, and urban growth monitoring in Tumkur City. From this point of view, this study attempts to close this gap by employing geographic and statistical methods to monitor the expansion of the study region. The study's objectives are (1) The examination of urban sprawl by using the Shannon entropy technique and the chi-square test. (2) to assess and analyze the behavior of urban expansion in the research region using a new methodology called "Degree of Goodness." Using these scientific findings, planners, decision-makers, and urban designers in the study area will contend that implementing ecological sustainability plans and employing sustainable urban development strategies will enhance the quality of life for present and future generations residing in cities.

STUDY AREA

Tumkur City is located southeast of Bangalore (Fig. 1). It is located between the latitudes 13°19'00" and 13°21'19" and longitudes 77°05'26" and 77°07'12". Tumkur city is located at an altitude of 835 m (2739.5 ft) above the mean sea level. The major city of Tumkur Distinct is the eleventh populated city in Karnataka. It is one of the seven smart cities in Karnataka, selected by the Indian government as part of the Smart City Mission. In 1961, the area of Tumkur city was 12.95 km^2; in 2011, it was increased to 64.27 km^2. According to the master plan map for 2021, it was 331.6 km^2. Tumkur is an ideal location for setting up industries along National highways (NH 48 and NH 73). It contains many industrial areas and industrial estates. According to the United Nations Population Projections and Census of India 2011 report the population of Tumkur city was 302000 in 2011, and, it is expected to rise to 506000 in 2030. According to Karnataka Municipal Reforms, cell reports declared that 37 slum areas are present in Tumkur City. Monitoring urban growth is crucial for local planning authorities to manage urban growth and development within the region's ecological or environmental carrying capacity since the growing population and the expansion of urban areas have led to several difficulties. For the benefit

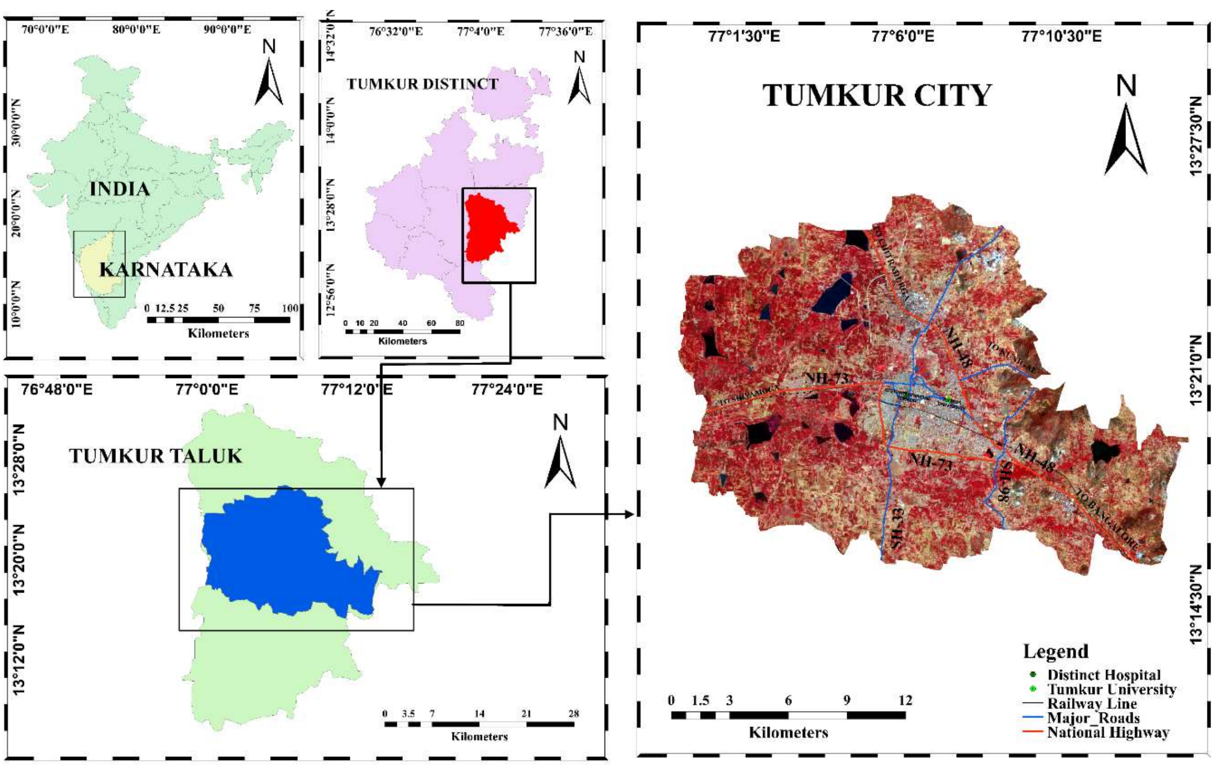


Fig. 1: Location map of study area.

of sustainability, urban authorities need to understand the nature of the urban growth in Tumkur city. With the rapid urbanization process, the demand for urban land is growing continuously, and urban growth has put tremendous pressure on protecting regional ecological environments and conserving incredible ruins.

DATA SOURCES AND METHODOLOGY

Materials

A LULC map and Urban growth change analysis were carried out using Landsat, LISS III, and Sentinel satellite images. LULC maps have been verified by Google Earth Pro samples as well as ground truth surveys. (Table 1) The city's population statistics from the United Nations Population Projections and the Census of India.

Modeling Framework

Image pre-processing and urban growth analysis: For meaningful and reliable results to be obtained, pre-processing of satellite images is crucial. To get appropriate outcomes initially, detecting atmospheric noise, such as haze formed by water vapor, smog, and atmospheric elements, is very necessary. It offers a variety of methods for analyzing the standard results of images to determine the accuracy of surface features.

A maximum likelihood classifier was used to create land use and land cover maps of the study area using satellite images 2000 (Landsat 5), 2005, 2009, 2012, (Resourcesat-1), 2015, 2020 (Sentinel-2A). Eleven land use and land cover categories have been chosen for LULC classification. These are Built-up areas, Fallow land, Double Crop, Scrub Land, Water Bodies, Scrub Land, Stoney Waste, Plantation, Kharif Crop, Scrub Forest, and Forest Plantation.

For the analysis, the zone-wise extracted built-up areas were used for monitoring the urban growth of the study area. The total area is partitioned into 8 equal sectors forming 8 different directions (North North West (NNW), North North East (NNE), West North West (WNW), East North East (ENE), West South West (WSW), South South West (SSW), East South East (ESE), South South East (SSE). This has been divided into multiple zones to extract the built-up area in different directions so that they can statistically be compared. It is worth mentioning that the radius of the circle should be large enough so that it includes the entire urban extent or the metropolitan area within it. Urban extent is a dynamic phenomenon; it changes over time, however, it is largest in the latest temporal instant. Therefore, the circle should be drawn in consideration of the latest image of the study. This has resulted in a matrix (Table 2) that shows built-up areas for each zone and each temporal instant. Fig. 2 briefly the flowchart of the entire methodology. The drawn circles are concentric and include the entire scope of the study from the center of the city. Hence, the circles have been drawn in a way that they include the regions constructed based on a radius of 500 m from each other and in different geographic directions. This division has been made such that the process of changes in construction in different parts and directions could be statistically compared. Essentially, the structure of urban boundaries is a dynamic process and greatly changes in different directions with time.

NDBI Index: The NDBI Index, assesses the expansion of urban areas, particularly ones built up or with artificial structures. NDBI is a built-up index image proposal by Zha (2003) using Landsat Thematic Mapper (TM) images

Table 1: Lists of satellite images used in LULC and NDBI investigations.

Data type and materials	Data source	(Row/Path)	Purposes
Topographical sheet	Naivik (Survey of India)	-	LULC
Landsat 5 (16/03/2000)	USGS Earth Explorer	(Row/Path Number = 144/51)	LULC
LISS III (06/08/2005)	Bhuvan (ISRO)	(Row/Path Number = 93/56)	
LISS III (31/03/2009)			
LISS III (08/02/2012)			
Sentinel (22/10/2015)	USGS Earth Explorer	-	
Sentinel (13/02/2020)		-	
Landsat 5 (18/02/2005)		(Row/Path Number = 144/51)	NDBI
Landsat 5 (18/04/2009)			
Landsat 5 (17/04/2012)			
City and Ward Boundary	Tumkur Urban Development Authority	-	LULC
The ground survey field attributes /Training data	Field measurement and observation	-	LULC

(Bramhe et al. 2018). NDBI maps are primarily based on two bands: Short Wave Infrared and Infrared Bands (Zheng et al. 2021, Vadakkuveettil & Grover 2023) Additionally, it ranges from -1 to +1, just like NDVI and other indices. The following formula was used to determine NDBI:

$$NDBI = \frac{\textbf{Shortwave Infrared wavelength} - \textbf{Near infrared Wavelength}}{\textbf{Shortwave Infrared wavelength} + \textbf{Near infrared Wavelength}} \quad \ldots(1)$$

Measuring Urban Area Expansion Intensity Index: The Urban Expansion Intensity Index, (UEII), could be a valuable tool for quantitatively assessing the urban spatial expansion difference (Yan et al. 2019). It calculates the level of urbanization and the rate at which town landscapes are expanding or contracting (Zhong et al. 2020). It is an indicator that takes into account both the length of expansion (Dong et al. 2007, Qiao et al. 2014, Al-Sherif et al. 2014, Yan et al. 2019, Xian et al. 2019) and the proportional growth in the size of urban areas is used. To calculate the UAEII, the following equation has been used :

$$\text{UAEII} = \frac{\text{UA}^{t2}{}_{b} - \text{UA}^{t1}{}_{b}}{\text{TA}_{b} * \Delta t} * 100 \quad \ldots(2)$$

Where, UA = Urban area; b = spatial unit; t1 = base year; t2 = ending year; **Δt** = t2 - t1, the difference of urban land at the base year and ending year of spatial unit i; TA = Total landscapes of the study region.

There are five categories in the UEII standard: slow-speed development (0 to 0.28), low-speed development (0.28 to 0.59), medium-speed development (0.59 to 1.05), high-speed development (1.05 to 1.92), and extremely high-speed development >1.92. (Zhong et al. 2020).

Annual Urban Expansion Rate (AUERI): The AUER calculates the mean annual expansion rate of built-up land expansion for the entire study area between the base year and the final year. The index yields an estimate depicting the quantum rate at which built-up land of a given region is changing (Alam et al. 2023, Acheampong et al. 2017).

The annual Urban Expansion Rate was calculated by using the formula.

$$A = \left[(ULAt^{t2} | ULAt^{t1})^{\frac{1}{t2-t1}} - 1 \right] * 100 \quad \ldots(3)$$

Where, UA = Urban area; b = spatial unit; t1 = base year; t2 = ending year; **Δt** = t2 - t1, the difference of urban land at the base year and ending year of spatial unit i; TA = Total landscapes of the study region.

Urban Sprawl Analysis Using Entropy Model

Shannon's Entropy: The Shannon Entropy Index (H) analyzed the urban spatial dispersion pattern (Dewa et al. 2022). The information theory, developed by Shannon (1948), gives entropy a statistical character. Richness and evenness, the two primary components of the Shannon Entropy Index, are used to calculate the degree of spatial concentration of built-up area. While evenness refers to the proportion of each object in a class, richness encompasses the number of classes or objects analyzed (Masisi et al. 2008, Al Sharif et al. 2014, Dewa et al. 2022).

Shannon's entropy is given by

$$\text{Hn} = \sum_{i=1}^{n} piloge(pi) \quad \ldots(4)$$

Where Pi is the portion of the variable in the i^{th} zone (in this example, the proportion of built-up area or urban patches in each zone. Greater entropy values show an uninterrupted dispersion of built land, which reflects urban sprawl, whereas lower entropy values show cluttering or less fragmentation of developed areas, which suggests a reduced chance of sprawl. (Antipova et al. 2022).

Pearson's Chi-square Test: Pearson's chi-square statistics considers the checking of freedom amongst pairs of variables chosen to explain the same category of land-cover change. Therefore, the chi-square test was performed with Pearson's chi-square expression: $(\text{observed \_ expected})^2$ /expected to determine the degree of freedom. It reveals the freedom or degree of deviation for the observed urban growth over the expected (Mohamed & Worku 2019, Al-Sherif 2014).

$$x_i{}^2 = \sum_{j=1}^{m} \frac{\left(M_J - M_J^E\right)^2}{M_J^E} \quad \ldots(5)$$

Where, xi^2 is degree of freedom, Mj is observed built-up area in j-th column for a specific row, Mj^E is expected built-up area in j-th column for a specific row. The expected built-up growth for each variable was calculated by the products of marginal totals, divided by the grand total. Therefore, the expected growth MEij for the i-th row and j-th column is

$$M_{IJ}^E = \frac{M_I^S \times M_J^S}{M_g} \quad \ldots(6)$$

Where,

MiS = Row Total

MJS = Column Total

Mg = Grand Total

Degree-of-Goodness: Since the chi-square (degree of freedom) and entropy (degree of sprawl) are different measures, one may sometimes contradict the other. Due to that, the 'degree of goodness' method necessitates urban growth analysis (Bhatta et al. 2010, Dadras et al. 2015). The degree of goodness is a direct measurement method. For this measurement, positive values are indicative of goodness, while negative ones are indicative of badness (Bhatta et al. 2010, Dadras et al. 2015).

$$G_i = log_e \left[\frac{1}{x_i{}^2 \left(\frac{H_i}{log_e(m)} \right)} \right] \quad \ldots(7)$$

RESULTS AND DISCUSSION

The accuracy assessment result shows that the overall accuracy values are 87%, 88%, 86%, 92%, and 94% in the years 2000, 2005, 2009, 2012, 2015, and 2020 respectively, and also corresponding kappa co-efficient in corresponding years are 0.80, 0.82, 0.84, 0.91, 0.92 and 0.94 respectively.

Urban Extent

To extract the built-up and non-built-up areas in a particular period after creating land use and land cover maps using temporal satellite images. Examining these classified images, even cursorily, one can see that the expansion of the city in the specified zones of the study area, some zones are very compact while in others more open space between built-up areas. In 2000, the built-up area was very low, but in 2020, the built-up area expanded compared to 2000 (Fig.

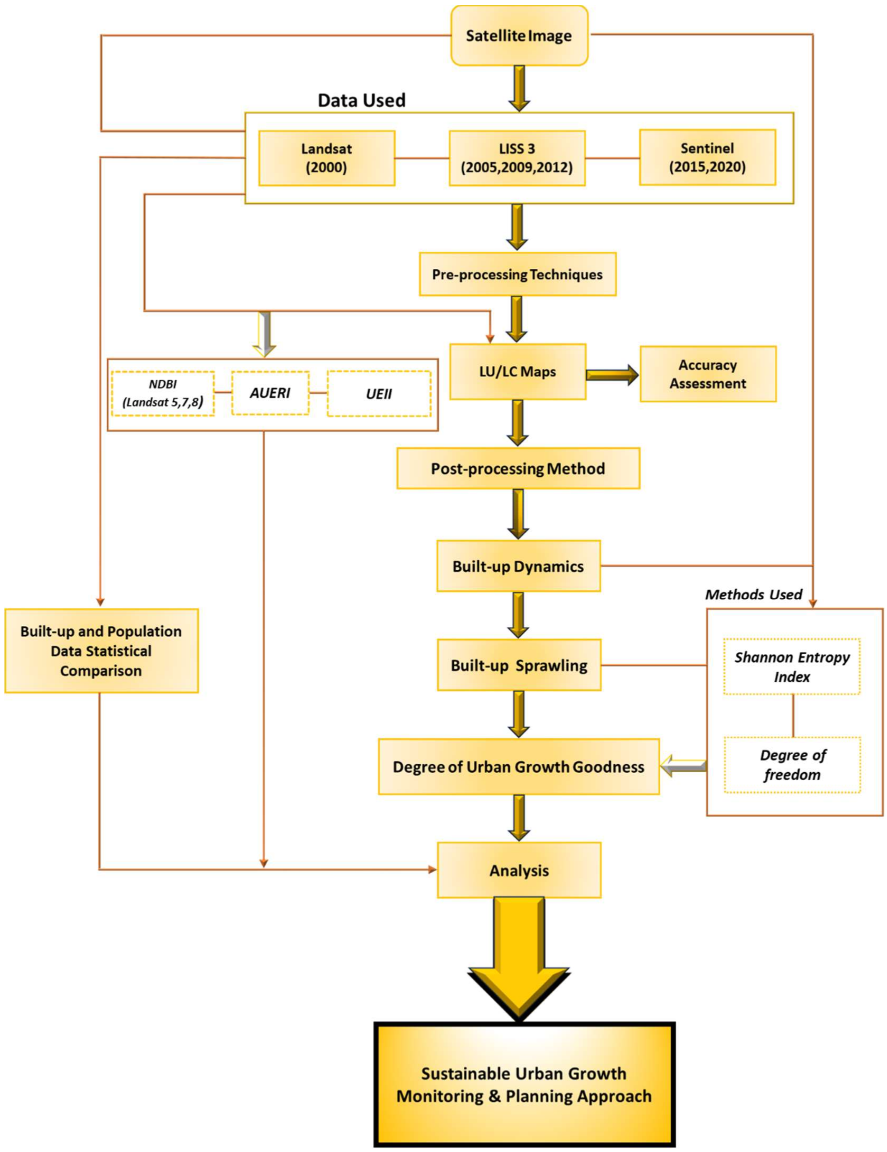


Fig. 2: Methodological flowchart used for the present study.

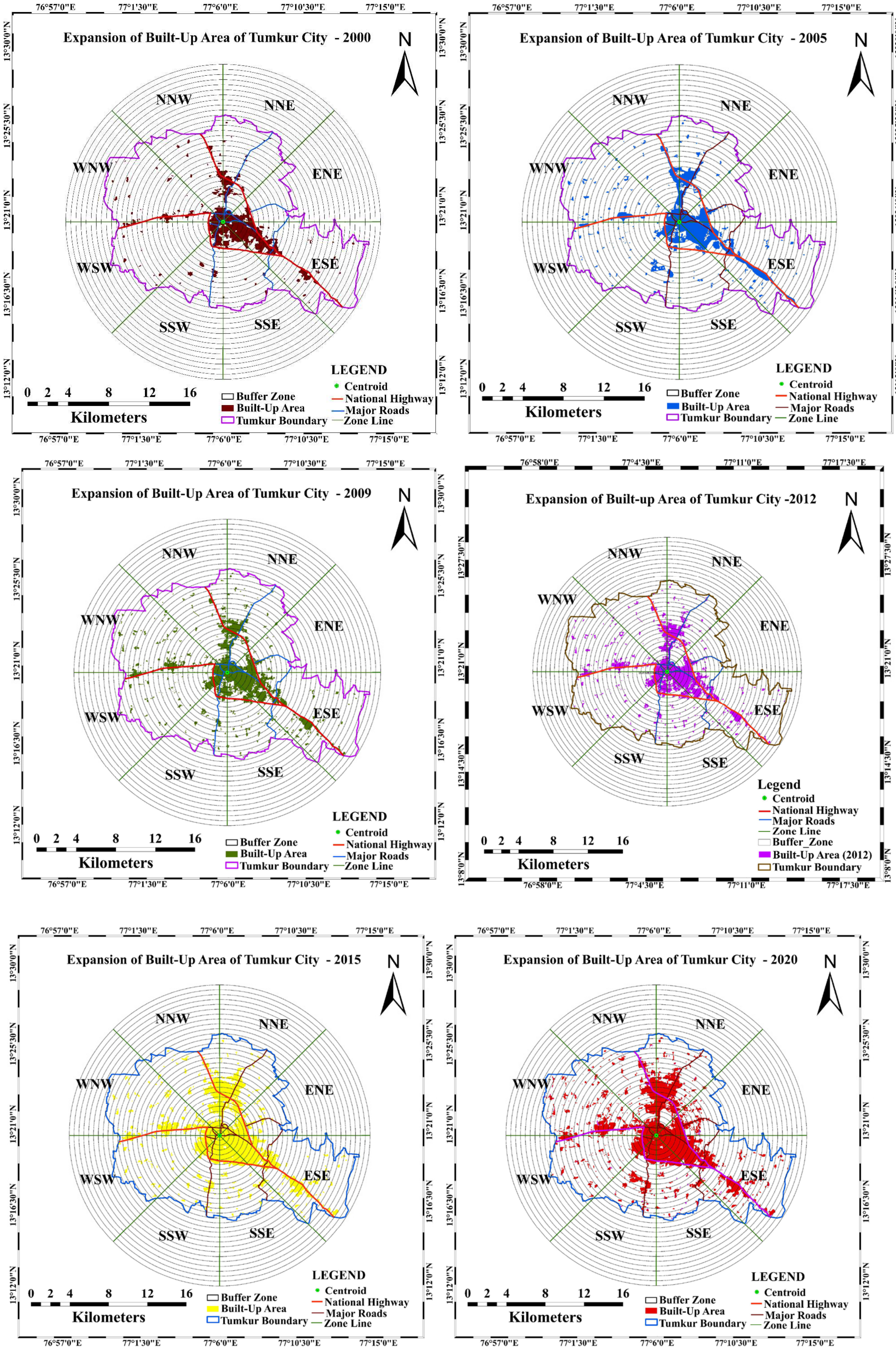


Fig. 3: Urban Sprawl Map of Tumkur City in 2000, 2005, 2009, 2012, 2015 and 2020.

Table 2: The Built-up areas of different zones in Tumkur City from 2000 to 2020.

Zones	Total Area (Sq. km)	2000	2005	2009	2012	2015	2020
NNW	38.08	2.505	3.626	3.56	3.89	6.08	7.158
NNE	37.77	3.195	5.034	5.18	6.31	9.20	10.44
WNW	54	2.352	3.29	4.39	4.74	6.70	8.654
ENE	21.74	1.972	2.75	3.03	3.10	4.208	5.328
WSW	44.46	1.338	2.460	3.12	3.26	4.412	5.56
SSW	25.92	2.35	3.113	2.98	3.05	4.433	5.13
ESE	68.82	9.19	10.66	12.04	11.95	15.125	16.53
SSE	29.95	2.08	2.36	3.32	3.45	5.848	6.019

Table 3: Annual Urban Expansion Rate values from 2000 to 2020.

Zones	2000 - 2005	2005 - 2009	2009 - 2012	2012 - 2015	2015 -2020
NNW	7.66	0.49	1.30	15.80	3.29
NNE	9.66	0.81	6.59	13.25	2.56
WNW	6.96	7.47	2.56	10.74	5.24
ENE	6.51	2.87	0.75	9.60	4.83
WSW	12.95	6.12	1.32	9.50	4.73
SSW	5.78	0.69	0.46	8.98	2.98
ESE	3.01	3.09	1.13	5.88	1.79
SSE	2.55	8.90	1.15	17.15	0.56

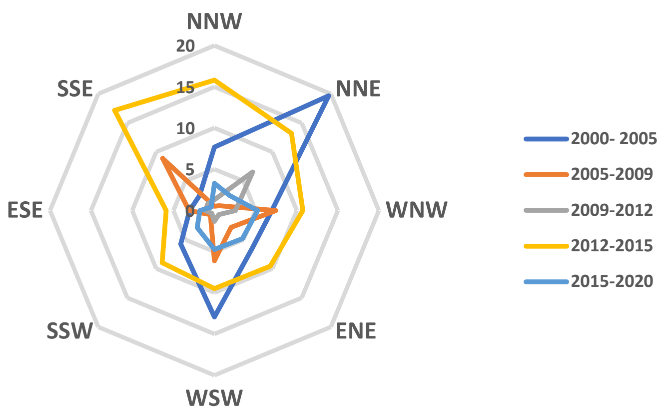


Fig. 4: Radar chart of Annual Urban Expansion Rate (AUER) of different zones.

3). The built-up areas of different zones are mentioned in Table 2.

Annual Urban Expansion Rate (AUER)

The urban expansion rate of zones from 2000 to 2005 could be faster compared to the AUER value of 2005 to 2009. Due to population growth, development of industries, and other reasons, the zone's speed of urban area expansion is high, and few areas of the zone are very low due to improper infrastructure facilities, etc. However, in the case of the 2009 to 2015 period, the AUER rate is very high. This is an indication of the development of built-up areas. According to the AUER, the scores are given in Table 3.

Zone-wise Annual Urban Expansion Rate (AUER) result for the region is presented in Fig. 4. This is designed to indicate the directional distribution of sprawl among the 8 quadrats. From 2000 to 2020 the AUER values were very high in zones like NNE, ENE, ESE, and WNW compared to other zones which indicated the growth of built-up in the form of commercial buildings, residential areas, infrastructure facilities, etc. in the area. From 2000 to 2020, in a few zones like NNW, WNW, WSW, and SSW,

Table 4: Urban Expansion Intensity Index of all zones (2000 to 2020).

Zones	Year				
	2000-2005	2005-2009	2009-2012	2012-2015	2015-2020
NNW	0.588	0.11	0.0875	1.90	0.56
NNE	0.97	0.1098	0.9796	2.55	0.68
WNW	0.348	0.5492	0.2160	1.20	0.723
ENE	0.676	0.373	0.107	1.69	1.030
WSW	0.5147	0.3712	0.1049	0.863	0.5164
SSW	0.585	0.108	0.064	1.71	0.54
ESE	0.4272	0.50130	0.2131	1.70	0.4097
SSE	0.1869	0.80	0.14468	2.60	0.4178
Total	0.5367	0.3653	0.2395	1.77	0.912

the settlement area increased due to population growth, the development of infrastructure facilities, and the growth of the transport network. After 2009, the rise of real estate, high industrial development, better resource availability, and the development of the transport system led to an increase in the development of settlements.

From 2000 to 2005, a few small-scale industries improved in a few villages like Nandhihalli, Chikkahalli, Chokkenahalli, Manchakalkuppe villages, and a few wards in Tumkur city limits. The development of settlements in the urban core region especially wards like Someshwarapura, Batawadi, M.G Road, Sapthgiri Extension, Ashokanagar, Upparhalli, Shanthinagara, Gandhi Nagara, Banashankari, Sadhashivanagara, Hegade Colony, K.H.B. Colony, Chikkepete, Sriranganagar, Kuvempunagara, Vinayakanagara, Vidyanagara is very high compared to periphery region of study area. The improvement of national highways and major roads in the study area led to the development of a few layouts in Shettyhalli, Kaytasandra, Badihallli, Sanapalya, Hirehalli, Kotkahalli, Habbathanahalli, Heggere, Hirehalli, Manchakalukuppe villages (Figs. 7, 8 and 9).

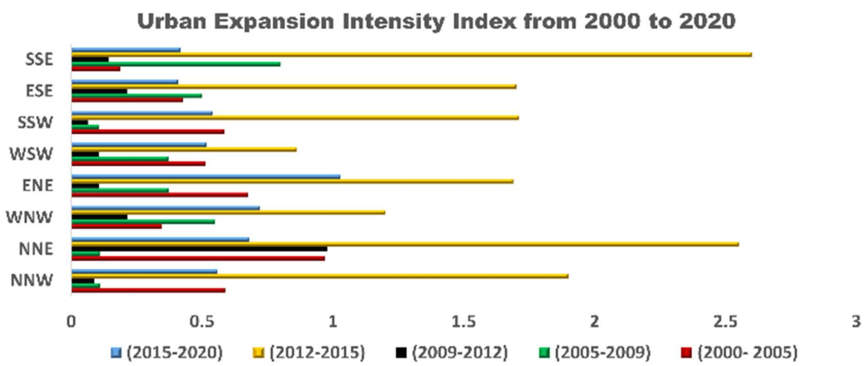


Fig. 5: Bar chart of UEII from 2000 to 2020.

Table 5: Observed growth in built-up area (in km^2).

Year	NNW	NNE	WNW	ENE	WSW	SSW	ESE	SSE	TOTAL
(2000-2005)	1.121	1.839	0.938	0.778	1.121	0.763	1.47	0.28	8.311
(2005-2009)	0.066	0.146	1.1	0.28	0.66	0.133	1.38	0.96	4.825
(2009-2012)	0.33	1.13	0.35	0.07	0.14	0.072	0.09	0.13	2.31
(2012-2015)	2.19	2.89	1.96	1.108	1.152	1.383	3.175	2.390	16.248
(2015-2020)	1.078	2.042	1.954	1.12	1.48	0.697	1.405	0.172	9.615
Total	4.785	8.047	6.332	3.356	4.222	2.78	7.52	3.93	41.209

Table 6: Expected growth in built-up area (in km^2).

Year	NNW	NNE	WNW	ENE	WSW	SSW	ESE	SSE
(2000-2005)	0.9650	0.9420	1.277	0.6768	0.8514	0.5606	1.5165	0.7925
(2005-2009)	2.6800	0.9421	0.7413	0.3929	0.4943	0.3254	1.5166	0.4601
(2009-2012)	0.2682	0.4510	0.3549	0.1881	0.2366	0.1558	0.4215	0.2202
(2012-2015)	1.886	3.1729	2.4965	0.6768	0.8514	1.0961	2.9650	1.5495
(2015-2020)	1.116	1.877	1.4774	0.7830	0.9850	0.6486	1.7545	0.9169

Table 7: Degree of freedom for urban growth in each zone.

Year	NNW	NNE	WNW	ENE	WSW	SSW	ESE	SSE
(2000-2005)	0.0248	0.028	0.089	0.015	0.085	0.073	0.00139	0.330
(2005-2009)	0.4359	0.672	0.172	0.032	0.054	0.113	0.283	0.074
(2009-2012)	0.0141	0.037	0.000045	0.074	0.143	0.031	0.260	0.036
(2012-2015)	0.3460	0.402	0.117	0.031	0.020	0.145	0.014	0.455
(2015-2020)	0.0013	0.014	0.154	0.144	0.248	0.0036	0.069	0.605

From 2005 to 2009, the settlements expanded in rural areas like Kanehalli, Kotkahalli, Palasadra, J.I Thimmlapura, Kuppuru, Chokkenahalli, Hirehalli, Pandithanahalli, Kundhuru in the area. The agricultural land has been converted into single-zone development of built-up areas in the form of residential, commercial, and educational institutions developed in Kunkamanahalli, Maranaipalya, Ballapura, Banavara, Gondapura, Hodhekallu, Byatha, Shinganahalli, Muthsandra, Vaddarahalli, etc. The new layouts were developed in industrial and surrounding areas like Maranaikanapaliya Rangapura, Birennakallu, Seegepalya, and Annenahalli villages.

From 2009 to 2012, the growth of large industries led to the conversion of agricultural land and scrubland into commercial and layouts for residential purposes. From 2012 to 2015 period, the central government's Smart City Mission implemented in Tumkur City influenced the development of infrastructure facilities like the improvement of the bypass, development of new schools and colleges, and construction of the corridor. During this period the large conversion of agricultural land in Hosahalli, Haronahalli, and Kuppur areas, and scrubland transformed into settlements in the form of layouts, in the Peripery of Haronahalli, Goolaharuve, Maraluru Amanikere, Kallahalli areas.

From 2015 to 2020 the central government implemented the Bharat Mala Project (development of NH4 and NH 73 highways), the Smart City Mission project, and many other projects that led to the development of more settlements in the form of residential infrastructure, and roads for connecting newly developed built-up areas in core and periphery regions, and the large compactness that appeared in core areas indication of urban agglomeration. During this period residential, educational, and commercial areas in highways and major roads connected areas like Kannenahalli, Bugadanahalli, Agalakunte, Asalipura, Ballapura, Banavara, Gowdihalli, Keggere, Doddasarangi, Kotkahalli, Mudigere, Palasandra, Hethenahalli, Gangasadra, Hosahalli, Adhalapura, Halanuru areas are developed.

Table 8: Degree-of-freedom for urban growth in each temporal span.

Year	Degree of Freedom
(2000-2005)	0.64969
(2005-2009)	1.43602
(2009-2012)	0.5976
(2012-2015)	1.5343
(2015-2020)	1.2420

Analysis of Urban Expansion Intensity Index

Between 2000 and 2020, an urban expansion intensity index of 0.11 at the lowest point and 2.60 at the highest point is considered a high urban expansion rate. UEII describes the nature of the urban expansion of Tumkur City; the zone-wise statistics are presented in Table 4. Between 2000 and 2005, the overall study area had an expansion intensity index of 0.53, considered moderate for urban expansion. During the initial stage of the growth of industries, the government's small infrastructure projects, improper transport facilities, and other different causes are the main reasons for the slow expansion of urban growth.

From 2005 to 2009, urban land in Tumkur City began dispersing to the east, north, west, and south-southwest, but in 2012-2020, urban land began to disperse almost in all directions. (i.e., South South East, West South West).

Furthermore, between 2009 and 2012, the UEII increased dramatically from 0.23 to 1.77 from 2012-2015; this rapid increase in UEII indicates an increased likelihood of urban sprawl occurring as a result of various infrastructure projects initiated by the government, an increase in industries, and increase in population. Fig. 5 notices that the UEII values in different zones have increased in different directions from 2000 to 2020. It is evident from the significant increase in UEII that urban sprawl is becoming more prevalent. It suggests that there was noticeable urban sprawl during this period, indicating the expansion of urban areas into previously undeveloped or rural areas. The large agricultural land, scrubland, and Plantations were converted into urban settlements.

Pearson's Chi-Square Statistics and Urban Growth

To determine the 'degree of freedom', a Chi-square test was performed with Pearson's chi-square expression: (observed_expected)^2/expected. It reveals the freedom or

Table 9: Shannon's entropy index of Tumkur City (zone-wise).

Year	Built-up Area (sq. km^2)	Entropy Value	Log (n)
2000	24.94	0.999	0.9030
2005	32.10	0.998	0.9030
2009	36.47	0.980	0.9030
2012	39.08	0.997	0.9030
2015	55.85	1.010	0.9030
2020	60.59	0.990	0.9030

degree of deviation for the observed urban growth over the expected. The observed urban growth and expected urban growth are presented in Table 5 and Table 6.

Overall freedom indicates a lack of equal weightage and lack of consistency in planning with the entire city. The higher degree of freedom for a zone is an indication of unstable development within the zone with the change of time.

The degree of freedom in each zone varies from one zone to another. The highest degree of freedom value is 0.672, recorded in the NNE zone, and the lowest is 0.000045, recorded in WNW. Table 7 shows that the freedom is high for NNW, NNE, ESE, and SSE. It indicates that those zones have harmful urban growth due to a lack of consistency in urban planning in the city. The very low degree of freedom of zones ENE, WSW, SSW, and WNW have low urban growth in the city. However; it is worth mentioning that a higher degree of freedom is not only considered as sprawl, instead it should be regarded as the disparity in growth as a process and/or pattern.

On the other hand, poor urban planning can bring opposite harmful effects like heavy traffic congestion, insufficient infrastructure, improper waste management, sanitation, and other issues in the city. The higher degree of freedom in different periods refers to the need for consistency in planning, managing, and controlling urban growth (Table 8). From 2012 to 2015 high degree of freedom indicated highly tremendous urban growth due to sizeable agricultural land transformed into built-up areas, both sides of highways and minor roads, etc.

Quantification of Urban Sprawl Using Shannon's Entropy

The Radar chart shows that between 2000 and 2020, the

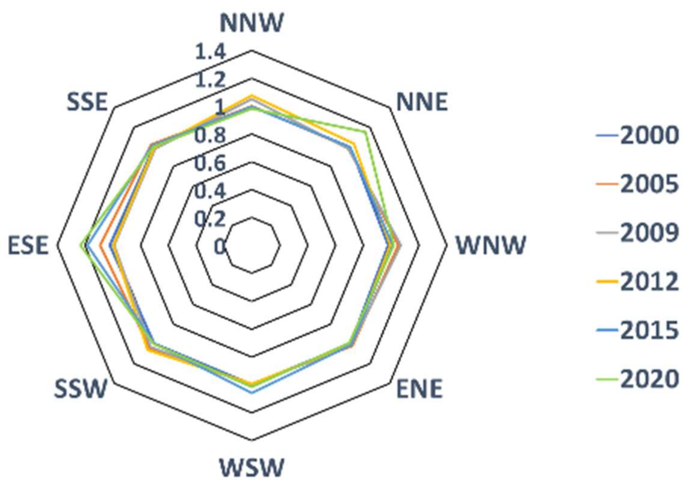


Fig. 6: Radar chart characterizing zone-wise urban sprawl pattern by temporal period.

Table 10: Shannon Entropy values of different zones from 2000 to 2020.

Year	Zones							
	NNW	NNE	WNW	ENE	WSW	SSW	ESE	SSE
2000	0.999	0.998	0.98	0.991	0.990	0.99	1.02	0.99
2005	1	0.99	1.05	0.995	0.998	1.04	1.09	1.02
2009	1.05	0.98	1.07	0.996	0.987	1.03	0.99	0.98
2012	1.075	1.035	0.991	0.997	0.995	1.05	0.99	0.99
2015	0.99	0.99	1.01	0.99	0.99	1.09	1.18	1.01
2020	0.98	1.15	1.02	0.99	0.99	1	1.23	1

Table 11: Shannon Entropy in different periods.

Years	Shannon Entropy
(2000-2005)	1.1208
(2005-2009)	1.01
(2009-2012)	1.09
(2012-2015)	1.20
(2015-2020)	1.05

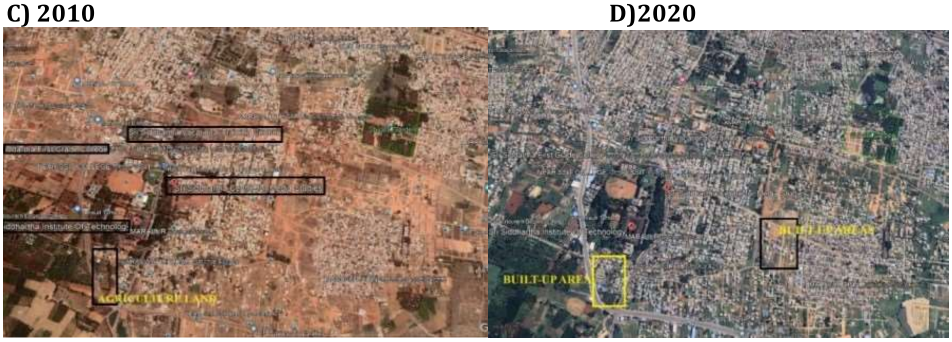
amount of entropy has increased irregularly. The entropy values obtained are 0.999 in 2000, 0.998 in 2005, 0.980 in 2009, 0.997 in 2012, 1.010 in 2015 and 0.990 in 2020. Shannon's entropy for the year 2000 is 0.999, and the log n value of this is 0.9030, which means that the development of urban built-up is more towards the dispersion (Table 9). Nevertheless, it was pretty high after 2015, and the entropy value is 1.010, and the log n value is 0.9030. New residential

A)2010 B)2020

(Source: Google Earth Map)

Fig. 7: Urban area development on both the sides of National Highway and agricultural land into Built-up land in the Heggere area.

C) 2010 D)2020



(Source Google Earth Map).

Fig. 8: Low-density development, Single-used developments, Commercial development in Tumkur city.

E) 2010 F)2020

(Source: Google Earth Map)

Fig. 9: The Growth of built-up areas in Satyamangala Industrial areas.

Table 12: Degree of goodness for urban growth.

Year	Zones							
	NNW	NNE	WNW	ENE	WSW	SSW	ESE	SSE
(2000-2005)	-1.56	-1.51	1.010	-1.78	1.030	-1.079	-2.79	0.426
(2005-2009)	0.316	-0.123	0.690	1.02	1.201	-0.881	-0.497	-1.071
(2009-2012)	-1.765	-1.366	1.16	-1.090	0.762	1.19	-0.487	1.08
(2012-2015)	0.344	-0.33	0.85	1.07	1.65	-0.777	-1.77	-0.275
(2015-2020)	1.10	-1.79	0.772	-0.797	0.564	2.36	-1.097	0.78

Table 13: The Overall Degree of Goodness for Urban Growth.

Years	Degree of Goodness	Behavior
(2000-2005)	- 0.093	Badness
(2005-2009)	-0.205	Badness
(2009-2012)	-0.1418	Badness
(2012-2015)	-0.079	Badness
(2015-2020)	-0.159	Badness

Table 14: Correlation of area statistics of Built-up land.

Year	Supervised	NDBI
2000	24.94	25.77
2005	32.10	33.51
2009	36.47	37.58
2012	39.08	40.78
2015	55.85	56.67
2020	60.59	61.53

areas, a few infrastructures implemented by smart city missions, and the development of new industries added during this period are the main reasons for the increase in dispersion between 2009 and 2020. Shannon's entropy values are calculated year-wise (Table 10), and each zone for all two decades is presented in Table 11.

Interestingly, the entropy values of all eight zones are close to log (n) values, indicating a high degree of dispersion. The index value increased gradually and reached 1.180 log (n) in 2014 indicating an increase in sprawl. KIADB has developed industrial estates at Sathyamanagar, Lingapura, and Antharasanahally along NH 4 in the northern part of the city and also in Hirehalli towards Bangalore. According to TUDA Report from 2000 to 2020, TUDA Developed 80 Layouts in North North East zones. ENE zone records the least sprawl extent and intensity when compared with other zones due to the presence of hill and quarrying activities. The urban edge sprawl has spread further away from the urban cluster, although at a maximal rate, along such an axis. On the other hand, the SSE zone is undergoing maximum contemporary urban growth and haphazard sprawl patterns influenced by industry. The core areas of all zones were more compact compared peripheral region. This shows severe development of built-up areas appeared in the study area.

The entropy value was 0.9923 in 2000 which is a gradual increase throughout and reached an index value of 1.02. This is due to the impact of increasing residential areas and newly established developmental activities conducted by the smart city mission. From the year 2000 to 2020, the WSW zone has remained consistent over the temporal period, with minimal fluctuations. WSW zone records the least sprawl extent and intensity compared to other zones. The NNW zone faces maximum expansion of built-up areas and haphazard sprawl patterns greatly influenced by industries (Fig. 6).

The development of industries leads to, the conversion of agricultural land into urban use (Fig. 7). The low-density development took place in small mining areas in villages like Maidala, Ajjappanahalli, Thippanahalli, Machanahalli, Hosahalli, Amalapura, Devaraypattna, H Byarsandra (Fig. 8 & 9).

Combination of Chi-square Test and Shannon Entropy Models

The Chi-square model for calculating the degree of freedom and the Shannon entropy model for computing the degree of sprawl have different measurements, which may contradict each other in some cases (as evident in the current study). Thus, it is also vital to determine the degree of goodness for urban growth. The degree of goodness is a direct measurement method. For this measurement, positive values are indicative of goodness, while negative ones are indicative of badness (Tables 12 and 13).

The development of industries and the growth of Population have created so many problems like no proper road facilities, lack of sewage, improper drainage facilities, unhygienic and sub-standard living conditions, lack of sanitation, lack of water supply and other amenities. In this study, however, the demonstrated approach of determining the goodness had a significant limitation: it needed to consider any policy variables of the past. It is worth mentioning that although industrialized countries may have proper planning policies for their cities, the cities in developing countries lack such policies in most cases, and they grow with all

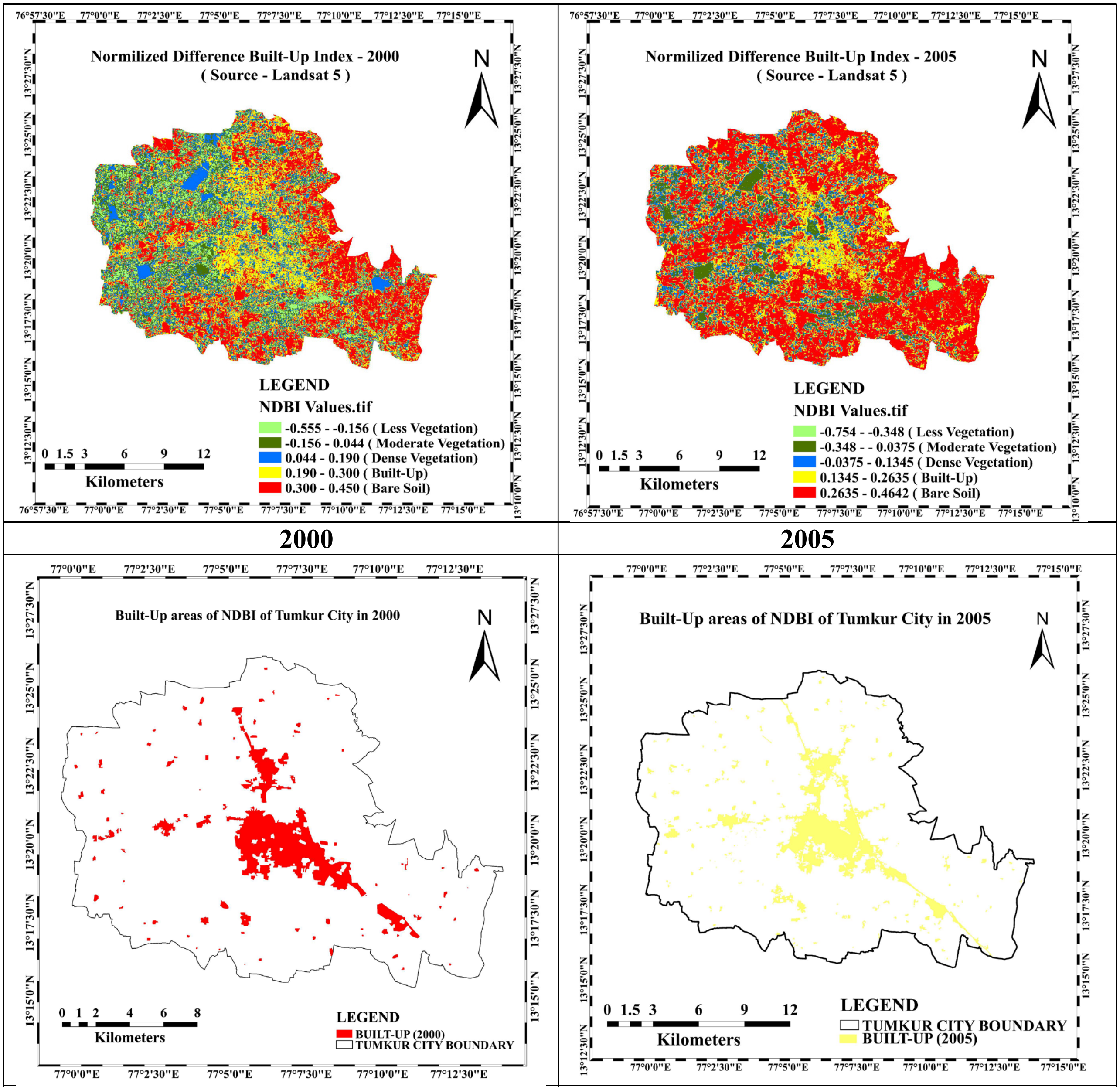

Normilized Difference Built-Up Index - 2000
(Source - Landsat 5)
N
LEGEND
NDBI Values.tif
-0.555 - -0.156 (Less Vegetation)
-0.156 - 0.044 (Moderate Vegetation)
0.044 - 0.190 (Dense Vegetation)
0.190 - 0.300 (Built-Up)
0.300 - 0.450 (Bare Soil)
0 1.5 3 6 9 12
Kilometers
Normilized Difference Built-Up Index - 2005
(Source - Landsat 5)
N
LEGEND
NDBI Values.tif
-0.754 - -0.348 (Less Vegetation)
-0.348 - - 0.0375 (Moderate Vegetation)
-0.0375 - 0.1345 (Dense Vegetation)
0.1345 - 0.2635 (Built-Up)
0.2635 - 0.4642 (Bare Soil)
0 1.5 3 6 9 12
Kilometers
2000
2005
Built-Up areas of NDBI of Tumkur City in 2000
N
0 1 2 4 6 8
Kilometers
LEGEND
BUILT-UP (2000)
TUMKUR CITY BOUNDARY
Built-Up areas of NDBI of Tumkur City in 2005
N
0 1.5 3 6 9 12
Kilometers
LEGEND
TUMKUR CITY BOUNDARY
BUILT-UP (2005)

Figure Cont....

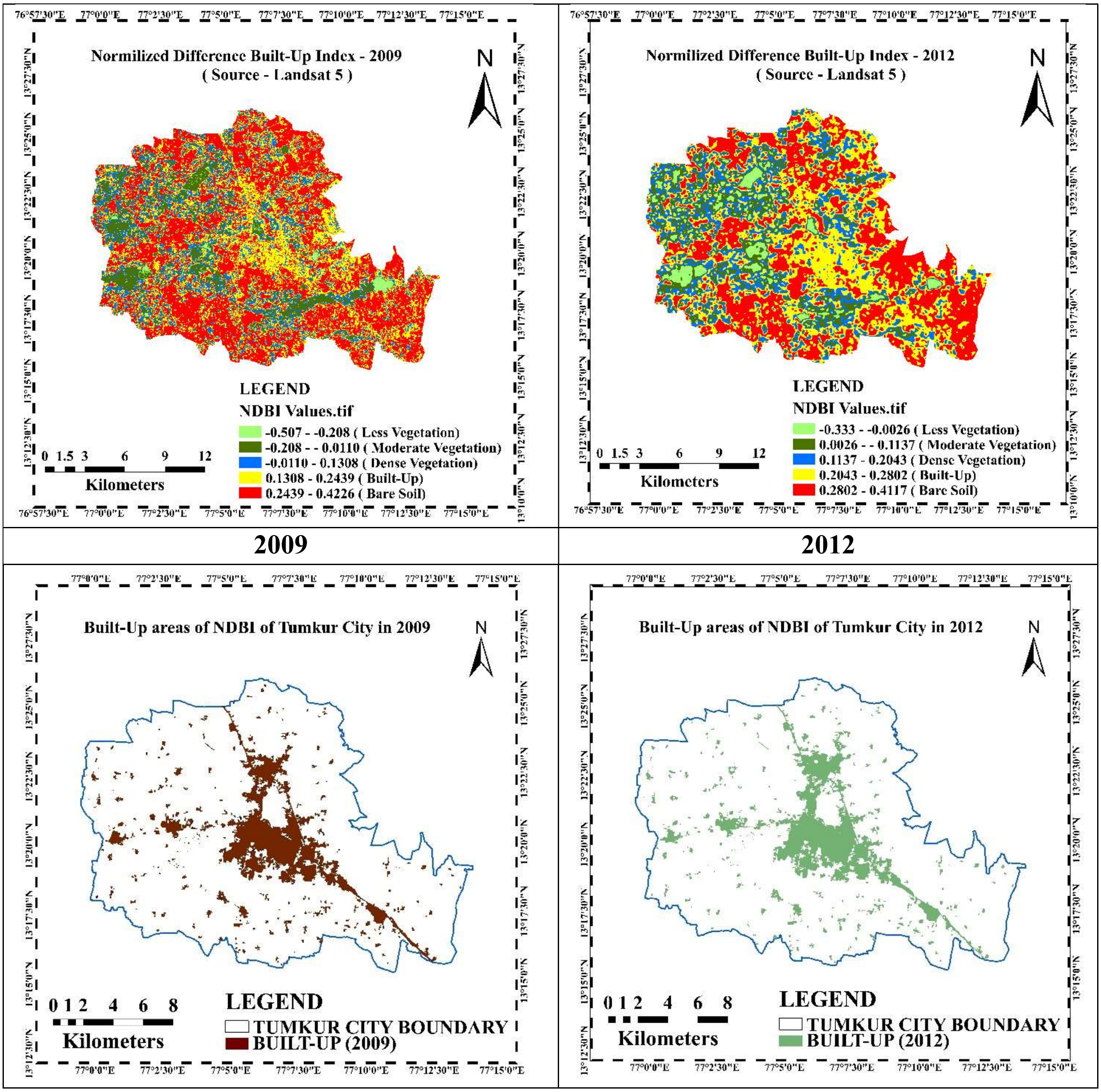

Normilized Difference Built-Up Index - 2009
(Source - Landsat 5)
LEGEND
NDBI Values.tif
-0.507 - -0.208 (Less Vegetation)
-0.208 - - 0.0110 (Moderate Vegetation)
-0.0110 - 0.1308 (Dense Vegetation)
0.1308 - 0.2439 (Built-Up)
0.2439 - 0.4226 (Bare Soil)
Kilometers
Normilized Difference Built-Up Index - 2012
(Source - Landsat 5)
LEGEND
NDBI Values.tif
-0.333 - -0.0026 (Less Vegetation)
0.0026 - - 0.1137 (Moderate Vegetation)
0.1137 - 0.2043 (Dense Vegetation)
0.2043 - 0.2802 (Built-Up)
0.2802 - 0.4117 (Bare Soil)
Kilometers
2009
2012
Built-Up areas of NDBI of Tumkur City in 2009
LEGEND
TUMKUR CITY BOUNDARY
BUILT-UP (2009)
Kilometers
Built-Up areas of NDBI of Tumkur City in 2012
LEGEND
TUMKUR CITY BOUNDARY
BUILT-UP (2012)
Kilometers

Figure Cont....

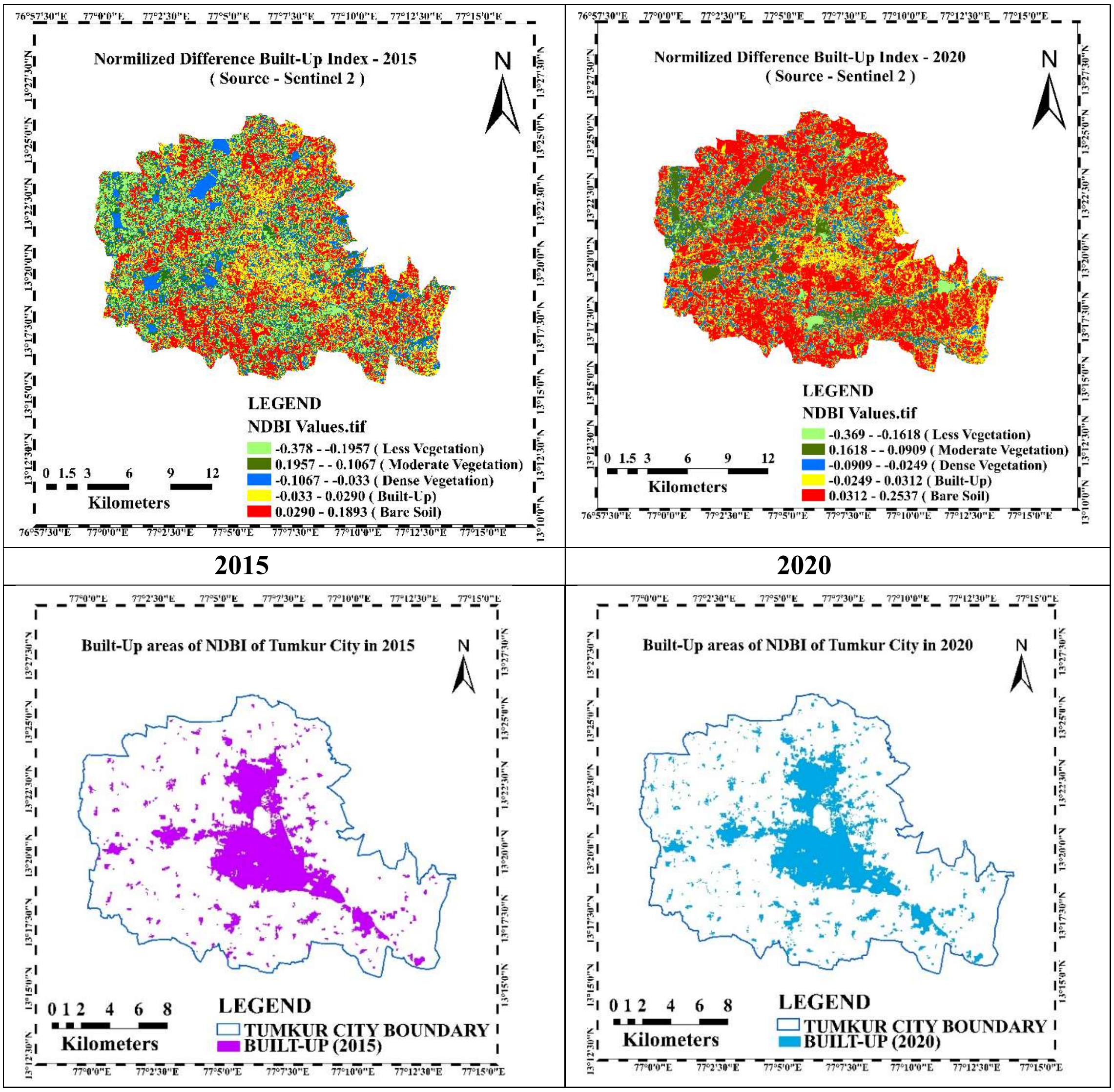


Fig. 10: NDBI and Built-up area map of NDBI in the Tumkur city area in (a) 2000, (b) 2005, (c) 2009 (d) 2012, (e) 2015, (f) 2020.

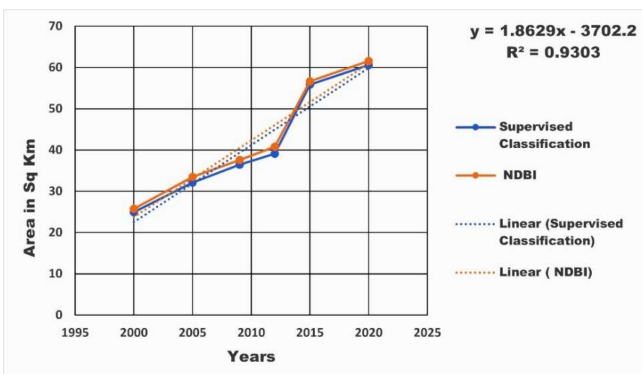


Fig. 11: Correlation Graph of Built-up areas of Supervised Classification and Built-up areas of NDBI.

Table 15: Population-level and growth rate for the Tumkur, from 2000 to 2020.

Year	Population Data	Growth Rate
2020	361,000	1.69%
2019	355,000	2.01%
2018	348,000	1.75%
2017	342,000	2.09%
2016	335,000	1.82%
2015	329,000	2.17%
2014	322,000	1.90%
2013	316,000	1.94%
2012	310,000	1.97%
2011	302143	2.01%
2010	298,000	1.71%
2009	293,000	2.09%
2008	287,000	2.14%
2007	281,000	1.81%
2006	276,000	1.85%
2005	271,000	1.88%
2004	266,000	2.31%
2003	260,000	1.96%
2002	255,000	1.59%
2001	248929	2.87%
2000	244,000	3.39%

(Source: United Nations population projections and Census of India 2011)

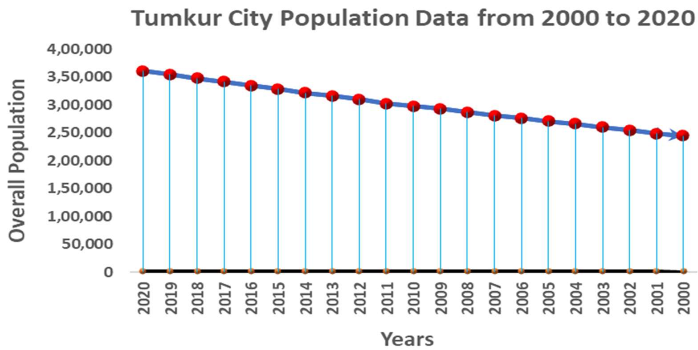


Fig. 12: Column graph of the Population growth rate of Tumkur City (2000-2020).

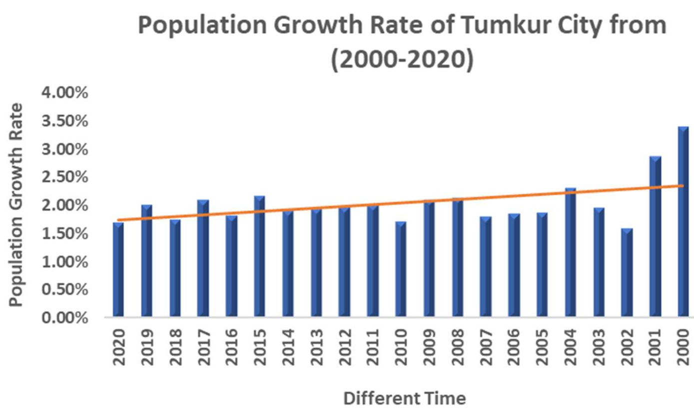


Fig. 13: Line graph of Tumkur City population data from (2000 to 2020).

Table 16: Population data and Built-up area of Tumkur City.

Year	Area (sq km^2)	Population Data
2000	24.94	244000
2005	32.10	271000
2009	36.47	293000
2012	39.08	310000
2015	55.85	329000
2020	60.59	361000

freedoms. Therefore, the demonstrated approach will benefit the cities in developing countries. According to the latest data collected by the Karnataka State Pollution Control Board (2018), Tumkur city is the first place in high air pollution cities in Karnataka. Tumakuru recorded a PM 10 level of 146 micrograms per cubic meter. The vehicular emissions and industrial emissions are the main reasons for the high pollution rate in Tumkur city.

Temporal Analysis of NDBI

An analysis of NDBI values in Tumkur between 2000 and 2020 is presented in Fig. 10. According to the NDBI indexes, the percentage of urban areas has increased significantly between these periods. Built-up areas of the core region have increased from 7.75 percent to 18.85 percent of the area. During 2000 the rural areas, where agricultural lands and vegetation are predominant, the NDBI index values were the lowest. Table 14 indicates that in the comparison between the two methods the built-up areas are almost the same and Fig. 11 shows a positive correlation between the two methods built-up areas. During the 2009 period, the expansion rate of urban areas in peripheral regions and industrial areas increases. During 2012 the agricultural land converted into built-up areas. A scattered settlement was converted into dense settlements during this period. From 2015 to 2020 NDBI values were very high in bare soil, and vegetation cover which indicated the conversion of water bodies, agricultural land, and vegetation into built-up areas in the form of large new layouts.

The statistics show a positive correlation between Built-up areas of NDBI and Supervised classification.

Population Data Analysis of Tumkur City (2000-2020)

According to Fig. 12 and Fig. 13, the population of Tumkur City in 2000 was 244,000, but in 2020 the population increased to 361,000. From 2000 to 2020, on average, every year, 5000 people were added to the list of population growth. Table 15 statistical analysis revealed that due to population growth, increased tremendously. The migration of people plays a major role in population growth apart from that, the growth of built-up areas in rural areas increased yearly. Table 16 statistics analysis revealed that population increases lead to causes of urban area growth.

CONCLUSION

The current study aims to investigate the urban growth of the Tumkur city using the retrieved spatial satellite data spanning two decades (2000-2020) using urban-related indices, and new statistical methods. The AUEII study revealed that the values of different years, like 2000, 2005, 2009, and 2012 are moderate, indicating the slow urban development activities present in Tumkur city. Year to year, the variation of built-up land occupancy due to sizeable agricultural land and vegetation cover converted into built-up areas. The UEII statistics show the expansion rate from 2000 to 2009 was a little slow later the growth of industries, implementation of various government infrastructure projects, and increasing population growth leads the expansion of built-up areas. The expansion of built-up land in rural areas gradually increases and leads to the destruction of vegetation like plantations and scrubland. During the expansion period large water bodies areas converted into built-up areas and agricultural land. The Normalised Built-up Index depicted that from 2000 to 2009 the peripheral region and rural areas had NDBI values low compared to the core of the city. After 2009 increasing built-up areas leads to increases in those areas. Pearson's Chi-square test and Shannon Entropy analysis revealed most urban sprawl appeared in the area. The degree of goodness is very which shows compactness in a few areas and expansion in a few regions. Finally, urban growth is the expansion of built-up due to population growth, destruction of agricultural land, and few water bodies. The degree of goodness model can be regarded as a sustainable development index and constitutes a vital tool for future researchers. Using these scientific conclusions of the study area's planners/ decision makers, and urban designers will maintain that sustainable urban development strategies for controlling the presence of an environmental imbalance in cities and to implement ecological sustainability plans will improve the living conditions of future generations in cities.

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