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SPATIO-TEMPORAL ANALYSIS FOR MONITORING URBAN GROWTH - A CASE STUDY OF INDORE CITY

J. ANTONY VINOTH KUMAR*, S.K. PATHAN*@ AND R.J. BHANDERI**
*Land Use Planning and Photogrammetric Division, Forestry, Land Use and Photogrammetric Group, Space Applications Centre (ISRO), Ahmedabad – 380 015, India
**Remote Sensing Applications and Image Processing Area, Space Applications Centre (ISRO), Ahmedabad – 380 015, India
@Corresponding author : subhan_kp@sac.isro.gov.in

ABSTRACT

Urban sprawl is characterized by haphazard patchwork of development, which leads to an improper development in any city. To prevent this kind of sprawl in future, it is necessary to monitor the growth of the city. Hence, an attempt has been made in the present study to monitor the urban growth over a period of time by employing Remote Sensing and Geographic Information System techniques in conjunction with Shannon entropy. Shannon entropy is a measure to determine the compactness or dispersion of built-up land growth in the urban areas. The growth patterns of urban built-up land have been studied initially by dividing the area into four zones. The observations have been made with respect to each zone. Then, the study area has been divided into concentric circles of 1 km buffers and the growth patterns have been studied based on urban built-up density with respect to each circular buffer in all four zones. These observations have been integrated with road network to check the influence of infrastructure on haphazard urban growth. It has been found from the study that Shannon entropy is a good measure to determine the spatial concentration or dispersion of built-up land in the city. The study also proved the potential of RS and GIS techniques in the spatio-temporal analysis of urban growth trends and their consequences in the lands adjoining to urban areas.

Introduction

Rapid urbanisation in the world is quite alarming, especially, in developing countries like India. Urbanisation is a process through which the productive agricultural lands, forests, surface water bodies and groundwater prospects are being irretrievably lost (Pathan *et al.*, 1989, 1991). This is

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mainly due to uncontrolled population growth resulting in serious problems viz. scarcity of food, informal settlements, environmental pollutions, destruction of ecological structure, unemployment, etc. (Maktav and Erber, 2005). This kind of uncontrolled, haphazard, low density human settlements will lead to urban sprawl. Urban sprawl, which is characterized by haphazard patchwork of development leads to an improper development in any city usually happens due to land-use/land cover conversion in which the growth rate of urbanised land significantly exceeds the rate of population growth over a specified time period, with a dominance of low-density impervious surfaces (Barnes *et al.*, 2000).

In India, the percentage of people living in cities and urban area has almost doubled to 27.8% in 2001 from 14% at the time of independence. This is expected to accelerate even further, and by 2021 over 40% of people will be in urban areas (GGIM, 2005; Census of India, 2001). To sustain this rapid urban growth, development should be planned in a sustainable manner to fulfill all the facilities like infrastructure, drainage, water supply, sanitation etc., For the purpose of sustainability; urban areas have to be properly monitored to maintain an internal equilibrium (Barredo and Demicheli, 2003). Taking it into account for future planning or urban development, the administrators and planners should have the knowledge of the present trend of urban growth. Therefore, to understand the urban growth the city should be properly monitored from the past to present through different time series data. It is primarily because the information on the existing land cover/land use plays a major role for urban planning and management (Zhang *et al.*, 2002). One of the important methods used for the time series analysis is "Density Gradients" of built-up land as they are potentially useful indices of measuring urban development (Torrens and Alberti, 2000). Keeping this in view, the present study is an attempt to monitor the urban growth over a time based upon density gradient method and evaluate its usefulness to monitor the urban dynamics with a specific case study.

Study Area and Methodology

Indore is situated almost centrally on the fertile Malwa plateau with its cardinal points 22° 43' N and 76° 42' E with an altitude of 602 m above mean sea level. It is the fast growing city in the Malwa region. The population of the city has increased from 5.75 lakh in 1971 to 15.97 lakh in 2001 (Census of India, 2001) registering a growth of nearly 300%. In view of the fact that there would be double the growth in next 20 to 25 years, Indore is primarily suited for our study.

Remote sensing techniques have already shown their importance in mapping urban land use/land cover, urban growth trends, and to monitor the changes in land use/land cover (Pathan *et al.*, 1993, 2004; Donnay *et al.*, 2001). It is a powerful tool for monitoring rapid changes in the landscape resulting from urban development (Alberti *et al.*, 2004) and capable of detecting and measuring a variety of elements relating to the morphology of cities (Yeh and Liu, 2001). It can provide useful information about land use patterns and their changes (Li and Yeh, 2001). Based upon these studies, a methodology has been worked out to carry out the spatial-temporal analysis of the growth of an urban area.

The entire study area of Indore city and its environs covering 822.42 km^2 has been divided into four rectangular zones taking Central Business District (CBD) of Indore city as the centre point. These are named as zone-1, 2, 3 and 4 representing all four directions (Northwest-NW, Northeast-NE, Southeast-SE and Southwest-SW), respectively. The growth of built-up land over time was monitored zone wise. In each zone, the percentage density of urban built-up was calculated for different periods. Later, the entire study area was also divided into concentric circles of 1 km radius from the centre of the city employing GIS techniques. The built-up land density in each concentric circle has been monitored through time series analysis. This was integrated with zone wise road density to study the impact of infrastructure development on urban

growth. Finally, the growth of urban built-up land and growth rate for different periods has been calculated. In addition to this, the population growth rate was also calculated. To find out the compactness or dispersion of the urban development, an integrated analysis has been carried out. To measure the compactness or dispersion of urban built-up, Shannon entropy method (Yeh and Liu, 2001; Li and Yeh, 2004; Lata *et al.*, 2001; Sudhira *et al.*, 2004) was adopted. Shannon's entropy (H_n) can be used to measure the degree of spatial concentration or dispersion of geographical variable (x_i) among 'n' concentric circles.

$$H_n = \sum_{i=1}^{n} p_i \log(1/p_i) \quad (1)$$

where, p_i is probability or proportion of a phenomenon (variable) occurring in the i^{th} concentric circle it can be found out through $\left(p_i = x_i / \sum_{i}^{n} x_i\right)$ where x_i is the observed value of the phenomenon in the i^{th} concentric circles and n is the total number of zone circles. As per Shannon entropy, if the distribution is maximally concentrated in one circle, the lowest value zero will be obtained. Conversely, an evenly distribution among the concentric circles will give a maximum of log n.

Results and Discussions

Shannon entropy was calculated using the approach mentioned under methodology for the years 1990, 1996 and 2000. The entropy values are presented in Table 1. From this table, one can notice that the entropy values are ranging from 0.657 to 0.989. Higher the value, higher is the dispersion i.e. sparse development. Less the entropy value, more is the compactness of the development. The calculated Shannon's entropy in the city confirms that the development of urban built-up land is sparse and leading to haphazard urban growth in the city, particularly in the fringes (peripherals of the city and rural-urban zones). In order to ascertain the validity of Shannon entropy, a detailed study related to the growth of urban built-up land and population growth has been carried out. The results are summarized in the subsequent paragraphs.

Table 1: Shannon entropy for different periods

Year	Entropy	Log (n)
1990	0.657	1.114
1996	0.925	1 279
2000	0.990	1 279

The per cent density of urban built-up calculated in each zone over a period of four decades is presented in Fig. 1. From this figure, it has been observed that the urban development through time was almost uniform in all zones except in Zone-4 in the year 2000. However, this phenomenon is not true when the built-up density has been studied in each concentric circle of 1 km radius. There is a lot of variation in the urban development between the concentric circles. In general, the built-up land density should keep reducing as the distance increases from the centre of the city. However, in the present study, it has been observed that the growth of urban or built-up density has reached its maximum in the first three circles itself. The details are as follows.

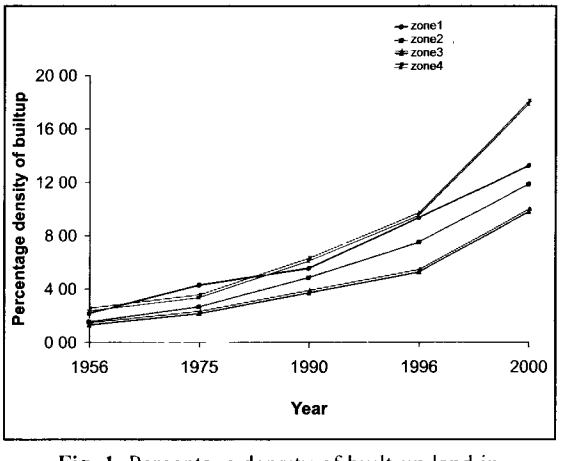

Fig. 1. Percentage density of built-up land in different zones

In any urban area, a state of 100% urbanisation can be achieved under unconstrained conditions and characterized by a completely built-up landscape (Dietzel *et al.*, 2005). In order to evaluate this phenomenon, the urban built-up land density over a period of time has been worked out with respect to all four zones and it is presented in Fig. 2. From this figure, one can observe that the urban built-up density or the development has reached only by 5 km in zone-1 by 1956 and the development has reached to 17 km by 2000, particularly during 1996-2000 periods. A similar trend has been observed even in zone-2 except some variation in the pattern of development. However, in zone-3, it has been noticed that the development lacks continuity during 1956 to 1975 between 4 and 7 km. After 1975, the sparse built-up land got densified and it is totally occupied by the built-up land up to 17 km and a sparse development in the region between 17 and 18 km.

In zone-4, it has been observed that there is a discontinuous development during the period 1990 to 1996 up to 11 km. However, the built-up density has been increased during the period 1996 to 2000. Therefore, this zone has registered maximum urban sprawl compare to other zones.

In order to find out the driving forces of this kind of development, an attempt has been made to calculate the zone wise road density. The road density (RD) has been calculated using the simple density formula.

$$RD = \frac{RL}{TA} \times 100$$

where, RL is Total Road length and TA is Total Area for the given zone. The transportation network map showing the spatial distribution of road network (Fig. 3). Zone wise road density for the two different

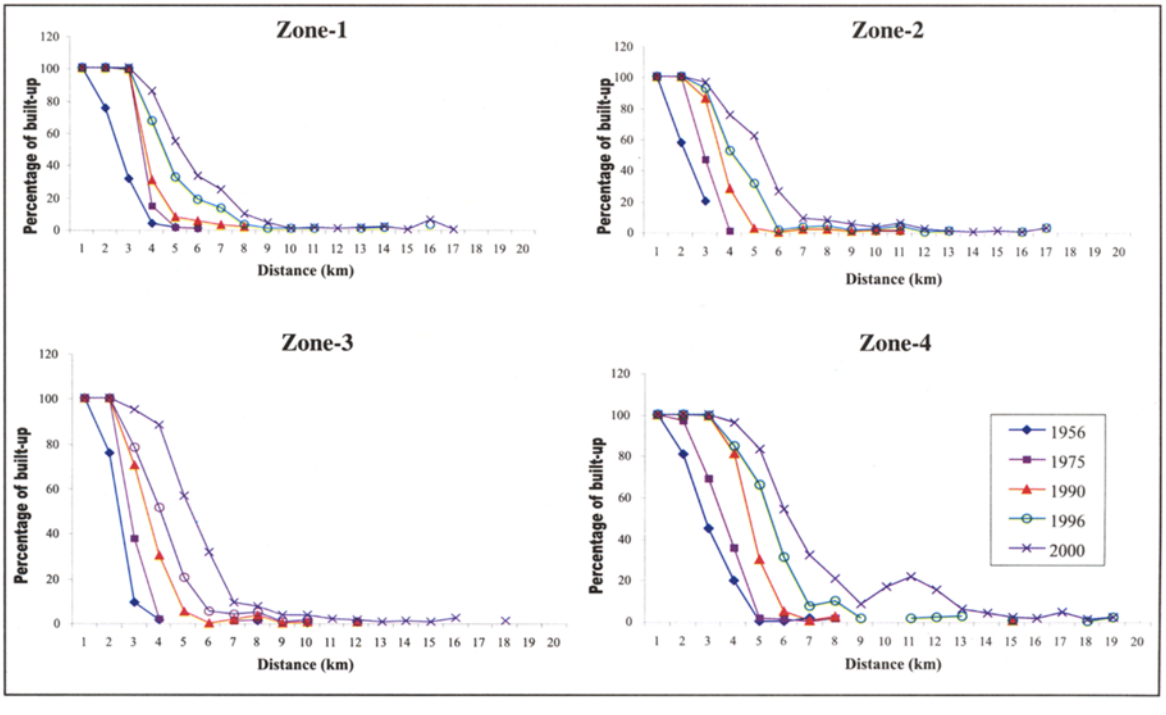

Fig. 2. Percentage built-up land densities in each zone for 1 km interval

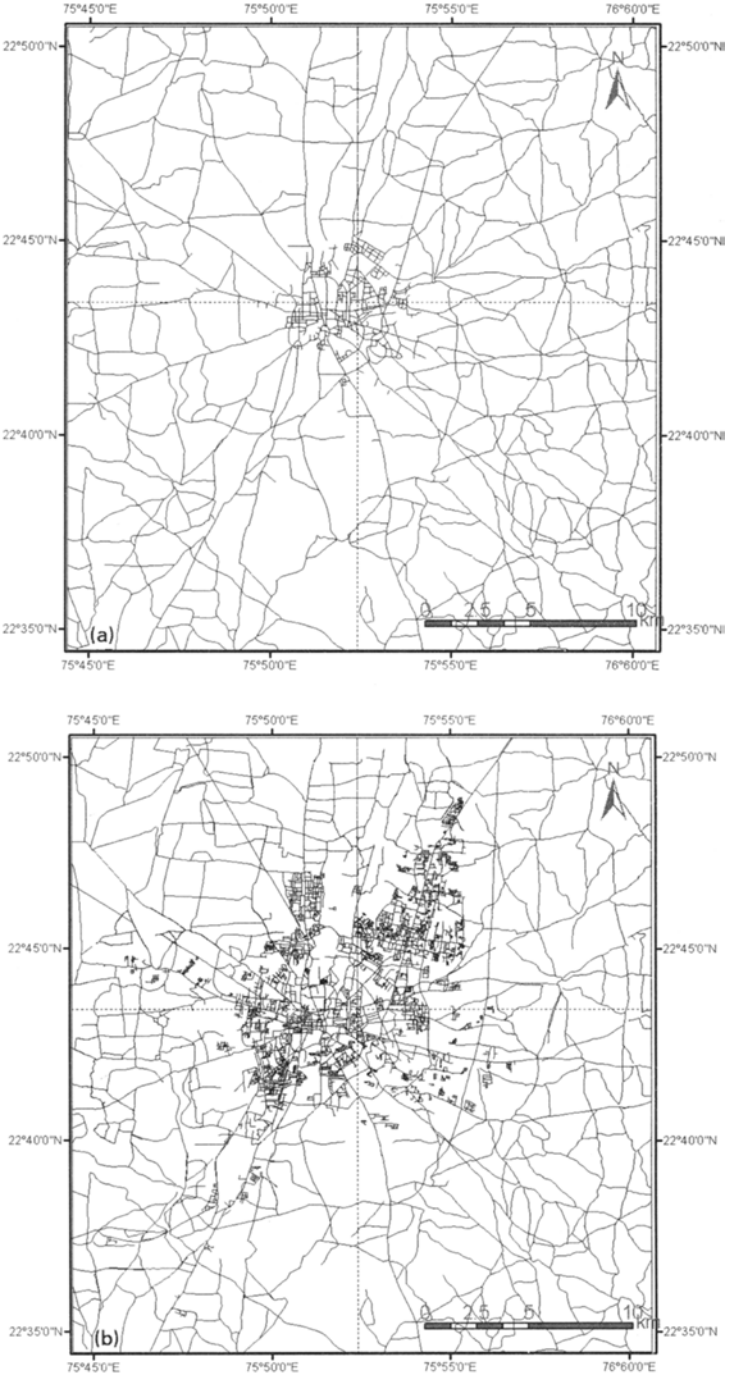

Fig. 3. Spatial distribution of road network in year 1975 (a) and the year 2000 (b)

periods is shown in Fig. 4. It has been observed from these figures that there is a lack of development in the infrastructure in zone-3 compare to other three zones.

To monitor the urban growth dynamics, the urban built-up density was plotted on the concentric circles created using GIS. This is done primarily to study the direction of development and is presented in Fig. 5. From this figure, it has been observed that the development is taking place in a linear fashion

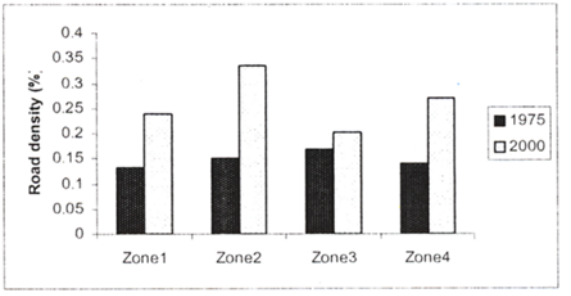

Fig. 4. Road density in different zones in percentage

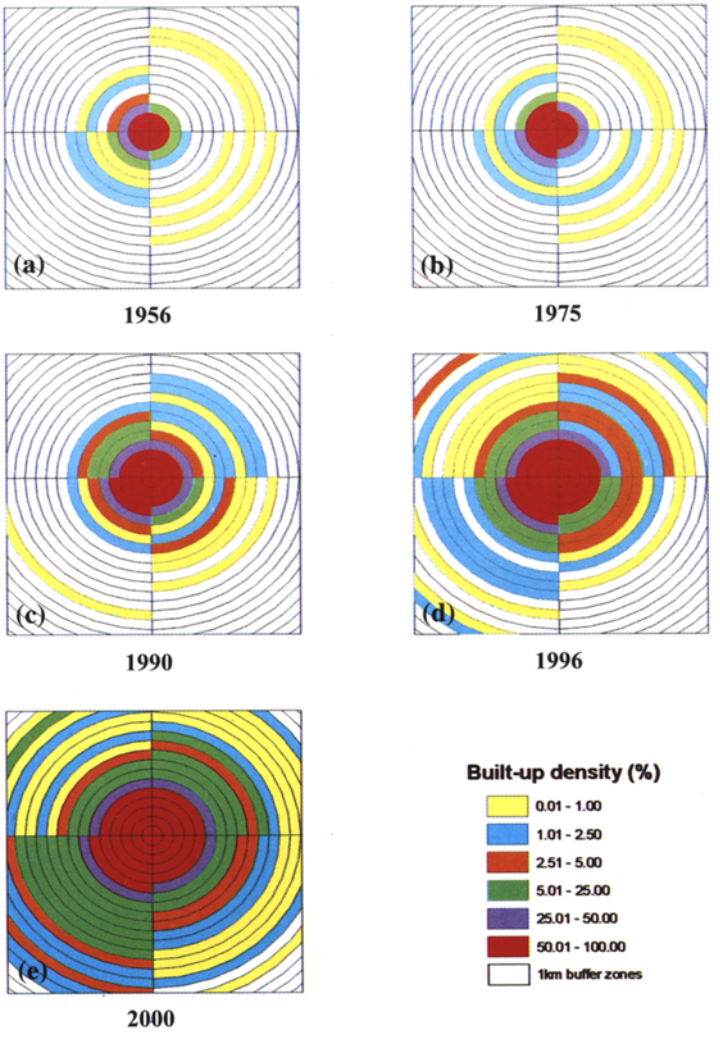

Fig. 5. Spatial distribution of urban built-up land in the years (a) 1956, (b) 1975, (c) 1990, (d) 1996 and (e) 2000.

between zone-1 to 4 (between 1956 and 1975). In addition to this, it has also been seen that there is an increase in per cent density of built-up land. But during the year 1975 to 1990, the development of built-up land has changed the direction and it is more towards the zone-2 i.e. on the NE direction with some isolated development in zone-4. After 1990, the development was almost in all directions but still the density is more in zone-2 and zone-4. The development during 1996 to 2000 was quite evenly distributed in all directions with some low-density sprawl in the fringes. This type of development is primarily attributed to the alignment of AB (Agra - Bombay) road in the city. This clearly states that the infrastructure development leads to the increase of built-up density in addition to the setting up of new industries, public, semi-public utilities, recreational areas etc.

This development has been compared with land use/land cover map of Indore city prepared using satellite data of year 2000 (Fig. 6). This figure confirms the development due to the location of industries in zone-2 on the urban fringe, which might have influenced the development of urban built-up and increase built-up density. The physical growth of urban built-up land over a period of four decades has also been studied with the help of maps prepared using SOI maps and Satellite data and is presented in Fig. 7. This has been integrated with

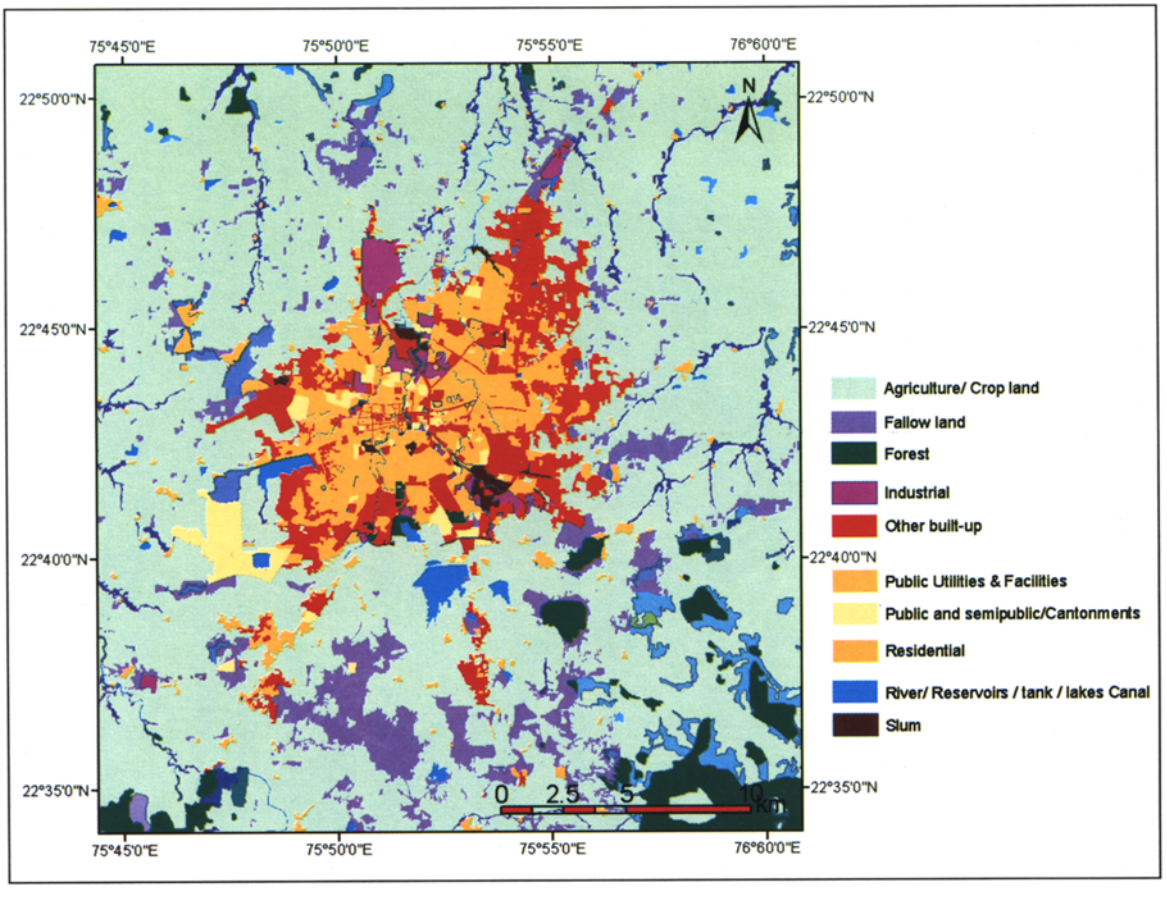

Fig. 6. Spatial extent and distribution of Land use/Land cover in the year 2000

the four zones and evaluated. It has been observed that the urban built-up growth has taken place more in zone-2 and zone-4 and less in zone-3 (Fig. 8). A comparative study between the population growth and built-up land density has also been carried out and is shown in Fig. 9. From this figure, one can notice that there is one to one correspondence between the population and built-up growth. But, during the period from 1996 to 2000, the built-up growth rate has increased than the population growth rate. This indicates the sparse development in the fringe areas of the city.

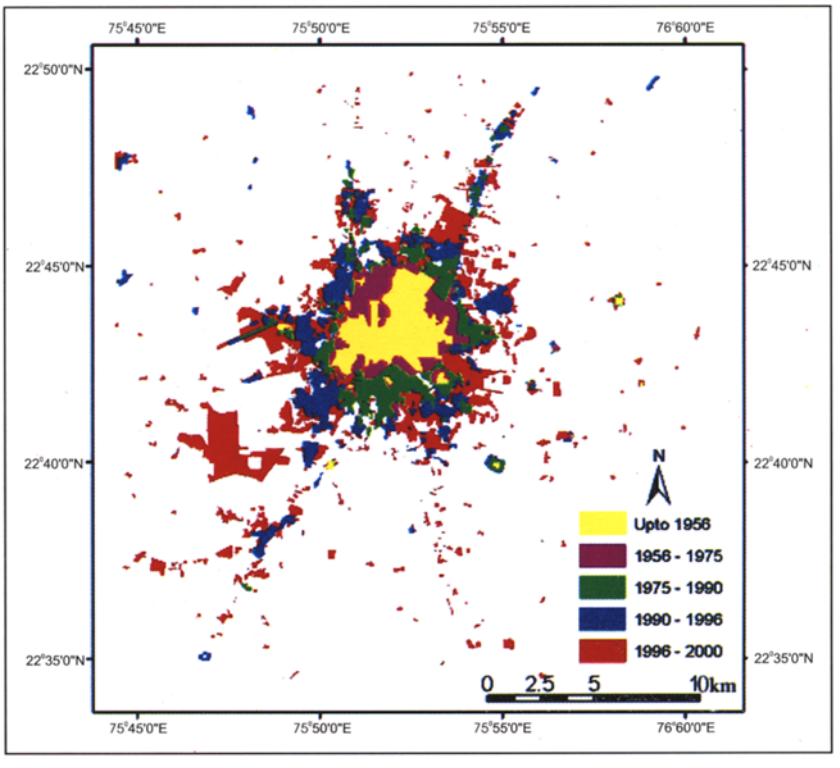

Fig. 7. Urban sprawl over a period of four decades

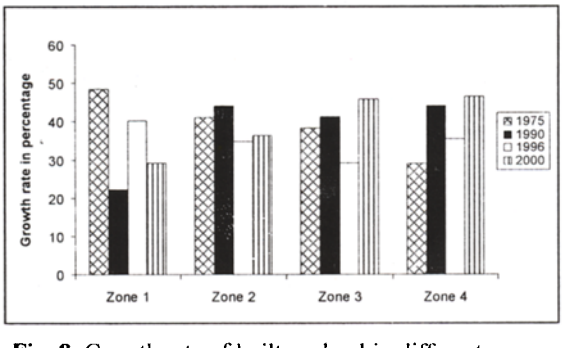

Fig. 8. Growth rate of built-up land in different zones

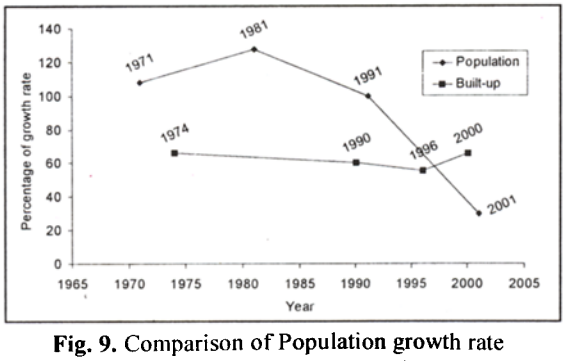

Fig. 9. Comparison of Population growth rate with respect to Built-up growth rate

Shannon's entropy for the year 1990 is 0.657 and log n value of this is 1.114, which denotes that the development is not much dispersed. But it was quite high for the year 1996 and the value of entropy is 0.925 and the log n value is 1.279. For the year 2000 the entropy value of 0.990 is almost near to the log n value of 1.279. The calculated Shannon entropy confirms the development of urban built-up is more towards the dispersion.

Conclusion

Measurement of urban built-up density shows its importance in the monitoring of urban growth expansion over the different periods. This approach is quite helpful in monitoring the urban dynamics. The zone approach is not sufficient to notice the urban sprawl, while the concentric circle approach is more appropriate for identifying the growth as well as its dispersion. From the study, it became very clear that the built-up density is more along the highways and in the CBD. The primary attributes for this kind of development or expansion are not only of population growth but also of the facilities. For the sustainable urban development, proper infrastructure development in an approachable manner to all the residents i.e. concentric zones should be planned. This study concludes that measurement of built-up density using Shannon's entropy can be effective in monitoring the spatial urban growth dynamics.

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