URBAN GROWTH ANALYSES USING SPATIAL AND TEMPORAL DATA

Authors:

H. S. Sudhira[1], T. V. Ramachandra*[1] Karthik S. Raj[1], and K. S. Jagadish[2]

Affiliation:

* Corresponding Author

[1] Energy and Wetlands Research Group,
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore – 560 012, India
Telephone: +91 – 80 – 360 0985 / 394 2506
FAX: +91 – 80 – 360 1428 / 360 0683 / 360 0085

[2] Department of Civil Engineering,
Indian Institute of Science,
Bangalore – 560 012, India

Abstract

Urban growth identification, quantification, and the knowledge of rate and trends of growth would help in regional planning with better infrastructure in environmentally sound way. This requires analyses of spatial and temporal data, which can be done with the help of spatial and temporal technologies such as Remote Sensing, Geographic Information System (GIS) and Global Positioning System (GPS). This paper focuses on urban growth pattern analyses being carried out for the radial and linear sprawl considering Bangalore – Mysore highway. Various GIS layers such as built-up theme along the highway, road network, city boundary etc. were generated using collateral data such as the Survey of India toposheet, etc. Spatial changes in built-up area and the pattern of sprawl were studied using GIS. Further this analysis was complemented with the computation of Shannon's entropy that helped in identifying prevalent sprawl zones and rate of growth, which also helped in delineating potential sprawl locations. This study revealed that the Bangalore North and South taluks contributed mainly to the sprawl with 559% increase in built-up area and high degree of dispersion. The Mysore and Srirangapatna region showed 128% change in built-up area and a high potential for sprawl with slightly high dispersion. The degree of sprawl was found to be directly proportional to the distances from the cities.

Keywords: urban growth, sprawl, GIS, GPS, remote sensing, entropy, spatial and temporal analyses

INTRODUCTION

Understanding the phenomenon of urbanisation and analyses of patterns of urbanisation would help in addressing the needs of the present and future needs of a region. This plays a key role in planning for infrastructure and becomes crucial in regional planning especially when resources are scarce. Unchecked urbanisation is often referred colloquially as sprawl poses serious problems in infrastructure planning and implementation that leads to unforeseen consequences. In this context, prior knowledge of patterns of sprawl and its trend would help the development machinery in planning the basic necessities of a region. This requires spatial and statistical data for a different time period. Temporal data acquired remotely (i.e. remote sensing data) for a region along with the historical data of a region (such as population growth patterns, etc.) would help in finding out the patterns and trends of sprawl. Geographic Information System or GIS would help in integrating both spatial and statistical data and generate themes based on various growth trends.

The process of urbanisation is fairly contributed by population growth, migration and infrastructure initiatives resulting in the growth of villages into towns; towns into cities and cities into metros. However in such a phenomenon for ecologically feasible development, planning requires an understanding of the growth dynamics. Nevertheless in most cases there is lot of inadequacies to ascertain the nature of uncontrolled progression of urban sprawls. Sprawl is considered to be an unplanned outgrowth of urban centers along the periphery of the cities, along highways, along the road connecting a city, etc. Due to lack of prior planning these outgrowths are devoid of basic amenities like water, electricity, sanitation, etc. Provision of certain infrastructure facilities like new roads and highways, fuel such sprawls that ultimately result in inefficient and drastic change in land use affecting the ecosystem.

Usually sprawls take place on the urban fringe, at the edge of an urban area or along the highways in most parts of the globe. The need for understanding urban sprawl is already stressed (Sierra Club, 1998; 2001; The Regionalist, 1997) and attempted in the developed countries (Batty et al., 1999; Torrens and Alberti, 2000; Barnes et al., 2001, Yeh and Li, 2001; Hurd et al., 2001; Epstein et al., 2002). Typically conditions in environmental systems with gross measures of urbanization are correlated with population density with built-up area (The Regionalist, 1997; Berry, 1990). Added to this, recently concluded 2001 national census show that with the current trend, at least 33% of the Indian population would be in urban centers by 2016. This substantiates the need to analyze and understand the urban sprawl phenomenon in the context of a developing country to address effective resource utilization and infrastructure allocation. The most common form of sprawl either radial (across a city) or along the highways is being investigated by many. In addition to these sprawls, there is a need to understand the sprawl that is taking place, when a city / town is connected by a road, which is most common in developing countries.

Normally, when a rural pockets are connected to a city by a road. At initial stages, development in the form of service centers such as shops, cafeteria, etc. can be seen on the roadside, which eventually become the hub of rural economic activity leading to sprawl. An enormous amount of upsurge could be observed along these roads. This type of upsurge caused by a road network between urban / semi-urban / rural centers is very much prevalent and persistent at most places in India. These regions are devoid of any infrastructure, since planners are unable to visualize this type of growth patterns. This growth is normally left out in all government surveys (census), as this cannot be grouped under either urban or rural centre. The investigation of patterns of this kind of growth is very crucial from regional planning point of view to provide basic amenities in these regions. Further, with the Prime Minister of India's pet project, "Golden Quadrilateral of National Highways Development Project" initiative of linking villages, towns and cities and building 4-lane roads, this investigation gains importance and significance. Prior visualising the trends and patterns of growth enable the planning machineries to plan for appropriate basic infrastructure facilities (water, electricity, sanitation, etc.). The study of this kind reveals the type, extent and nature of sprawl taking place in a region and the drivers responsible for the growth. This would help developers and town planners to project growth patterns and facilitate various infrastructure facilities. In this paper, an attempt is made to identify the sprawl pattern, quantify sprawl across roads in terms of Shannon's entropy, and estimate the rate of change in built-up area over a period with the help of spatial and statistical data of nearly three decades using GIS.

The physical expressions and patterns of sprawl on landscapes can be detected, mapped, and analyzed using remote sensing data and geographical information system (GIS) (Barnes et al., 2001) with image processing and classification. The patterns of sprawl could be described using a variety of metrics and through visual interpretation techniques. Characterization of urbanized landscapes over time and computation of spatial indices that measure dimensions such as contagion, the patchiness of landscapes, fractal dimension, and patch shape complexity are done statistically by Northeast Applications of Useable Technology In Land Use Planning for Urban Sprawl (Hurd et al., 2001; NAUTILUS, 2001).

In the recent years understanding the dynamics of sprawl, quantifying them and subsequently predicting the same for a future scenario has gained significant importance. Batty et al. (2001) are successful in analyzing this phenomenon using differential equations and developing a model to simulate sprawl using cellular automata for the Ann Arbor, Michigan region. Various issues concerned with quantifying urban sprawl phenomenon are addressed (Torrens and Alberti, 2000; Barnes et al., 2001) to arrive at a common platform for defining the process. Most of these studies quantify sprawl considering the impervious or the built-up as the key feature of sprawl.

The Shannon's entropy index reflects the concentration of dispersion of spatial variable in a specified area, to measure and differentiate types of sprawl would be useful in quantifying the sprawl (Yeh and Li, 2001). This measure is based on the notion that landscape entropy or disorganization increases with sprawl. The urban land uses are viewed as interrupted and fragmented previously homogenous rural landscapes, thereby increasing landscape disorganization. Similar approach was adopted to quantify urban sprawl in Udupi – Mangalore highway (Sudhira et al., 2003) and for Hyderabad City, India (Lata et al., 2001).

Built-up area as an indicator of urban sprawl

The percentage of an area covered by impervious surfaces such as asphalt and concrete is a straightforward measure of development (Barnes et al., 2001) and these surfaces can be easily detected and interpreted in remotely sensed data. This is based on the assumption that developed areas have greater proportions of impervious surfaces, i.e. the built-up areas as compared to the lesser-developed areas. Further, the population in the region also influences sprawl. The proportion of the total population in a region to the total built-up of the region is a measure of quantifying sprawl. Epstein et al. (2002) also employ a similar technique for mapping suburban sprawl and compared the result with rural and urban centers. Thus the sprawl is characterized by an increase in the built-up area along the urban and rural fringe and this attribute gives considerable information for understanding the behaviour of such phenomenon. Earlier studies carried out in parts of the world highlight and conform that the built-up area could be used as fairly accurate parameter for urban sprawl analyses. The other parameter that is considered as an indicator of urban sprawl is the nighttime data captured with the help of radars or geo-stationary satellites.

STUDY AREA

This study was carried out in the Bangalore - Mysore highway, between 12^o 19’ 30’’ N to 13^o 01’ 15’’ N latitudes and 76^o 45’ 30’’ E to 77^o 31’ 44’’ E longitudes. Eight taluks straddle the Bangalore – Mysore highway as well as areas adjacent to these, which have been influenced by the highway. It includes Mysore taluk of Mysore district, Srirangapatna, Mandya and Maddur taluks of Mandya district, Channapatna, Ramanagaram, Bangalore South and Bangalore North taluks of Bangalore district. This is one of the well-linked regions of Karnataka state and covers an area of 4,152 sq. km with about 1,013 settlements. This segment happens to be one of the prime urban corridors of the state. The cities like Mysore, Srirangapatna and Bangalore has been capitals of erstwhile kingdoms and so naturally development has its effect since historical time. However expansion of Bangalore in recent times, as a major economic centre with development of industries and commercial establishments have given impetus to the growth. Early 90's boom in the software sector with consequent infrastructure initiatives, has contributed to hike in population, mainly due to migration from less developed pockets of India (Orissa, Bihar, etc.) to Karnataka. The radial sprawl due to Bangalore city's growth is seen curbing smaller villages on the periphery.

The present investigation analyse the growth pattern within a buffer of 4 km across the roads connecting Bangalore with Ramanagaram, Ramanagaram with Channapatna, Channapatna with Maddur, Maddur with Mandya, Mandya with Srirangapatna and Srirangapatna with Mysore (Figure 1).

METHODOLOGY TO MEASURE URBAN SPRAWL

The complexity of a dynamic phenomenon such as urban sprawl could be understood with land use change analyses, sprawl pattern and computation of sprawl indicator index. As a prelude to this analyses, various GIS base layers such as drainage network, roads and railway network and the administrative boundaries from the toposheets were created.

The highway passing between the two cities was digitized separately and a buffer region of 4 km around this was created. This buffer region is created to demarcate the study region around the road. Following this, land cover and land use analyses was done using remote sensing data.

Urban sprawl over the period of three decades (1972-98) was determined by computing the area of all the settlements from the digitized toposheets of 1971-72 and comparing it with the area obtained from the classified satellite imagery for the built-up theme. The toposheets (Table 1) in digital format were first geo-registered. The area under built-up (for 1972) was added to this attribute database after digitization of the toposheets for the built-up feature for the study area.

Satellite image – IRS - LISS data scenes covering Path 99 – Row 65 and Path 100 – Row 64 was procured from National Remote Sensing Agency (NRSA), Hyderabad for the years 1998.

The standard processes for the analyses of LISS data such as band extraction, restoration, classification, and enhancement were carried out. Band extraction was done initially through a programme written in C++ and subsequently IDRISI 32 was used for image analyses. Supervised classification approach was adopted as it was found more accurate compared to unsupervised classification. The Maximum Likelihood Classifier (MLC) or Gaussian classifier was employed for the image classification. The original classification of land-use of 16 categories was aggregated to vegetation, built-up (residential & commercial), agricultural and open lands, and water bodies.

Area under built-up theme after classification was extracted from classified images, which gave the urban area of 1998. Further, by applying vector analyses, the built-up area under villages selected for the region between Bangalore – Mysore was computed.

Shannon's Entropy

The Shannon's entropy approach (Yeh and Li, 2001) was computed to detect and quantify the urban sprawl phenomenon. The Shannon's entropy, H_n is given by,

$$\mathbf{H_n = - \Sigma P_i \log_e (P_i)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. \ 1$$

where;

P_i = Proportion of the variable in the i^{th} zone

n = Total number of zones

The value of entropy ranges from 0 to log n. Value of 0 indicates that the distribution is very compact, while values closer to log n reveal that the distribution is very dispersed. Higher values of entropy indicate the occurrence of sprawl.

DATA COLLECTION

The data collection was carried out in two phases. This involved primary data collection and secondary data collection. The nature of these data and their source are shown in Table 1.

The Survey of India toposheet of 1:50000 scale was used for the current study, which has the following features:

- Drainage, water bodies, irrigation systems;
- Contours;
- Built-up area;
- Roads and rail network;
- Administrative boundaries.

RESULTS AND DISCUSSION

The built-up area for 1972 was extracted from the digitized toposheets and is shown in Figure 2. Then villagewise built-up area was computed by overlaying the layer with village boundaries (taluk map with village boundaries) and added to the attribute database for further analyses.

LISS sensor data obtained from the NRSA in three bands, viz., Band 2 (green), Band 3 (red) and Band 4 (near infrared), were used to create a False Colour Composite (FCC). Training polygons (with their co-ordinates) were chosen from the composite image and corresponding attribute data was obtained in the field for these polygons (using GPS). Based on these signatures, corresponding to various land features, image classification was done using Guassian Maximum Likelihood Classifier. From the original classification of land-use of 16 categories the image was reclassified to four broader categories as vegetation, water bodies, open land, and built-up. The built-up theme identified from the image is shown in Figure 3.

From the classified image the area under the built-up theme was computed. Area under villagewise built-up theme in the study area was also computed by overlaying a vector layer with village boundaries and tabulated accordingly for further analyses.

Built-up area and Shannon's entropy

The built-up area computed for temporal data indicated that there was 194% increase in the built-up area from the seventies to late nineties. A more detailed investigation of the distribution of the built-up (Table 2) revealed that the change is higher as the proximity to Bangalore increases. The Bangalore North – South segment had the highest increase in built-up area while it was least in Srirangapatna – Mysore segment with 128%. It can also be observed that there is a declining trend in the change in built-up area as one move from Bangalore towards Mysore.

Shannon's entropy was computed for villagewise built-up area, wherein each village was considered as an individual zone (n = total number of villages). This revealed that the distribution of built-up in the region in 1972 was slightly dispersed than in 1999. However the degree of dispersion has come down marginally and that distribution is less dispersed or there is the less presence of sprawl when the entire stretch is considered. The values obtained ranges from 2.658 (in 1972) to 2.556 (in 1998) and log n for this region is 4.477. These are higher than the half way mark of log n (that is 2.238) and show some degree of dispersion of built-up in the region. This non-uniform dispersed growth along the road connecting Bangalore and Mysore necessitated further detailed investigations for identifying the pockets of higher growth.

Detailed investigation on the phenomenon was done in the next phase by dividing the study area in to segments / zones. The entire segment of Bangalore – Mysore was split in to two as Bangalore – Ramanagaram and Channapatna – Mysore segments. The percentage built-up change and entropy was calculated for these two segments. The Bangalore – Ramanagaram segment had a higher value of percentage built-up change (330%) than the Channapatna – Mysore segment (181%). The entropy values for the Bangalore – Ramanagaram segment ranges from 2.690 (for 1972) to 2.699 (for 1998) while log n for this region is 3.583 suggests similar trend. In the Channapatna – Mysore segment the entropy value ranged from 2.320 (for 1972) to 2.083 (for 1998) and log n is 3.951. This analysis reveals that the distribution is more dispersed in Bangalore – Ramanagaram segment compared to the later.

On further division of the two segments into four to identify where the actual sprawl is occurring; the segments such as, Bangalore North – South, Ramanagaram – Channapatna, Maddur – Mandya and Srirangapatna – Mysore were obtained. From the results of these (Table 2) this clearly indicated that there was more dispersed distribution of built-up in the region closer to Bangalore and this decreased as the proximity to the city increased. The Bangalore North –South taluks had the highest increase in terms of the percentage built-up change and the entropy values also showed that there was more dispersion in this taluk, thus indicating higher sprawl in this region. Higher sprawl due to the proximity of

Bangalore is observed till Channapatna – Ramanagaram segment and fades away towards Mandya. It also inferred that in the Mandya – Maddur segment the distribution was slightly compact with radial sprawl. But in the Srirangapatna – Mysore segment the value of entropy showed marginal change in entropy. Here, the degree of sprawl is not as severe as that in case of other segments, but the marginal increase in entropy value certainly indicates the possibility of increasing sprawl due to enhanced economic activities at Mysore.

With the results of the Shannon's entropy indicating that regions nearer to Bangalore city had more degree of sprawl, it was decided to work out and understand the patterns of growth in the regions surrounding Bangalore city, in all directions. It was seen that Bangalore sprawling in radial direction from the city centre and linear growth is noticed along all five major roads connecting the city - spreading as five arms stretched outwards (Figure 4). The space between the arms or the major roads acts as the sinks for city development. Further, it is seen that the development occurred around the ring roads that connected these major roads.

CONCLUSION

The study investigated the urban sprawl phenomenon occurring along the Bangalore – Mysore highway and found that there has been an overall increase in the built-up area by 194%. The Bangalore North – South taluks having the highest percentage (559%) increase and Srirangapatna – Mysore with the lowest percentage (128%) change in built-up area. Further it was also found the change in built-up was high as the distance from

Bangalore decreased. With the Shannon's entropy analysis, the study could identify where the sprawl was taking place and its degree as well. The Bangalore North – South taluks showed higher value entropy indicating sprawl, while the Mandya – Maddur taluks showed lower entropy value indicating compactness or less dispersion. Further, it is seen that the Bangalore city was sprawling in radial direction (from the city centre) as well as linearly along the major roads. The study demonstrates GIS and remote sensing coupled with statistical analyses, such as arriving at Shannon's entropy help immensely in spatial and temporal analyses for studying the sprawl and for delineating the regions with higher sprawl.

ACKNOWLEDGEMENTS

We thank ISRO – IISc Space Technology Cell for financial assistance to carry out field investigations and NRSA, Hyderabad for providing the satellite data required for the study. We are grateful to Ministry of Environment and Forests, Government of India and Indian Institute of Science for infrastructure support. We thank Mr. Aswath and Mr. Kamal for their active participation in field data collection and in preparation of base layers.

REFERENCES

Barnes, K. B., Morgan III, J. M., Roberge, M C., and Lowe, S. (2001). Sprawl development: Its patterns, consequences, and measurement. Towson University. http://chesapeake.towson.edu/landscape/urbansprawl/download/Sprawl_white_paper.pdf

Batty, M., Xie, Y. and Sun, Z. (1999). The dynamics of urban sprawl. Working Paper Series, Paper 15, Centre for Advanced Spatial Analysis, University College London. http://www.casa.ac.uk/working_papers/

Berry, B. J. L. (1990). Urbanisation. In: The Earth as Transformed by Human Action (Eds.: B. L. Turner II, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews, and W. B. Meyer). Cambridge University Press, U. K., pp. 103 – 119.

Census of India. (1971). District Census Handbook – South Kanara District. Series –14, Mysore, Directorate of Census Operations.

Census of India. (1981). District Census Handbook – Dakshin Kannada District. Series – 9, Karnataka, Directorate of Census Operations.

Epstein, J., Payne, K., and Kramer, E. (2002). Techniques for mapping suburban sprawl. Photogrammetric Engineering and Remote Sensing, Vol. 63(9): pp 913 – 918.

Hurd, J. D., Wilson, E. H., Lammey, S. G., and Civeo, D. L. (2001). Characterization of forest fragmentation and urban sprawl using time sequential Landsat Imagery. Proc. ASPRS Annual Convention, St. Louis, MO. April 23–27, 2001.
http://resac.uconn.edu/publications/tech_papers/index.html

Lata, K. M., Sankar Rao, C. H., Krishna Prasad, V., Badrinath, K. V. S., Raghavaswamy. (2001). Measuring urban sprawl: a case study of Hyderabad. GISdevelopment, Vol. 5(12).

NAUTILUS. (2001). Characterization of Urban Sprawl.
http://resac.uconn.edu/research/urban_sprawl/index.htm

The Regionalist (1997). Debate on Theories of David Rusk. Volume 2, Number 3.

Sierra Club (1998). The Dark Side of the American Dream: The Costs and Consequences of Suburban Sprawl. http://www.sierraclub.org/sprawl/report98/

Sudhira, H. S., Ramachandra, T. V., and Jagadish, K. S. (2003). Urban sprawl pattern recognition and modeling using GIS. Proc. Map India – 2003, New Delhi. January 28 – 31, 2003.

Torrens, P. M., and Alberti, M. (2000). Measuring sprawl. Working paper no. 27, Centre for Advanced Spatial Analysis, University College London.
Available online: http://www.casa.ac.uk/working_papers/

Yeh, A. G. O. and Xia Li (2001). Measurement and Monitoring of Urban Sprawl in a Rapidly Growing Region Using Entropy. Photogrammetric Engineering and Remote Sensing, Vol. 67(1): pp 83.

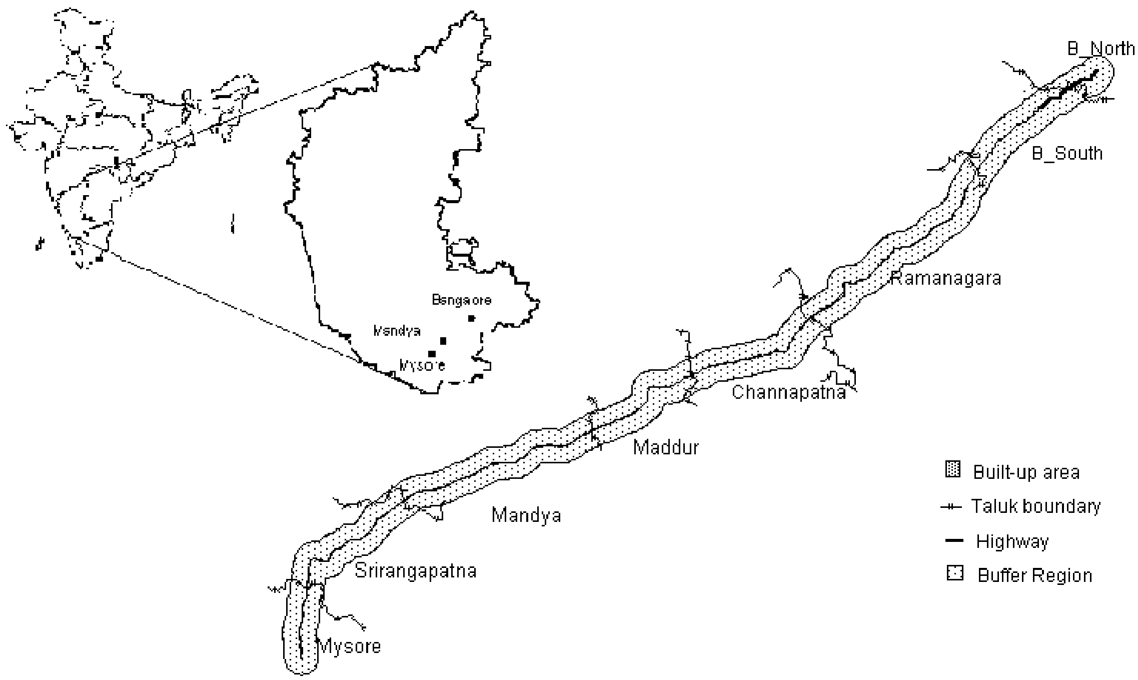

FIGURE 1: LOCATION OF STUDY AREA

TABLE 1: PRIMARY AND SECONDARY DATA DETAILS FOR THE STUDY AREA

SEGMENT	**MYSORE BANGALORE**	**SOURCE**
PRIMARY DATA	TOPOSHEETS NO. 57 H/2, 57 H/5, 57 H/6, 57 H/9, 57 D/11, 57 D/14, AND 57 D/15	SURVEY OF INDIA, SCALE 1:50000
	SATELLITE IMAGERY – LISS3; PATH: 100 ROW: 64 & PATH: 99 ROW: 65	NATIONAL REMOTE SENSING AGENCY (NRSA)
SECONDARY DATA	DEMOGRAPHIC DETAILS FROM PRIMARY CENSUS ABSTRACTS FOR 1971, 1981 & 1991	DIRECTORATE OF CENSUS OPERATIONS, CENSUS OF INDIA
	VILLAGE MAPS FOR TALUKS, VIZ. BANGALORE SOUTH, BANGALORE NORTH, RAMANAGARAM, CHANNAPATNA, MADDUR, MANDYA, SRIRANGAPATNA, MYSORE	DIRECTORATE OF SURVEY SETTLEMENT AND LAND RECORDS, GOVERNMENT OF KARNATAKA

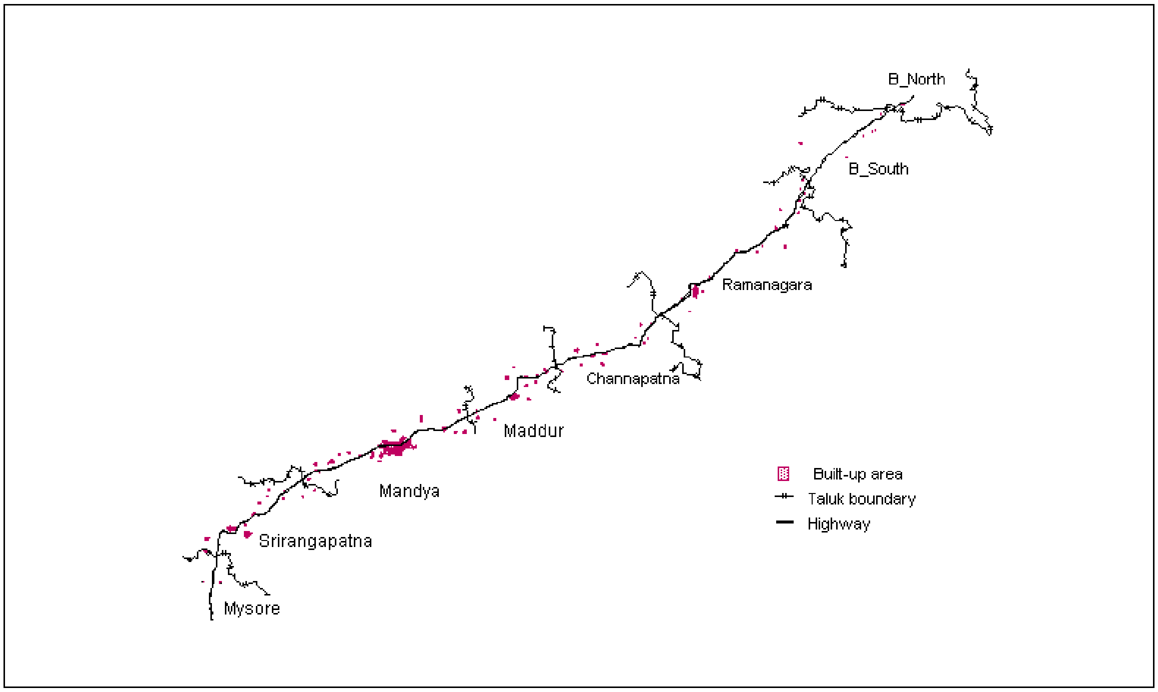

FIGURE 2: BUILT-UP AREA IN THE BANGALORE – MYSORE SEGMENT IN 1972

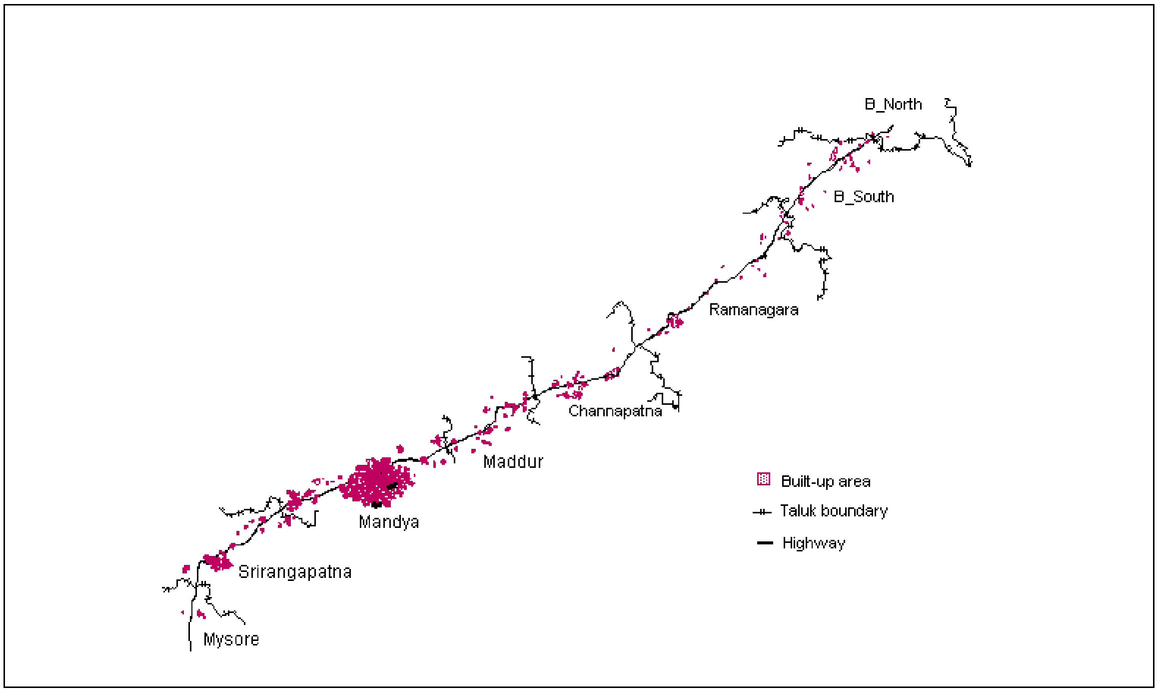

FIGURE 3: BUILT-UP AREA IN THE BANGALORE – MYSORE SEGMENT IN 1998

TABLE 2: BUILT-UP AREA AND SHANNON'S ENTROPY FOR THE STUDY AREA

Segment	Built-up Area		Percentage Change in Built-up Area	Shannon's Entropy		$\log_e n$
	1972	1998		1972	1998	
Bangalore – Mysore	8.2679	24.3344	194%	2.658	2.556	4.477
Bangalore – Ramanagaram	0.7494	3.2232	330%	2.69	2.699	3.5835
Channapatna – Mysore	7.5185	21.1112	181%	2.320	2.083	3.9512
Bangalore North – South	0.1296	0.8538	559%	2.427	2.338	2.565
Ramanagaram – Channapatna	0.9682	3.2777	239%	2.717	2.592	3.401
Mandya – Maddur	5.9324	17.3804	193%	1.662	1.434	3.434
Srirangapatna – Mysore	1.2377	2.8226	128%	1.803	1.922	2.639

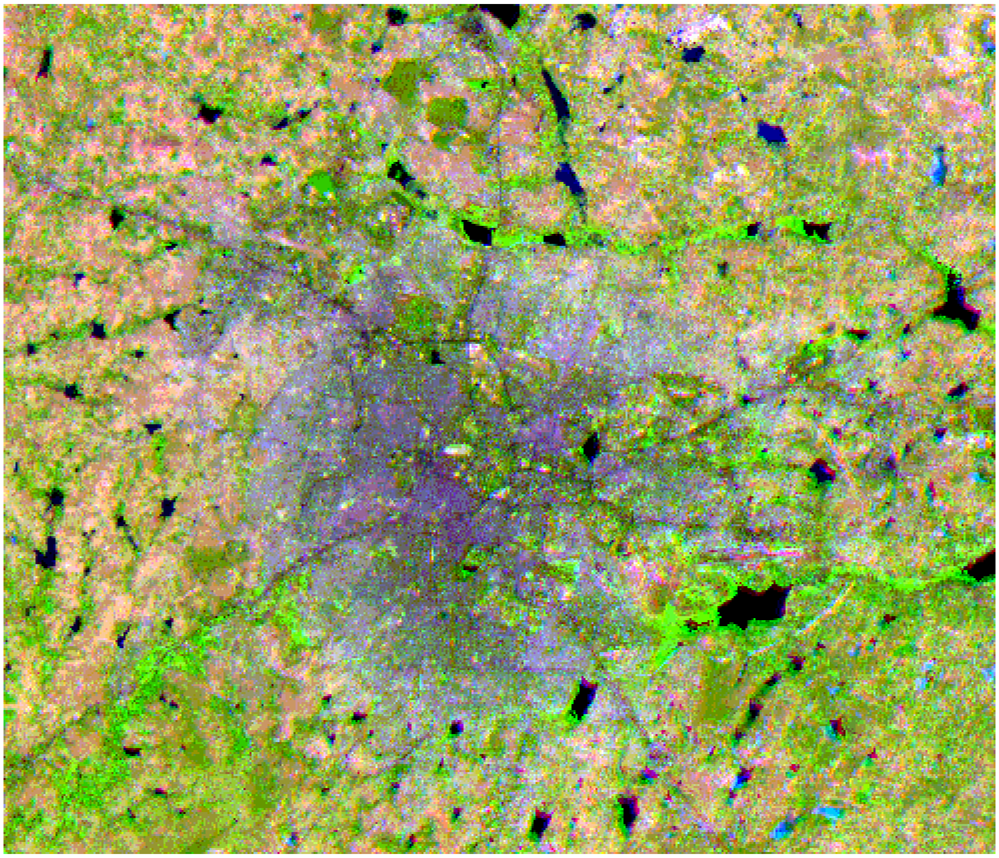

FIGURE 4: FCC OF BANGALORE CITY SHOWING RADIAL PATTERN OF GROWTH FROM THE CITY CENTRE AND LINEAR PATTERN ALONG THE HIGHWAYS