Spatiotemporal Patterns of Urbanization in Chennai City, Tamil Nadu, India Using Remote Sensing Data

M. B. Sridhar and R. Sathyanathan

Abstract Rapid urbanization in developing countries is leading to urban sprawl along the fringes of the cities. The land use of the regions surrounding the Chennai metropolitan area is changing drastically. It is vital to monitor and quantify the land-use change and the urban expansion process to achieve cities with proper planning, efficiency and sustainability. This paper aims to determine the land-use change in the study area for the years 1998, 2009 and 2019 using remote sensing data. Shannon's entropy was utilized to assess the nature of urban growth happening in the study area. The study region was divided into 50 zones of concentric circles drawn from the central business district point. The rate of urbanization in each zone shows gradual increasing trend from 2009 to 2019, moving outwards with a maximum value of 36.9% in the last zone. Whereas from 1998 to 2009, the rate of urbanization increases rapidly to attain a maximum value of 85.6% in the 31st zone and thereafter the value got decreased. Relative Shannon's entropy asserted that the city displayed a dispersed development from a distance of 12, 14 and 18 km from the city centre for the years 1998, 2009 and 2019, respectively.

Keywords Urbanization · Shannon's entropy · Relative Shannon entropy · Urban sprawl

1 Introduction

There is a large-scale shifting of rural population to urban population worldwide. Especially in developing countries, the shift is profound. The urban cities are expanding beyond their geographical limits. Rapid urbanization has caused radical changes in the landscapes [1]. Historically, urbanization is the biggest driver of land

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use land cover changes [2]. Changes in land cover and rapid urbanization results in food and water scarcity, environmental deterioration, loss of farming lands, demolition of forests, encroachment of waterways and surface water bodies, changes in biotic diversity. These changes cannot be well understood without the knowledge of urbanization that causes them.

The development of a scattered and isolated piece of land surrounded by vacant lands is considered urban sprawl [3]. Ewing et al. [4] state sprawl as strip development along highways and leapfrog includes low density urban developments. Remote sensing has been extensively used to facilitate the studies related to land use land cover changes, urban growth and sprawl identification [5]. Thematic images from satellite data are availed to understand the land use land cover changes occurring over time [6–8]. While classifying the images, impervious land surfaces such as buildings, pavements and other infrastructure facilities are mapped as urban areas [9]. The extent of urban land cover change over the decadal period was determined using land cover analysis. Many metrics were proposed to differentiate, identify and quantify the nature of urbanization. Urbanization can be either of compact nature or sprawling nature. Compact development is considered sustainable and a desired way of urbanization, whereas sprawling is considered as an undesired way of urbanization. The lack of consensus in the definition of sprawl has made its quantitative measurement a problematic task. The relative comparison of the quantified sprawl values among different cities have also been hindered by the lack of consensus and definitive technologies [10]. Spatial metrics such as percentage of landscape, largest patch index, patch density, edge density, patch cohesion index and landscape shape index are being utilized to evaluate the nature of the urbanization [11–13].

Shannon's Entropy is a spatial metric widely used to measure urban sprawl [1, 14–17]. It is used to measure the degree of dispersion among the variables. Shannon's entropy value helps to understand better the nature of urbanization, viz., compact or dispersed (sprawl).

In this study, Shannon's entropy is utilized to study the nature of urbanization happening in the Chennai city, Tamil Nadu, India for a decadal period (1998–2009). Relative Shannon entropy is used to determine the zone in which the transition of urban development from compact to sprawl happened for each decade.

2 Study

Chennai is the capital of the state of Tamil Nadu in India. It is situated on the east coast of India at a latitude and longitude of 13.0827° N, 80.2707° E. Established as Madras corporation in 1688, Chennai is the oldest municipal body in India. As per the 2011 census, the Chennai district covered an area of 178.2 km^2 and a population of 4.64 million. (Fig. 1) shows the shapefile of Chennai administrative boundary as per census 2011 along with the 50 km radial buffer. The study area considered covers an area of 4088 km^2.

Fig.1 Study region for
Chennai
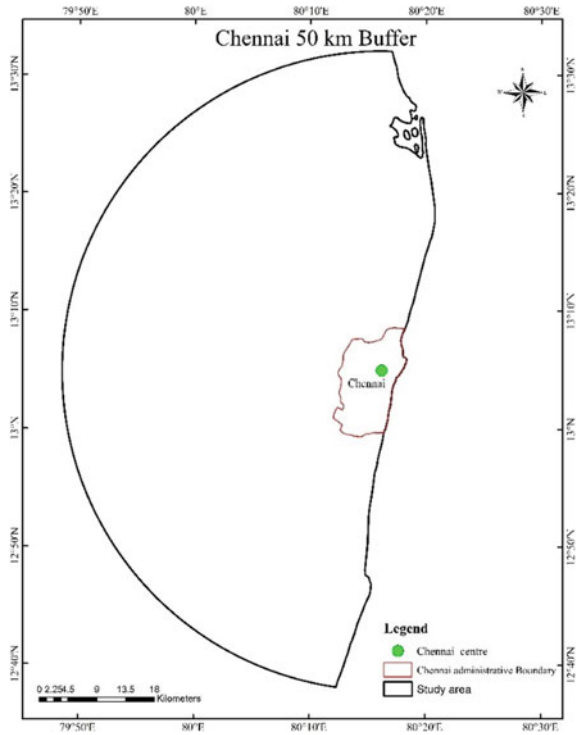
3   Methodology

The satellite images were projected to UTM (WGS-84) coordinate system. The
satellite images were enhanced by edge enhancement. The study region is extracted
from the enhanced satellite images. A combined classification technique is utilized to
classify land use land cover into five categories, viz., water bodies, urban, vegetation,
agriculture and barren. Unsupervised classification is performed to divide the satellite
images into 100 bands. Each band is then manually evaluated with the ground truth
data and it is recoded into one of the mentioned classes. This method of classification
has produced higher user's accuracy.

3.1   Shannon's Entropy

The study region was divided into 50 zones of concentric circles with a 1 km incre-
mental radius. The concentric circles are drawn from the centre of Chennai at a
latitude and longitude of 13.0827° N, 80.2707° E. Each circle is clipped with the
study area shapefile so that only a portion of the concentric circles that cover the

Fig. 2 50 zones of the study region
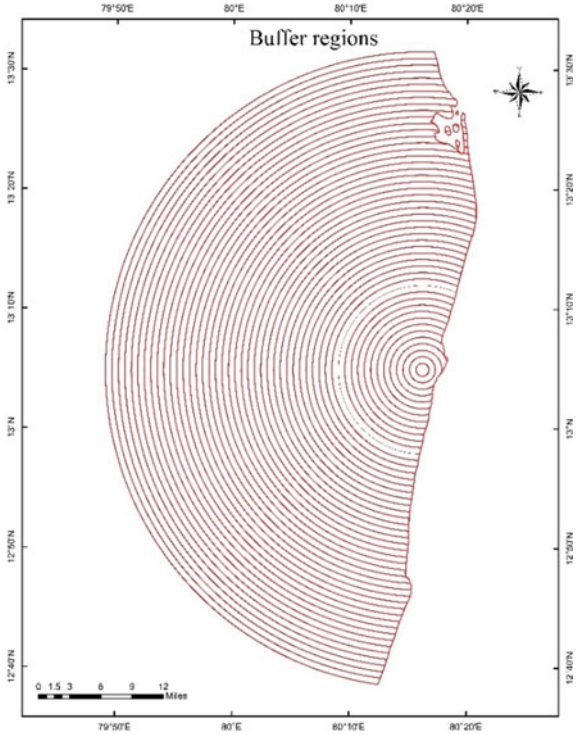
land area is retained for the study purpose. The 50 zones which are considered for this study are given in (Fig. 2).

Shannon's entropy gives the measure of variability among the variables possible outcomes [18].

$$H_n = \sum_{i=1}^{n} P_i \log(P_i)$$

P_i is the proportion of the build-up area in the ith zone, n represents the number of zones. P_i is the ratio between the urban area in the ith zone to overall urban area. The value of Shannon's entropy varies from 0 to log n. The values closer to 0 indicates compact development and the values closer to log n indicate dispersed development. As the number of zones considered for this study is 50, the log n value corresponding to log 50 is 1.69897.

3.2 Relative Shannon Entropy

Relative Shannon entropy is calculated using the formulae [10]

$$H'_n = \frac{H_n}{\log_e(n)}$$

H_n is the Shannon entropy value and n represents the number of zones. The value of relative Shannon entropy varies between 0 and 1. 0.5 is considered as the threshold that differentiates compact development and urban development. The zone at which this threshold point is reached is generally measured to identify the location after which sprawl occurs.

4 Results and Discussions

4.1 Land Use Land Cover (LULC) Classification

The land use land cover classification for the years 1998, 2009 and 2019 is depicted in the (Figs. 3, 4 and 5). It is observed that the urban area has increased by 71.77% between 1998 and 2009 and 36.91% between 2009 and 2019. There is a reduction in the land areas covered by water bodies, vegetation, agriculture and barren land over the last 20 years. Table 1 illustrates the area of various LULC for the years 1998, 2009 and 2019.
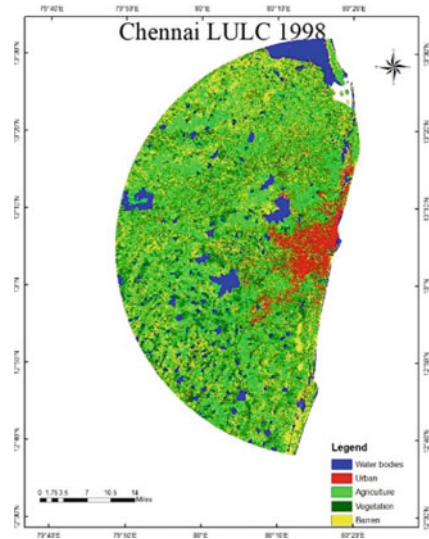
Fig. 3 LULC of 1998

Fig. 4 LULC of 2009
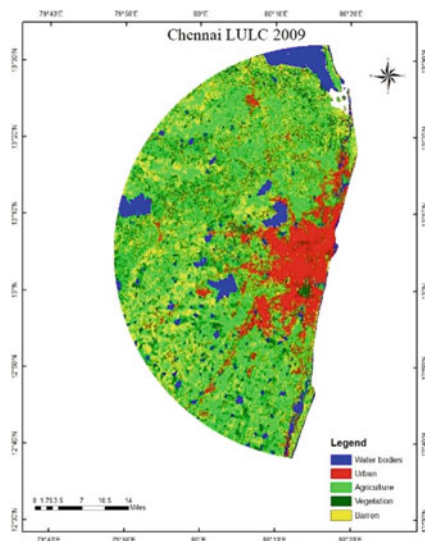
Fig. 5 LULC of 2019
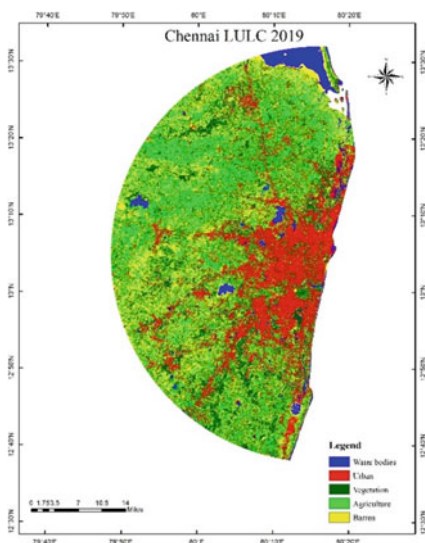
Table 1 Results of land use land cover analysis

Land class\year	1998 (km^2)	2009 (km^2)	2019 (km^2)
Water bodies	357.319	295.478	161.345
Urban	363.632	624.619	855.180
Agriculture	1323.660	1543.035	1189.660
Vegetation	976.088	617.224	862.838
Barren	1067.950	1008.294	1019.627
Total	4088.65	4088.65	4088.65

4.2 Urban Area

The land use land cover image is cropped for each zone and each year separately. The urban area is determined for all the 50 zones of each year. The difference between the urban areas for 1998 and 2009 for the first eight zones was less than 10%. There was a profound difference in the urban areas of 1998 and 2009 from zone 9 onwards. The urban area difference, which was 12% in zone 9, steadily increased to a difference of 85% in zone 26. The minimum difference in the early years is because the central core areas have already been urbanized to the maximum extent. Most of the urbanization between 1998 and 2009 has happened from zone 9 to zone 26. In other words, maximum urban development was witnessed between 9 and 26 km from the centre of the city. In contrast, the urban difference between 2009 and 2019 is evenly spread among all the zones. The urban difference has gradually increased and reached a maximum of 36% in the last designated zone. The nature of urban growth also gradually increases from the centre zones to the peripheral zones. This highlights that the outer edges of the city are getting urbanized at a rapid phase. The comparison of the urban area in each zone for the three different years is represented in (Fig. 6).
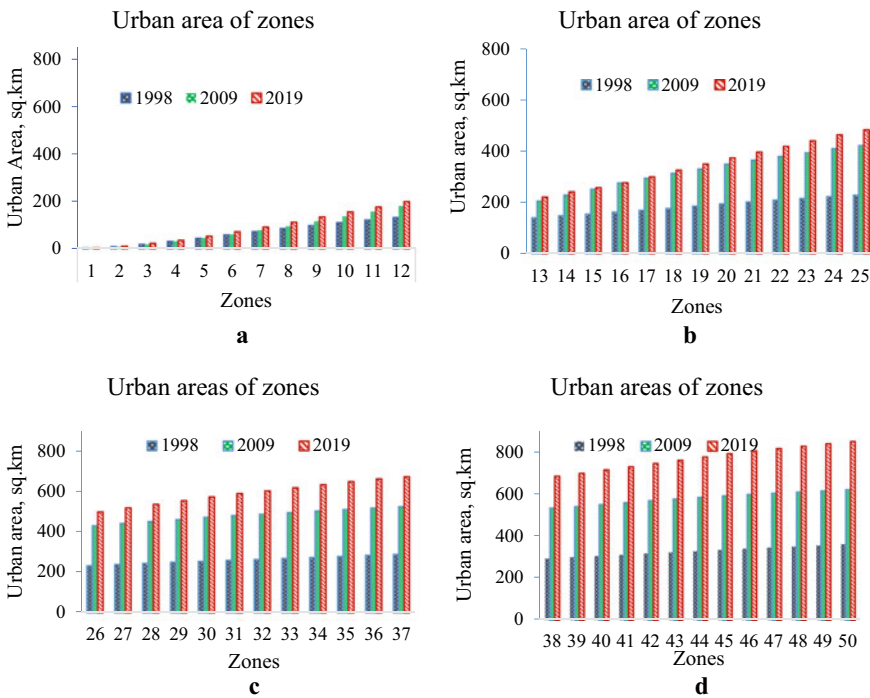

Fig. 6 **a** Urban area comparison, 1–12 zones, **b** Urban area comparison, 13–25 zones, **c** Urban area comparison, 26–37 zones, **d** Urban area comparison, 38–50 zones

4.3   Shannon Entropy

The Shannon entropy value up to each zone for the three different years (1998, 2009 and 2019) is given in (Table 2). The Shannon entropy values for the entire region are 1.668, 1.650, 1.680 for the years 1998, 2009 and 2019, respectively. The study region being huge, the direct interpretation of the Shannon entropy value would not convey the necessary understanding. The values of 1.668, 1.650 and 1.680 are very near to the maximum possible value of log n (1.69), which interprets the likelihood of maximum sprawl for all three years.

The Shannon's entropy value of the three years for different zones is depicted in (Fig. 7). It is evident the Shannon entropy value got reduced in the year 2019 when compared to 1998 and 2009, which envisages that urban development has become more compact from 2009 to 2019.

4.4   Relative Shannon Entropy

Relative Shannon entropy is adopted to find the pattern of growth. Generally, 0.5 is considered as the threshold relative Shannon entropy value. If the entropy value is less than 0.5, it is considered as compact development. If the value of entropy is more than 0.5, it is considered as disperse [19]. Table 3 gives the zones at which the threshold value had reached for the examining years. In 1998, sprawling development happened after zone 12; in 2009 and 2019, it had happened beyond zone 14 and zone 18, respectively.

From this, it is evident that the distance from the city centre to the point where the compact urban development happened had also increased over the years. In 1998, the compact urban development was witnessed till 12 km radius, and in 2009 and 2019, it was witnessed upto 14 km and 18 km radius, respectively, from the city centre. The important location names are represented along the threshold boundaries in (Fig. 8).

5   Conclusion

This study investigated the nature of urbanization happening in the city of Chennai. Remote sensing data combined with Shannon's entropy facilitates the measurement of spatial extents of urbanization pattern. The calculated land cover analysis indicated that the rate of urbanization during the years 1998 to 2009 was 71.77%, whereas it was 36.91% for the years between 2009 and 2019. Further, the study region was divided into 50 zones of concentric circles with a 1 km incremental radius to determine the zonal urbanization. Urbanization during the years 1998 to 2009 had increased more than 50% for each zone from zone 14 onwards, and for the years 2009 to 2019, a gradual increase in urbanization was witnessed for each zone, with a maximum of

Table 2 Shannon entropy and relative Shannon entropy value for 50 zones

Zones	Shannon entropy (H_n)			Relative Shannon entropy (H'_n)		
	1998	2009	2019	1998	2009	2019
1	0.012	0.008	0.008	–	–	–
2	0.043	0.029	0.026	0.142	0.095	0.086
3	0.085	0.058	0.052	0.178	0.122	0.109
4	0.134	0.091	0.081	0.223	0.151	0.134
5	0.187	0.128	0.114	0.268	0.183	0.163
6	0.244	0.168	0.150	0.313	0.216	0.193
7	0.297	0.211	0.188	0.352	0.249	0.223
8	0.348	0.255	0.227	0.386	0.282	0.251
9	0.400	0.303	0.268	0.419	0.317	0.280
10	0.449	0.353	0.309	0.449	0.353	0.309
11	0.494	0.401	0.347	0.474	0.385	0.333
12	0.539	0.455	0.389	0.499	0.422	0.361
13	0.578	0.510	0.430	0.519	0.458	0.386
14	0.614	0.564	0.469	0.536	0.492	0.409
15	0.645	0.616	0.502	0.548	0.524	0.427
16	0.681	0.671	0.539	0.566	0.557	0.447
17	0.714	0.717	0.581	0.580	0.583	0.472
18	0.748	0.763	0.627	0.596	0.608	0.500
19	0.787	0.806	0.671	0.615	0.630	0.525
20	0.826	0.851	0.715	0.635	0.654	0.550
21	0.862	0.892	0.756	0.652	0.674	0.572
22	0.895	0.930	0.798	0.667	0.693	0.594
23	0.927	0.968	0.839	0.681	0.711	0.616
24	0.960	1.009	0.881	0.695	0.731	0.639
25	0.989	1.041	0.919	0.707	0.745	0.657
26	1.017	1.072	0.955	0.719	0.758	0.675
27	1.048	1.104	0.994	0.732	0.771	0.694
28	1.076	1.132	1.028	0.744	0.782	0.710
29	1.103	1.160	1.063	0.754	0.793	0.727
30	1.128	1.192	1.100	0.764	0.807	0.745
31	1.152	1.218	1.133	0.773	0.817	0.760
32	1.176	1.240	1.163	0.781	0.824	0.772
33	1.201	1.264	1.193	0.791	0.832	0.786
34	1.228	1.287	1.225	0.802	0.840	0.800
35	1.254	1.311	1.256	0.812	0.849	0.813

(continued)

Table 2 (continued)

| Zones	Shannon entropy (H_n)			Relative Shannon entropy (H'_n)		
	1998	2009	2019	1998	2009	2019
36	1.279	1.333	1.284	0.822	0.857	0.825
37	1.304	1.354	1.308	0.832	0.863	0.834
38	1.329	1.378	1.333	0.841	0.873	0.844
39	1.356	1.401	1.362	0.852	0.880	0.856
40	1.384	1.429	1.395	0.864	0.892	0.871
41	1.415	1.455	1.425	0.877	0.902	0.884
42	1.445	1.483	1.458	0.890	0.914	0.898
43	1.473	1.508	1.490	0.902	0.923	0.912
44	1.500	1.531	1.521	0.913	0.932	0.926
45	1.529	1.554	1.554	0.925	0.940	0.940
46	1.558	1.575	1.582	0.937	0.947	0.951
47	1.585	1.594	1.606	0.948	0.953	0.960
48	1.610	1.612	1.630	0.957	0.959	0.970
49	1.638	1.632	1.656	0.969	0.965	0.980
50	1.668	1.650	1.680	0.982	0.971	0.989
Overall	1.668	1.650	1.650			
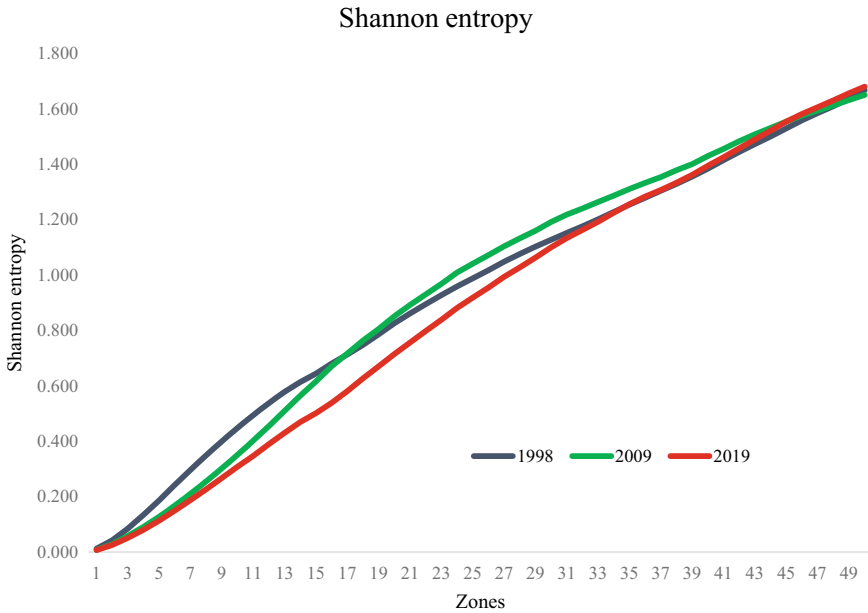
Fig. 7 Shannon entropy for the various zones in 1998, 2009 and 2019

Table 3 Threshold distance

Years	The distance at which threshold is reached (km)
1998	12
2009	14
2019	18

Fig. 8 Threshold boundaries for years 1998, 2009 and 2019
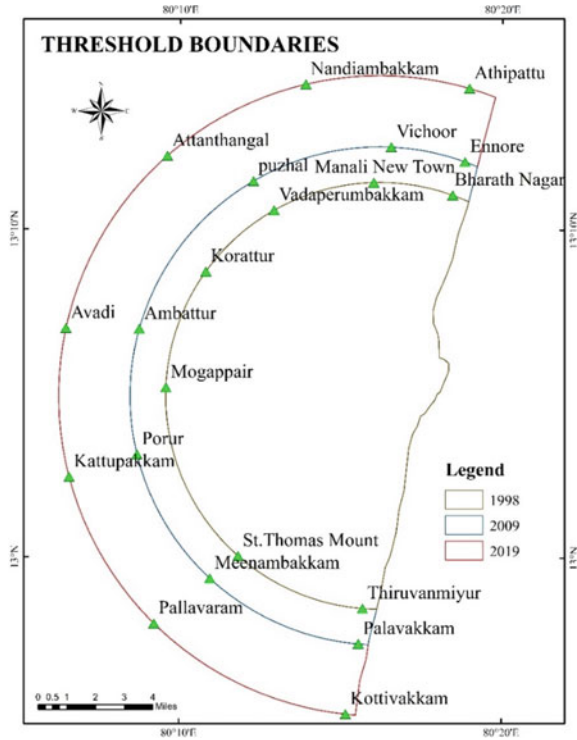
36% in the 50th zone. From the threshold Shannon entropy value, it was observed during the year 1998 the Chennai city has undergone compact development up to 12 km radius from the city centre and sprawl development beyond that. Similarly, in the year 2009, there was a compact development up to 14 km radius, and for 2019, the compact development was up to 18 km radius from the city centre. The exterior regions of the city beyond the administrative district boundary are undergoing rapid urbanization, which requires proper planning and regulation of urban development. Comparing the Shannon entropy values for the three years, it was observed that the urban development had become more compact during 2019.

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