

CHARACTERISING URBAN SPRAWL FROM REMOTE SENSING DATA AND USING LANDSCAPE METRICS

H. S. SUDHIRA
Research Scholar
Department of Management Studies and
Centre for Sustainable Technologies,
Indian Institute of Science,
Bangalore – 560 012
India
Tel: +91 80 2293 2786
Fax: +91 80 2360 4534
E-mail: sudhira@mgmt.iisc.ernet.in

T. V. RAMACHANDRA
Associate Faculty
Centre for Sustainable Technologies and
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore – 560 012
India
Tel: +91 80 2293 3099
Fax: +91 80 2360 1428
E-mail: cestvr@ces.iisc.ernet.in

Abstract: Urban sprawl refers to the outgrowth of urban areas caused by uncontrolled, uncoordinated and unplanned growth. This outgrowth seen along the periphery of cities, along highways, and along roads connecting a city, lacks basic amenities like sanitation, treated water supply, primary health centre, etc. as planners were unable to visualise such growth during planning, policy and decision-making. Sprawl generally infers to some type of uncoordinated development with impacts such as loss of agricultural land, open space and ecologically sensitive habitats in and around urban areas due to lack of integrated and holistic approaches in regional planning. In developing countries, where urbanisation rates are high, urban sprawl is a significant contributor of the land use change. However, characterising sprawl has become a contentious issue with numerous arguments both for and against the phenomenon. Meanwhile, effective metrics to characterise sprawl in India are required to characterise this. We have attempted to capture urban sprawl over the landscape and hence adopt landscape metrics for characterising sprawl. We further ascribe that prevalence of sprawl leads to erosion of landscape elements. The satellite remote sensing data for Bangalore, India, of Landsat TM and Landsat ETM+ for 1992 and 2000, were used and through a multi-stage classification process, post-classification change detection was performed. Bangalore city is popularly known as ‘the garden city’ of India is experiencing rapid urban growth and consequent to the software boom, the city is now referred as ‘IT Capital’ of India. The growth Bangalore is experiencing has significant implications on land use. The landscape metrics adopted were computed and the compared for these two time-periods to characterise sprawl. It was evident from these metrics the amount of dispersion and dispersed growth taking place in radial direction across Bangalore. The study demonstrates the utility of using landscape metrics for characterising urban sprawl.

Keywords: urban sprawl, metrics, landscape, remote sensing, Bangalore

1. SPRAWLING CITIES AND URBANISING LANDSCAPES

With the advent of 21st century, development in India has gathered momentum with a population of more than a billion humans inhabiting the country. Economic activities coupled with the thrust on infrastructure development to meet the requirements of unprecedented population growth and migration into urban centres has resulted in extensive urbanization with a rate of almost 3 percent annual growth of urban population. Consequent to this, urban and peri-urban areas are expanding with a change in land use along the highways and in the immediate vicinity of the city. These dispersed development outside of compact urban and village centres along

highways and in rural countryside are termed as sprawl and are devoid of basic amenities. Generally sprawl is ascribed to some type of development with implications such as loss of agricultural land, open space and ecologically sensitive habitats. Although accurate definition of urban sprawl is debated, a general consensus is that urban sprawl is characterized by unplanned and uneven pattern of growth, driven by multitude of processes and leading to inefficient resource utilization. The direct implication of such sprawl is change in land use and land cover of the region as sprawl induces the increase in built-up and paved area.

According to the 2001 census, almost 34 percent of the population live in urban centres in the state of Karnataka. Consequently most towns and cities are expanding like never before thus resulting in urban sprawl. However as a result of this expanse, neighbouring landscapes mostly open spaces are disappearing leading to urbanised landscapes. This paper characterises the sprawl at a landscape level in Bangalore city of Karnataka state, India. Bangalore has emerged as industrial and commercial centre of India in recent times. Bangalore city in India has been subjected to intense urban growth and has led to sprawl. This phenomenon is characterised following the traditional approaches for delineating urban growth using remote sensing data and landscape metrics., The next section attempts to highlight the erosion of landscape elements. In the subsequent section description of the study area followed by data, research method and tools are discussed. In the next section, the land use change detection is followed by the discussion, analysis and results on landscape metrics for characterising sprawl. The paper concludes with the utility of landscape metrics in characterising sprawl and the need for such metrics to address the erosion of landscape elements due to urban sprawl.

1.1 Urban Sprawl and Erosion of Landscape Elements

Studying urban growth has been an intense subject of research especially with the availability of spatial data and geospatial tools. Typically the degree of urban growth or sprawl is attempted by quantifying for the amount of paved surface or the built-up area in a given region obtained from the classification of remotely sensed data or other geospatial data (Torrens and Alberti, 2000; Barnes et al., 2001; Galster et al., 2001; Epstein et al., 2002). Characterising the pattern of urban sprawl would then rest on noting the extent of built-up areas and its associated measures that depict sprawl based on the notion of built-up or paved area. A key aspect in the expansion of built-up area is its engulfing of surrounding open spaces within the landscape. Earlier studies focussed on the extent of built-up expansion than loss of open spaces. It is noted that prevalence of open spaces like water bodies, vegetation, open land, etc. are landscape elements. Addressing urban growth resulting in sprawl at a landscape level, this expanse is ascribed as erosion of landscape elements. Hence an attempt is made to assess the extent and pattern of such expanse while answering whether urban sprawl has resulted in erosion of landscapes leading to loss of open spaces comprising water bodies, vegetation, etc.

2. STUDY AREA: BANGALORE

Bangalore is the principal administrative, cultural, commercial and industrial centre of the state of Karnataka. The city of Bangalore is situated at an altitude of 920 metres above mean sea level. Geographically it is located on 12.95° N latitude and 77.57° E longitude. The city enjoys a pleasant and equable climate throughout the year. Its tree-lined streets and abundant greenery have led to it being called the 'Garden City'

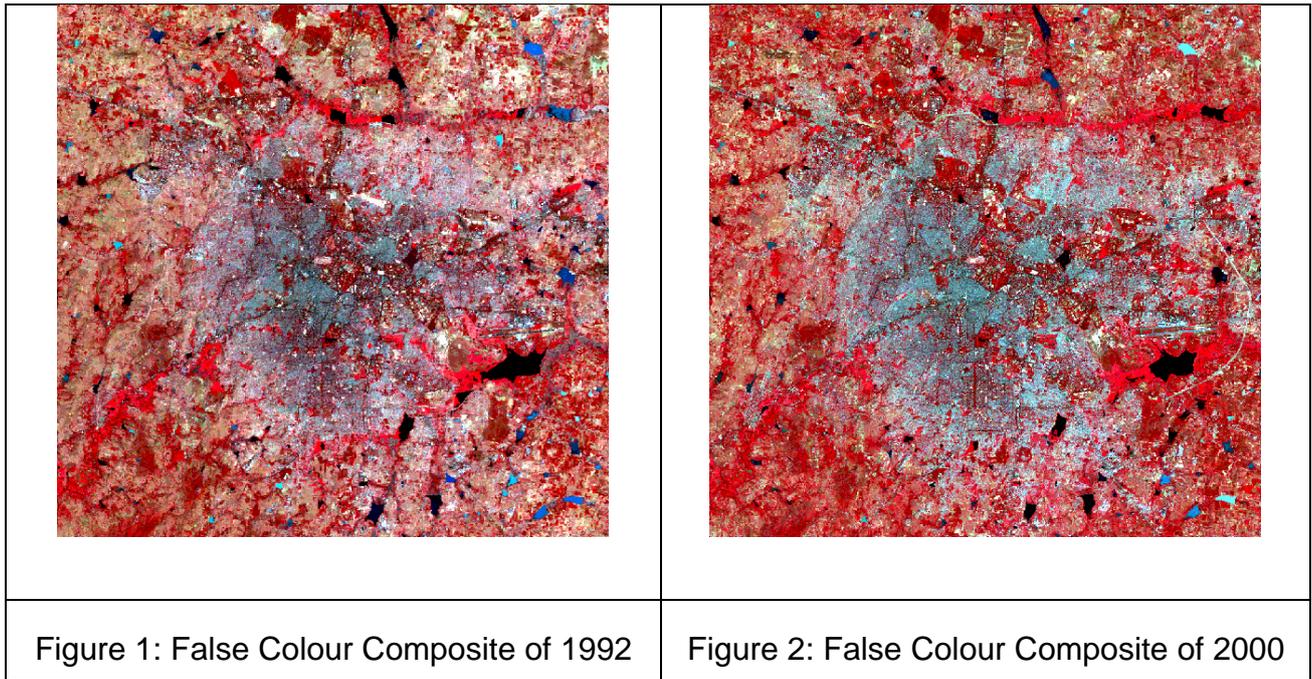
of India. Early 90's boom in the software sector with consequent infrastructure initiatives, has contributed to rise in population, mainly due to migration. It is now home to more than 1000 high-tech companies apart from numerous establishments in manufacturing and processing industries. The population of Bangalore as per the 2001 census was 5,686,844 while it was 163,091 in the beginning of the last century (1901). With a booming economic activity, migration in search of livelihood, and availability of land favoured by salubrious climate all round the year, sprawl has been prevalent in and around Bangalore. Recently, the city administrative jurisdiction was expanded to 716 square kilometres agglomerating neighbouring outgrowth. The expansion of Bangalore in recent times with concentrated development of industries and commercial establishments, the growth appears to have reached the threshold, evident from the crisis in terms of infrastructure, delivery of services, amenities, etc.

2.1 Data Collection

The remote sensing data for land cover by NASA's Landsat TM for 1992 and Landsat ETM+ for 2000 was obtained from the Global Land Cover Facility (GLCF – <http://www.landcover.org/>), Institute for Advanced Computer Studies, University of Maryland, United States of America.

3. RESEARCH METHOD AND TOOLS

The remote sensing data obtained from GLCF are initially processed to quantify the land use of Bangalore city broadly into 4 classes – built-up, agriculture and vegetation, open land, and water bodies. The multi-spectral data of Landsat TM and Landsat ETM+ with a spatial resolution of 30 m each were analysed using IDRISI 32 (Eastman, 1999; <http://www.clarklabs.org>). The image analyses included image registration, false colour composite (FCC) generation, enhancement and classification. The image geo-registration was rectified with respect to the ground control points collected from the Survey of India toposheets. After image geo-registration, the false colour composites were generated using the bands: green, red and near-infrared (Figure 1 and 2). The next step involved classification of the multi-spectral remote sensing data, which was carried through a two-stage classification process: unsupervised and supervised. In the unsupervised classification the number of clusters for classification was identified through the number of distinct peaks obtained from the histogram. For the supervised classification the signatures were derived from the training data obtained in the field using GPS for distinctive land uses and some of the land use features obtained from unsupervised classification. The signatures were generated for each of the land uses and were verified with the composite image. Based on these signatures, corresponding to various land features, supervised image classification was done using Gaussian Maximum Likelihood Classifier (Figure 3 and 4). Further the classified images were reclassified to note the expansion of built-up during 1992 and 2000 (Figure 5 and 6).



3.1 Land Use Change Detection

The classified images for land use in 1992 and 2000 are shown in Figure 4 and 5. The extent of land use during 1992 and 2000 comprised of built-up with 142.54 sq. km and 186.42 sq. km respectively. Similarly the extent of non-built-up comprising open land, vegetation and water bodies made up of 1449.35 sq. km and 1405.42 sq. km respectively during 1992 and 2000. The land use change was detected based on the difference in land use post classification. During the span of eight years, it is observed that the extent of built-up area has increased by 30.8 %. The extent of increase in built-up area depicts only the magnitude of change and does not suggest the pattern of this transition. Analysing the probable land use change from various non-built-up classes to built-up the cross-tabulation for the two classified images were performed. It was noted that the land use change from open land into vegetation was significant while the major land use that contributed to the increase of built-up was by the open land use class.

The extent of land use change from non-built-up to built-up was analysed separately and noted that the percentage increase in built-up areas was around 30 percent while the reduction in non-built-up area was 3 percent (Table 1).

Table 1: Extent of Land use change among Built-up and Non-built-up

Land use	1992 (sq. km)	2000 (sq. km)	Percentage Change
Built-up	142.54	186.42	+ 30.78 %
Non Built-up	1449.35	1405.47	- 03.03 %

This change in built-up areas does not reveal any pattern of land use change necessitating landscape level characterisation of sprawl.

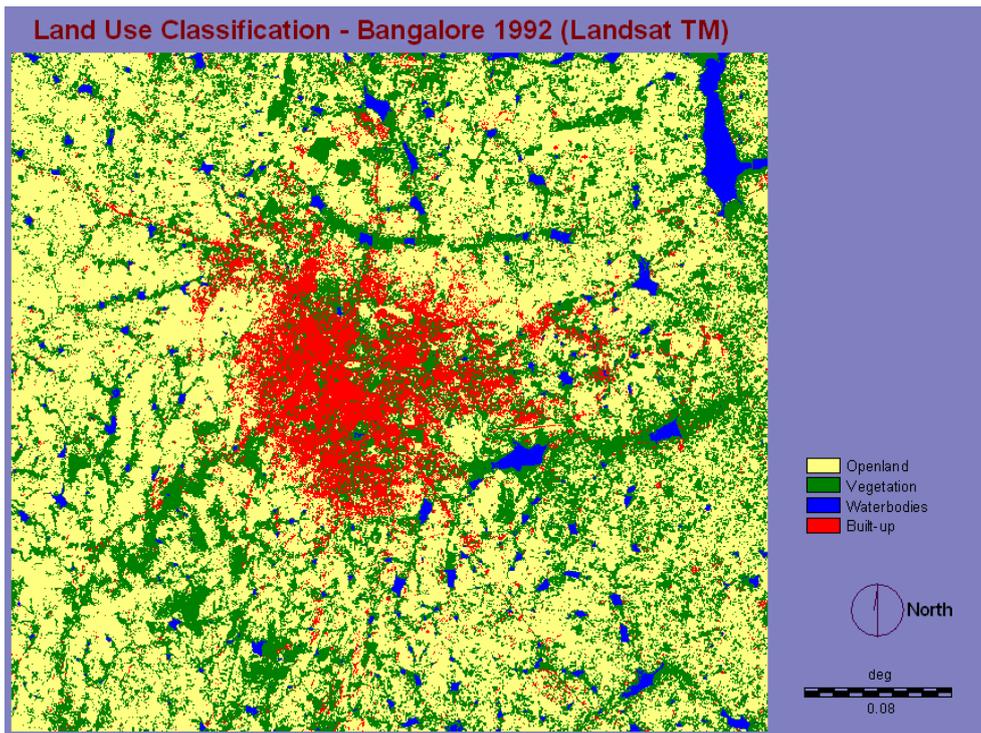


Figure 3: Land use classification for Bangalore – 1992 based on Landsat TM data

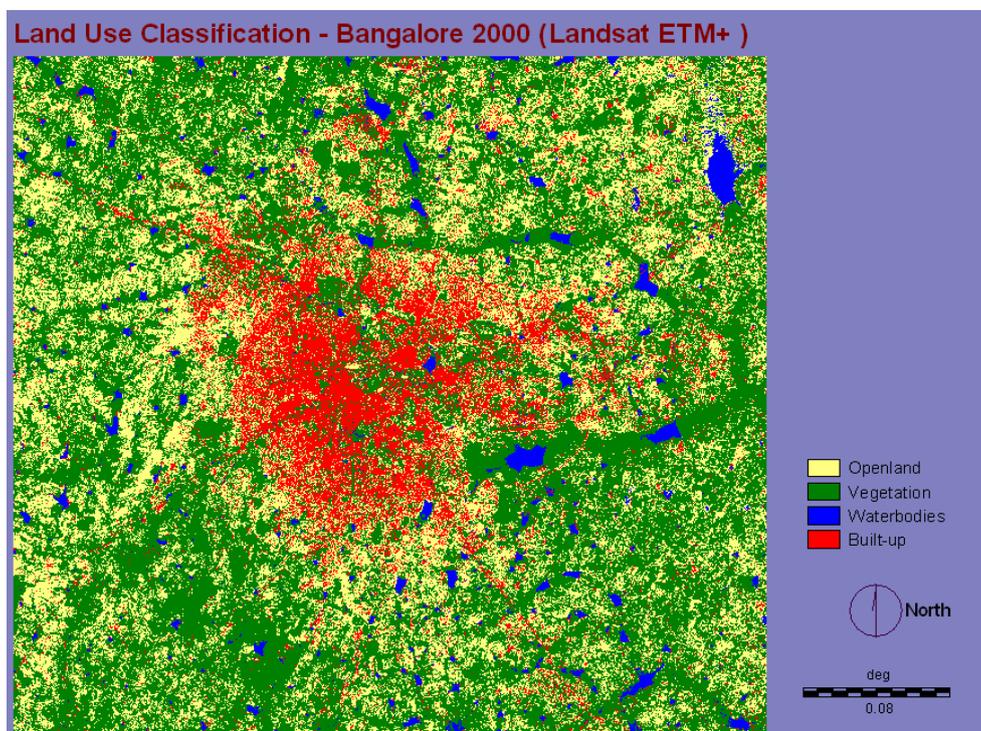


Figure 4: Land use classification for Bangalore – 2000 based on Landsat ETM+ data

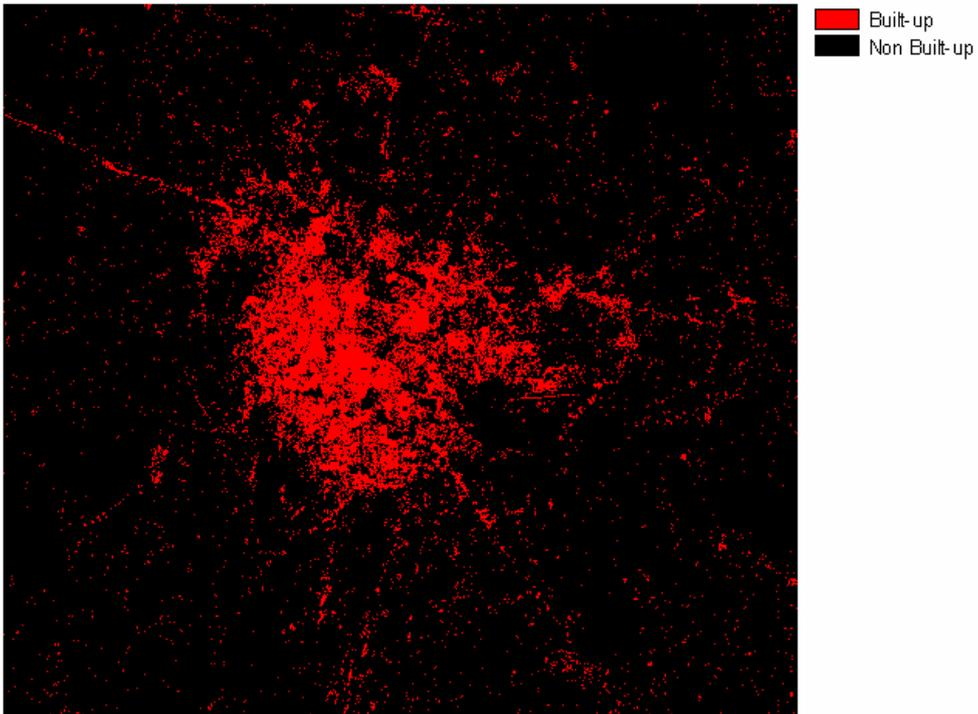


Figure 5: Expansion of Built-up – 1992

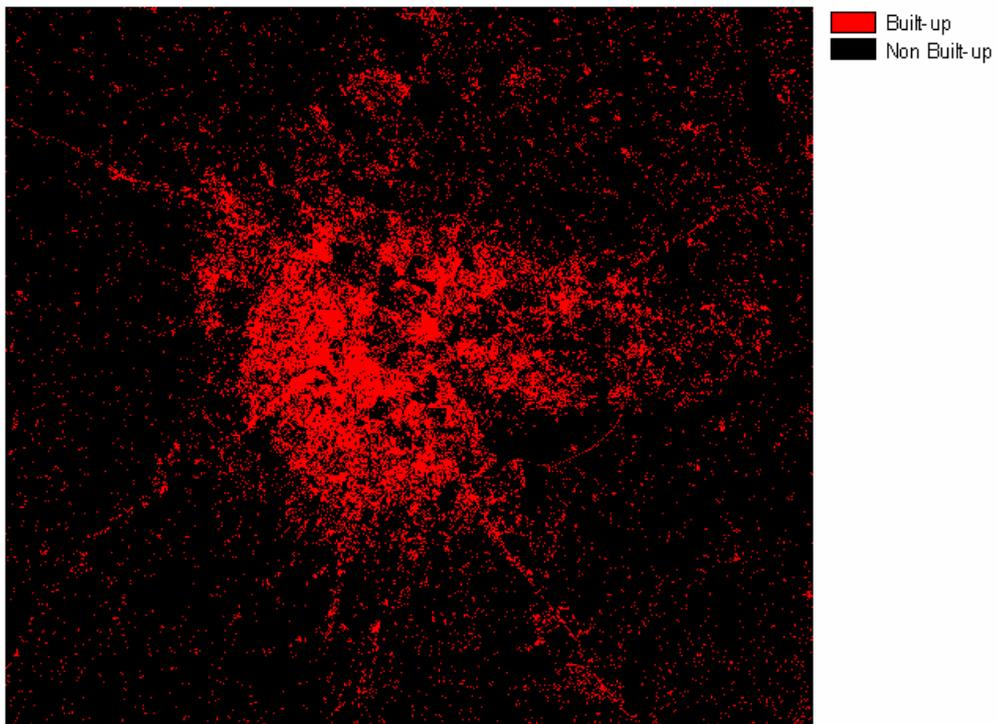


Figure 6: Expansion of Built-up - 2000

4. LANDSCAPE METRICS FOR CHARACTERISING SPRAWL

Characterising landscape properties at the landscape level involves calculating the fragmentation, patchiness, porosity, patch density, interspersion and juxtaposition, relative richness, diversity, and dominance in terms of structure, function, and change (ICIMOD, 1999; Civco et al. 2002). The landscape metrics, normally used in investigations of landscape ecology are extended here to characterise the pattern of urban sprawl.

The landscape pattern metrics are used in studying forest patches (Trani and Giles, 1999; Civco, et al. 2002). Most of the indices are correlated among themselves, because there are only a few primary measurements that can be made from patches (patch type, area, edge, and neighbour type), and all metrics are then derived from these primary measures. In order to quantify urban sprawl in terms of spatial patterns, the landscape metrics (patchiness, built-up density) were computed.

Patchiness or NDC (Number of Different Classes) is the measurement of the density of patches of all types or number of clusters within the $n \times n$ window. In other words, it is a measure of the number of heterogeneous polygons over a particular area. Greater the patchiness more heterogeneous the landscape is (Murphy, 1985). In this case the density of patches among different categories was computed for a 3x3 window. The computation of patchiness using 3x3 moving window revealed that single class category was maximum in 1992 (47.5 %) while 2 heterogeneous class category was maximum (51.58 %) in 2000. The minimum distribution of patches was that of 4 heterogeneous classes with 0.16 % in 1992 and 0.72 % in 2000 (Table 2). This revealed that the change in homogeneous patch came down from 47.5 % in 1992 to 30.12 % in 2000 (Figure 7 and 8).

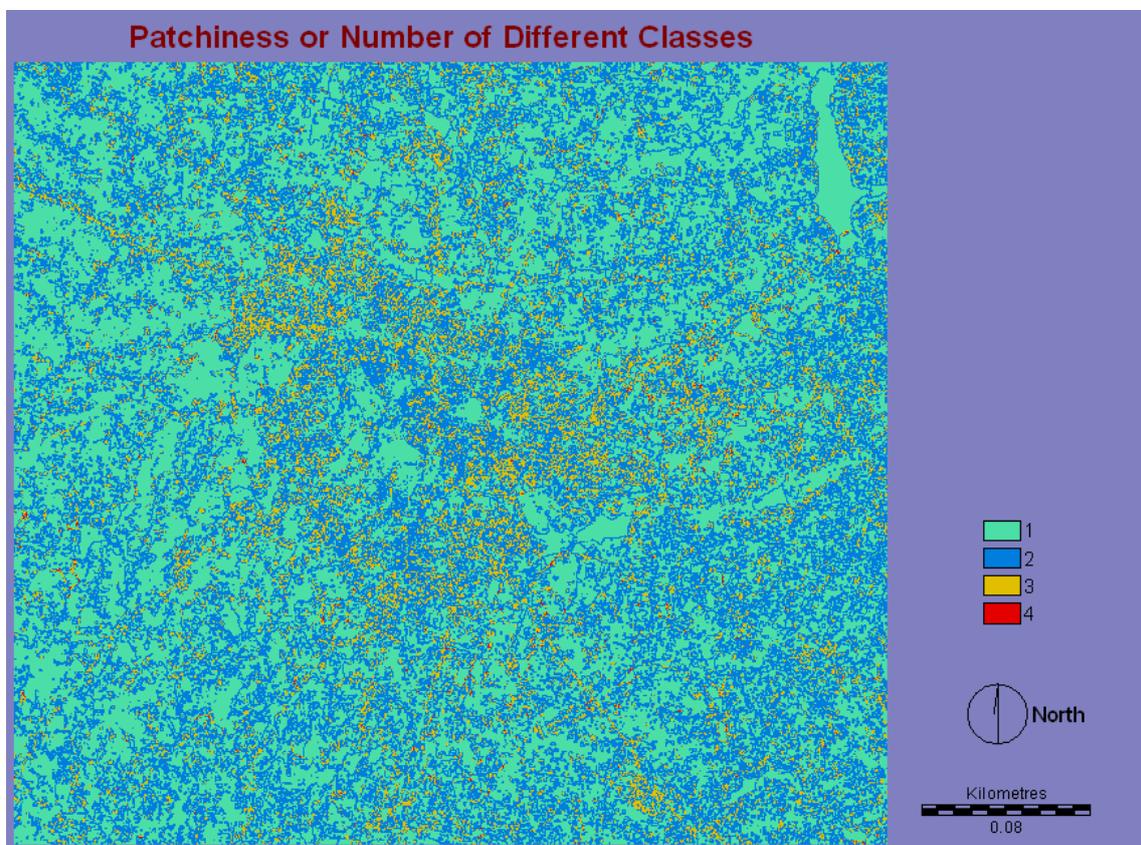


Figure 7: Patchiness in 1992

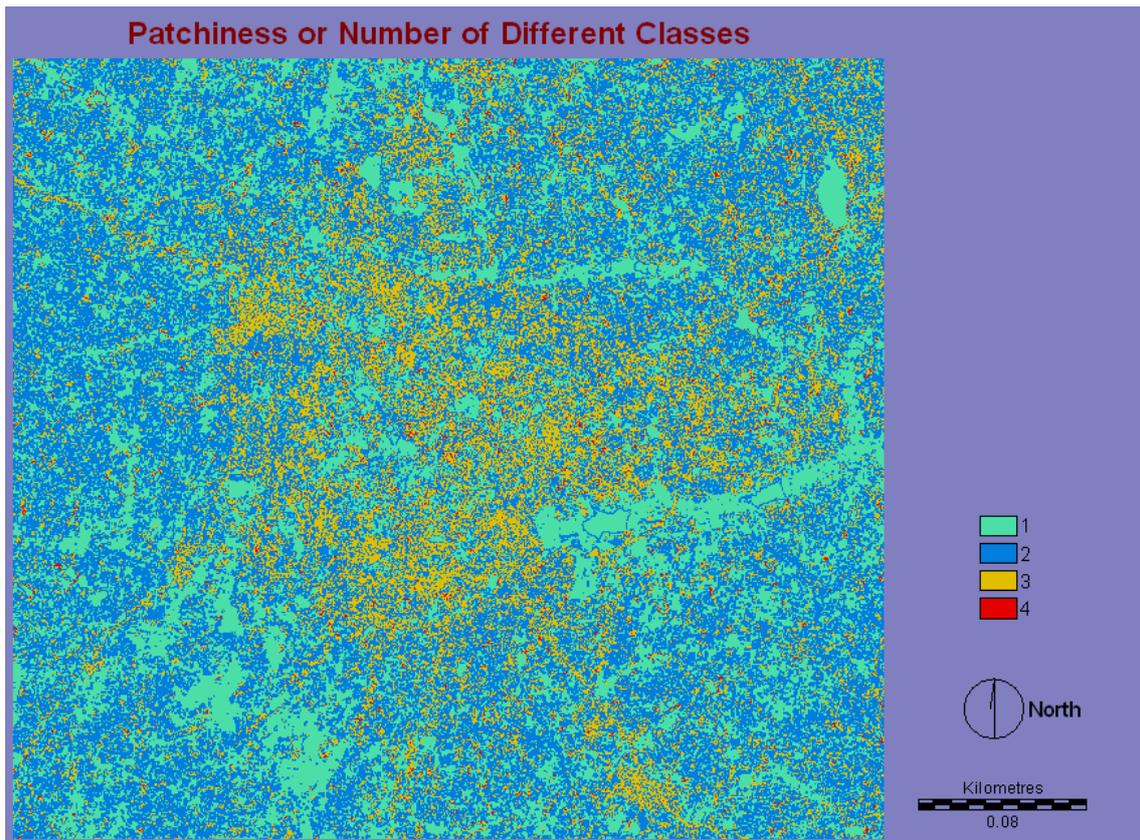


Figure 8: Patchiness in 2000

Table 2: Percentage distribution of patches

Number of Classes	Percentage distribution (1992)	Percentage distribution (2000)
1	756.26	479.62
2	692.67	821.10
3	140.29	279.64
4	2.66	11.47

Map density values are computed by dividing number of built-up pixels to the total number of pixels in a kernel. This when applied to a classified image converts land cover classes to density classes, which is given in Figure 9 and 10. Depending on the density levels, it could be further grouped as low, medium and high density (Figure 11 and 12). Based on this, relative share of each category was computed (area and percentage).

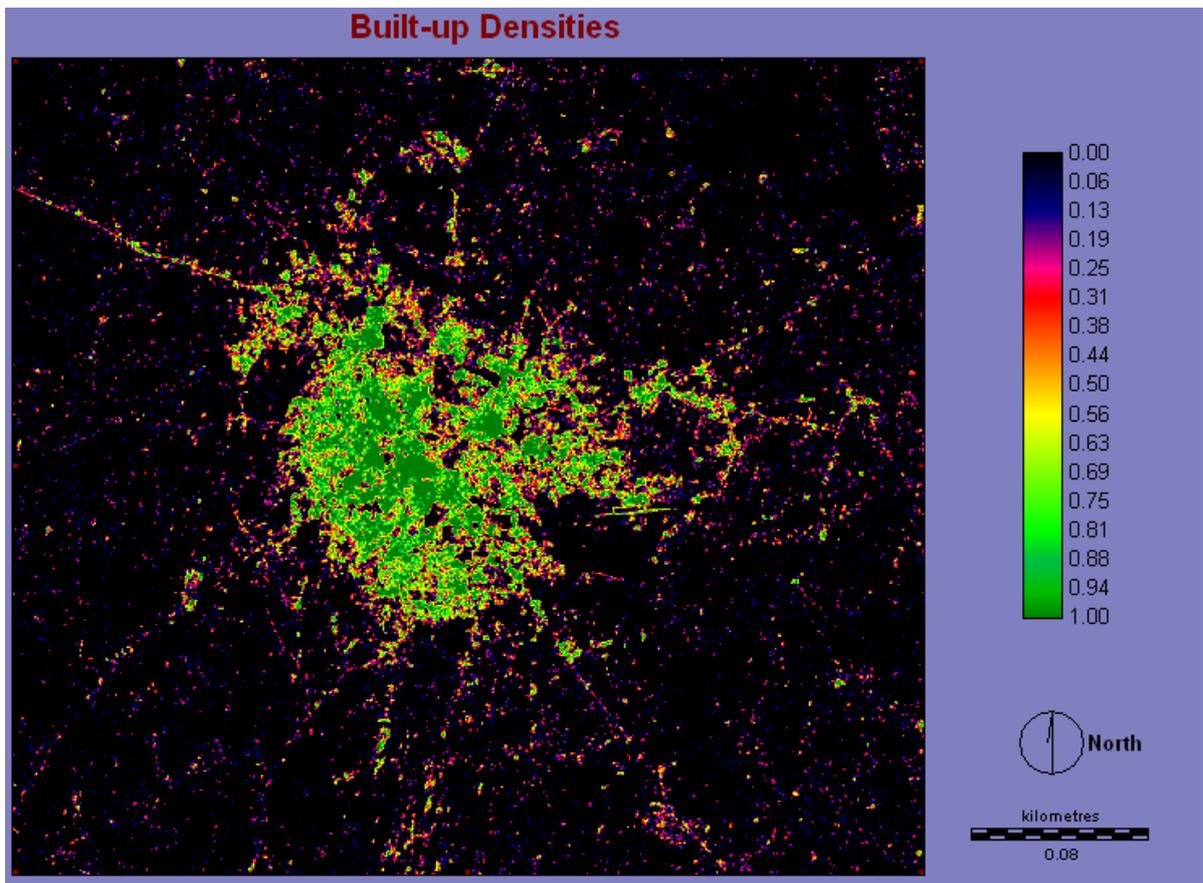


Figure 9: Built-up Densities 1992

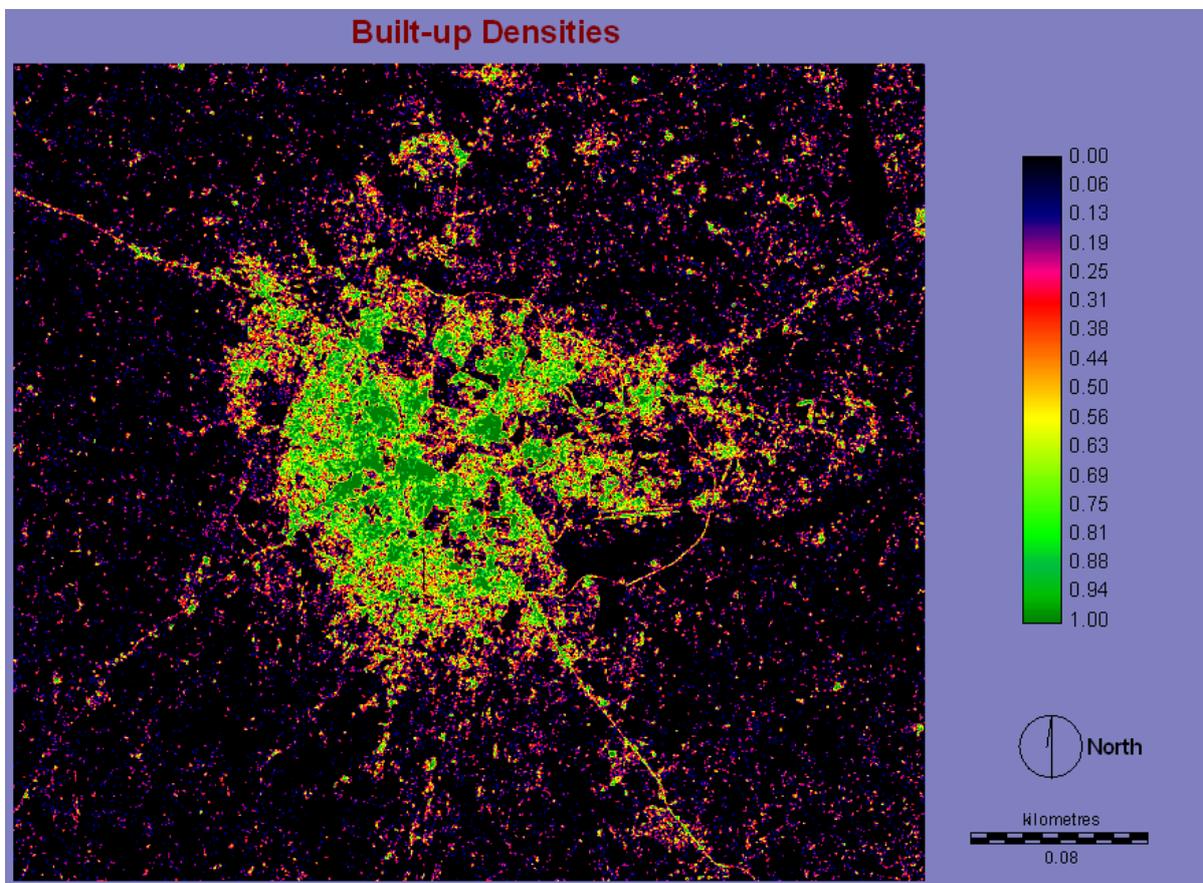


Figure 10: Built-up Densities 2000

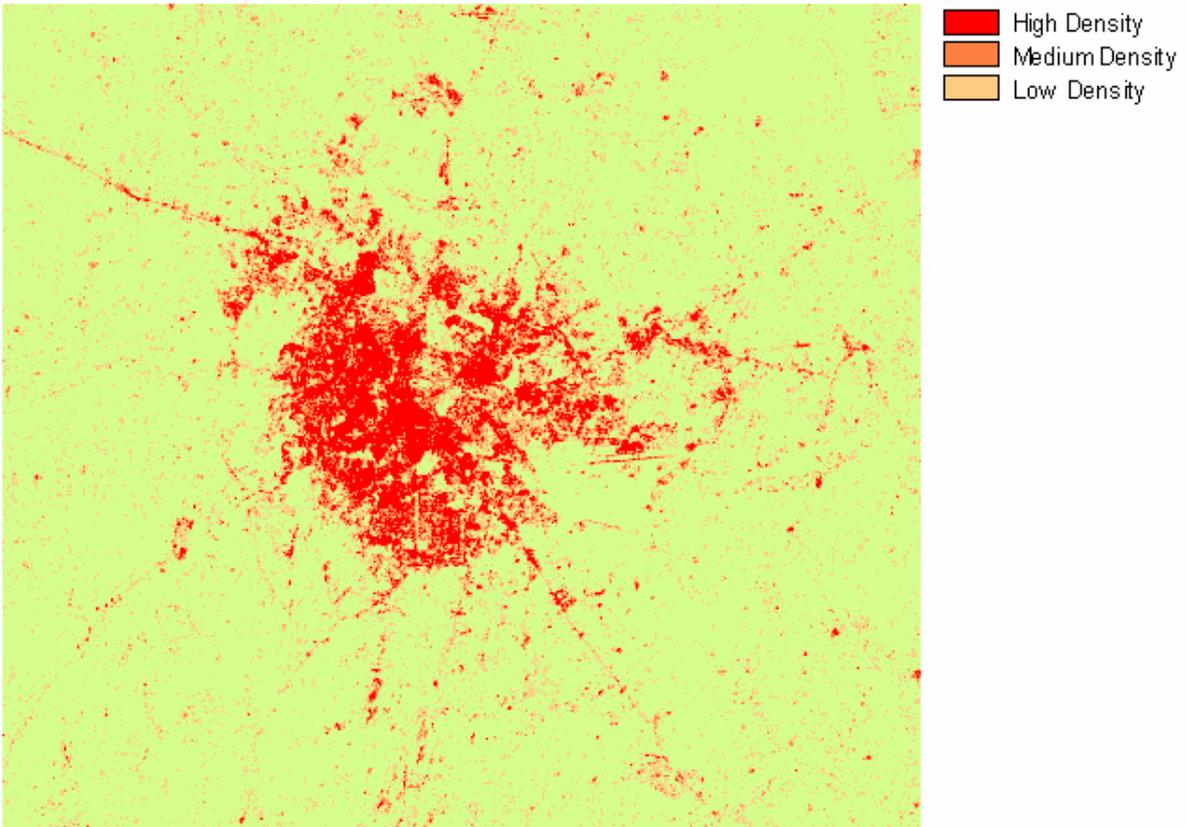


Figure 11: Classification of Built-up Densities – 1992

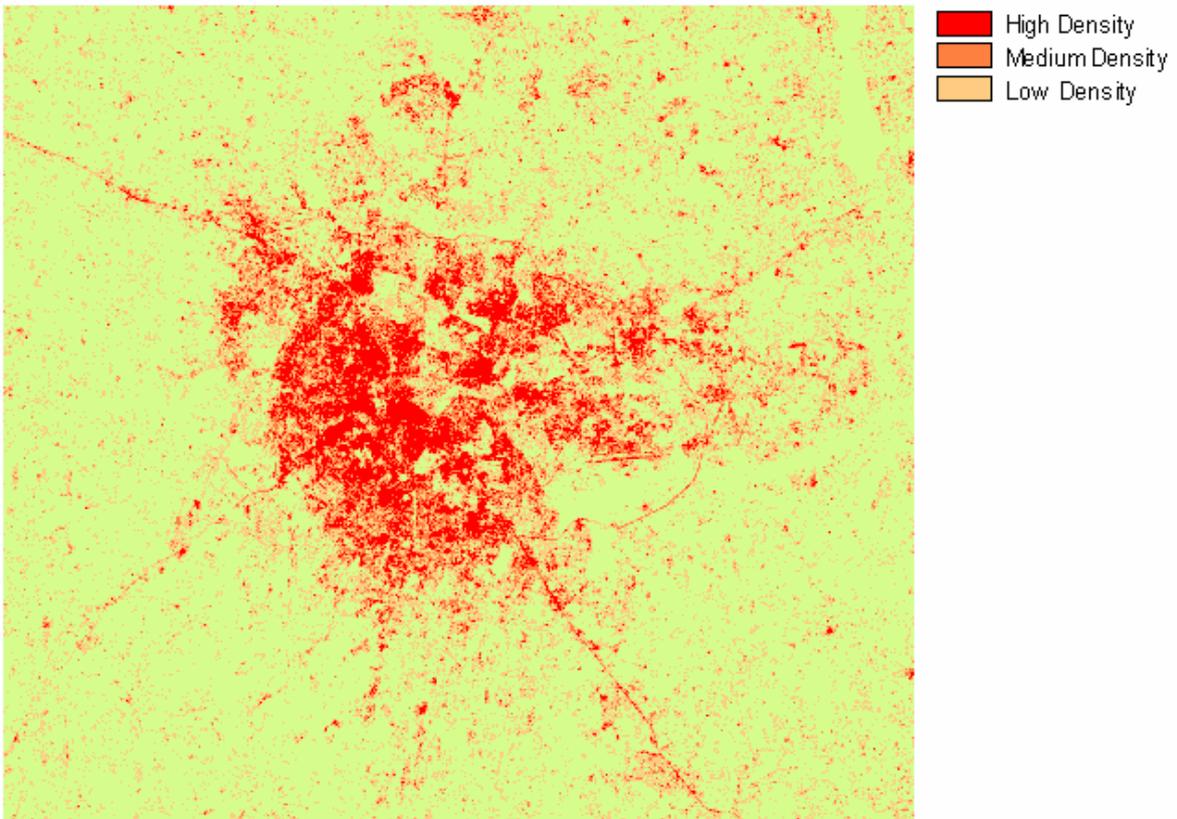


Figure 12: Classification of Built-up Densities – 2000

Table 3: Distribution of built-up densities

Category	Area (sq. km)		Percentage	
	1992	2000	1992	2000
Low density	183.49	310.78	55.71	62.41
Medium density	66.88	109.22	20.30	21.93
High density	78.99	77.94	23.98	15.65

The computation of built-up density gave the distribution of the high, medium and low-density built-up clusters in the study area. High density of built-up would refer to clustered or more compact nature of the built-up areas, while medium density would refer to relatively lesser compact built-up and low density referred to loosely or sparsely spread built-up areas. The percentage of high-density built-up area decreased from 23.98 % in 1992 to 15.65 % in 2000. However, the low density built-up area increased from 55.71 % in 1992 to 62.41 % in 2000 (Table 3). This revealed that the compact or high density built-up proportionally decreased while the low density built-up increased, suggesting more dispersed growth or presence of sprawl. It is observed the low and medium density areas were found all along the periphery of the city and high density was dominated in the core city. The distribution of low density was the maximum in the study area and this could be inferred as the higher dispersion of the built-up in the study area.

5. CONCLUSIONS

It is noted that although the extent of built-up area increase was around 30 percent, it did not reveal any pattern of the built-up spread or suggested the characteristic of sprawl. However by computing the landscape metrics of patchiness and map densities it revealed the pattern of sprawl over the two periods. It is inferred from the computation of patchiness the reduction in homogenous patches and a consequent increase in patches with 2 heterogeneous classes. It may be noted that the reliance on the metrics is dependent on the accuracy of classification, the discussion of which, is beyond the scope of this paper. Further the computation of built-up densities based on the notion of map density in landscape metrics revealed the high distribution of low density built-up areas along the periphery with the high density built-up areas towards the city centre. The analyses revealed the nature and pattern on sprawl suggesting a radial pattern of urban sprawl. An important aspect of the study was noting the erosion of landscape elements with loss of water bodies, vegetation, etc. Though, the study brought out the extent of such loss, the implications of such loss was not attempted.

Characterising urban growth using multi-temporal remote sensing data has been quite popular for a while although there have been few studies that addressed the extent of urban growth resulting in sprawl through appropriate metrics. In this paper we demonstrate the utility of landscape metrics like patchiness and built-up density for characterising urban sprawl. However, a critical challenge is to identify ecological sensitive habitats that may be prone to sprawl and address the extent of low density sprawl that results in inefficient resource usage. Further noting the pattern of development taking place along the periphery of the city like Bangalore should be

used as tool for effective monitoring and enhancing management options for land use. In the next stage, it is imperative to understand the process of sprawl by the change in patterns. This might help to understand the dynamics that leads to such out growth.

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