

Effect of Landscape Metrics on Varied Spatial Extents of Bangalore, India

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Abstract

Landscape fragmentation and dispersed urban growth can be viewed as both cause and consequence of land-use change especially in the context of urban growth. Several metrics from landscape ecology has been already applied to quantify the urban landscapes. However, the use of these metrics in land-use planning and policy making is still lacking. Furthermore, what is critical is to understand the effect and applicability of these metrics at different scales and extent. Typically these metrics are applied at given city's landscape level. However, these may not capture the variations in certain parts of the city since the estimation of the metrics would get aggregated at the city's landscape level. In order to examine the effects of some of these metrics at different spatial extents, a study has been carried out by applying some of the popular landscape metrics for the city of Bangalore. We have created two subset images of varying extent within the city's landscape called: north-east and south-west subsets. Satellite remote sensing data for two time periods 2000 and 2009 were collected and analyzed. Through a multi-stage classification process, post-classification change detection was performed. A highlight of the research is that it utilizes the Landsat ETM+ data with Scan Line Corrector (SLC)-off scenes by employing methods to rectify the anomalies. Landscape metrics viz., Total Class Area (CA), Percentage of Landscape (PLAND), Shannon's Diversity Index (Entropy), Largest Shape Index (LSI), Largest Patch Index (LPI), Clumpiness Index (CLUMPY), Normalized Landscape Shape Index (nLSI) and Contagion Index (CONTAG) were estimated for the entire extent and the two subsets. The analyses revealed that most metrics at landscape-level and the class-level suggest similar trends over the two time periods. However, metrics like LPI and CONTAG did capture the variations across the different extents and time. Some metrics like the CA and PLAND were useful to depict the extent of the land cover changes. Given the radial pattern of outgrowth for a city like Bangalore, most metrics seem to be conveying similar responses to the land cover changes despite the variation of extents. On the one hand, this study ascertained the rapidly changing land cover and its effect on the landscape elements and on the other hand, it could study the effect of landscape metrics on varied spatial extent. Thus, suggesting that perhaps these metrics could even be applied at varied extents while not affecting the overall inferences drastically. Finally, the paper concludes stressing the utility of landscape metrics as potential tools that can be employed for devising land-use policies for future urban expansion.

Key words: Urban landscape fragmentation, Urban sprawl, Bangalore, Land-use policy.

1. Introduction

1.1 Urbanizing Landscapes

Urban sprawl is the outgrowth along the periphery of cities and along highways. Although accurate definition of urban sprawl may be debated, a general consensus is that urban sprawl is characterized by an unplanned and uneven pattern of growth, driven by multitude of processes and leading to

inefficient resource utilization. Urban growth, as such is a continuously evolving natural process due to population growth rates (birth and death rates, Egan and Bendick, 1986). An increased urban population and growth in urban areas is inadvertent with an unpremeditated population growth and migration. While the world urban population is set to double from 3.4 billion in 2009 to 6.3 billion 2050, most of the population growth is expected to occur in towns and cities of less developed regions. Particularly, Asia is projected to see

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its urban population increase by 1.7 billion (United Nations, 2010).

In India, urban population is currently growing at around 2.3 per cent per annum. The number of urban agglomerations and towns in India has increased from 3697 in 1991 to 4378 in 2001. By 2001, there were 35 urban agglomerations / cities having a population of more than one million from 25 urban agglomerations in 1991. Of the 4000 plus urban agglomerations, about 38 per cent reside in just 35 urban areas, thus indicating the magnitude of urbanisation prevailing in the country. This clearly indicates the magnitude of concentrated growth and urban primacy, which also has lead to urban sprawl. Further, the impending 2011 Census would further ascertain the trend of this growth. As one of the fastest growing economies in the world, India faces stiff challenges in managing this urban growth leading to sprawl and ensuring effective delivery of basic services in these urban areas.

As a result of the rapid urban expanse, neighbouring landscapes mostly open spaces are disappearing leading to urbanised landscapes. This paper attempts to study and examine the changes in landscape metrics for varied spatial extents of Bangalore, the capital city of Karnataka state, India. Over the last decade, Bangalore has emerged as a leading centre for information technology based industries in India. Alongside, the development of manufacturing and garment industries with an influx of large migrant population has also led to the rapid growth of the city, both spatially and economically. Consequently, prevalent land-use has been under tremendous pressure for conversion to non-agricultural uses, chiefly: residential, institutional, industrial, commercial and transportation. It is suspected that this has led to fragmentation of habitats leading to isolation or dispersed urban patches in the periphery of the city due to lack of appreciation towards landscape ecology in the prevalent land-use planning practices. In an attempt to ascertain this process, temporal satellite remote sensing data is used and analyzed to quantify the land cover change over two time periods. Here we attempt to demonstrate the applicability of landscape metrics to two but different landscapes within the urban sprawl of Bangalore. The next section briefly reviews some of the literature on urban growth and landscape fragmentation and its metrics as applied in urban contexts. In the subsequent section description of the study area followed by data, research method and tools are discussed. In the latter section, the land-cover change detection is followed by the analysis results and discussion on landscape metrics. The paper concludes stressing the utility of landscape metrics as potential tools that can be employed for devising land-use policies for future urban expansion.

1.2 Landscape Fragmentation

Landscapes are spatially heterogeneous geographic areas characterized by diverse interacting patches or ecosystems, ranging from relatively natural terrestrial and aquatic systems

such as forests, grasslands and lakes to human-dominated environments including agricultural and urban settings (Turner *et al.*, 2001). According to Forman and Gordon (1986), the landscape is a distinct, measurable unit defined by its recognizable and spatially repetitive cluster of interacting ecosystems, geomorphology, and disturbance regimes. The characterization of landscape are typically attempted to determine their structure, function, and change of an ecosystem.

A wide variety of indices developed to characterize landscapes has often been applied to study spatial landscape patterns in the field of landscape ecology; they can be categorized into: area / density / edge, shape, core area, isolation / proximity, contrast, contagion, connectivity and diversity metrics (McGarigal and Marks, 1994). However, only recently has landscape metrics been used in the study of urban morphology (Seto and Fragkias, 2005). The proliferation of landscape metrics, together with the use of remote sensing technology, provides a potential means for analyzing the spatial patterns of urban evolution (Yu and Ng, 2007).

Characterizing 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 (Civco *et al.*, 2002). Different landscape metrics are used for different land use types to understand the landscape characteristic of interest based on the phenomenon under investigation. Herald *et al.* (2002) used seven landscape metrics for structure and changes in urban land use. Metrics were used to detect landscape patterns, biodiversity and habitat fragmentation, changes in landscapes, effect of scale in landscape structure (Gardner *et al.*, 1993; Keitt *et al.*, 1997; Frohn *et al.*, 1996; O'Neill *et al.*, 1996, Li and Reynolds, 1993; McGarigal and Marks, 1994). Overview of various uses of different landscape metrics are given in Uuemaa *et al.* (2011).

Fragmentation is one of the most important processes of landscape change because it represents the breaking up of a cohesive habitat into smaller and more isolated parcels (Forman, 1995). Relative to the study of urbanization, fragmentation has been attributed as a cause and consequence of land-use change. Forman (1995) addressed that fragmentation tend to cause land transformation which is an important process in landscape as more and more development occurs.

The growing appreciation of landscape ecology in urban systems has resulted in employing some of the landscape metrics in the characterization of urban growth (Barnes *et al.*, 2001; Hurd *et al.*, 2001; Epstein *et al.*, 2002). Extending Torrens and Alberti (2000)'s notion of urban sprawl Galster *et al.* (2001) defines it as a pattern of land use in an urban agglomeration that exhibits low levels of some combination of eight distinct dimensions: density, continuity,

concentration, clustering, centrality, nuclearity, mixed uses and proximity. Huang *et al.* (2009) has employed eight landscape metrics for analyzing the spatial and temporal changes of landscape patterns of peri-urbanization in Taipei-Taoyuan area: total urban area, number of urban patches, mean urban patch area, largest patch index, area-weighted mean shape index, area-weighted mean patch fractal dimension index, edge density of urban area, and contagion index. To quantify the spatial pattern of urbanization in the Shanghai metropolitan area using landscape-level metrics, the study by Zhang *et al.* (2003) indicated that metrics like patch density (PD), edge density (ED), and patch and landscape shape complexity increased, while it revealed sharp decrease in the largest and mean patch size (MPS), agriculture land-use type, and landscape connectivity.

On the implication of urban land-use change on ecology, some studies suggest that rates of local extinction and elimination of native species have become more rampant and reaching higher values (Marzluff, 2001; McKinney, 2002). According to McKinney (2002), much of these growths happen in the areas that are already stressed with human induced changes like sensitive watersheds and wildlife habitats. During urban growth, on one hand, the habitats of native species gets fragmented or isolated or lost, eventually leading to decline or extinction of species and on the other hand, the urban exploiter species starts occupying such areas. This eventually leads to homogenization of species, more so with non-native species, leading to extirpation of local - indigenous species and establishment of non-native species (McKinney, 2006). Thus, it is imperative that urban land-use policy should also look into the ecological perspective of land-use, which has huge implication on biodiversity.

In the recent past, some studies have been undertaken to ascertain the urban growth using remote sensing data. Ramachandra and Kumar (2009) use a series of multi-temporal data, though in coarse resolution in studying the changing urban landscape. Studies show that Bangalore is ever-growing in terms of urban space by extending the urban area into the rural-urban fringe and how it has affected the ecological space (Narayanan and Hanjagi, 2009).

From the above review of select literature, it is evident that several metrics from landscape ecology has been already applied to quantify the urban landscapes. However, the use of these metrics in land-use planning and policy making is still lacking. Furthermore, what is critical is to understand the effect and applicability of some of these metrics at different scales and extent of the city's landscape. Typically these metrics are applied at given city's landscape level. However, these may not suggest the variations in certain parts of the city since the metrics would get aggregated at the city's landscape level. In order to examine the effects of some of these metrics at different extents, this paper attempts to evaluate the effects of some of the popular landscape metrics for the city of Bangalore.

2. Study Area: Bangalore, India

Bangalore is located at 12.59° north latitude and 77.57° east longitude, almost equidistant from both eastern and western coast of the South Indian peninsula, and is situated at an altitude of 920 m above mean sea level. The mean annual total rainfall is about 880 mm with about 60 rainy days a year over the last 10 years. The summer temperature ranges from 18° C to 38° C, while the winter temperature ranges from 12° C to 25° C. Thus, Bangalore enjoys a salubrious climate all round the year. Bangalore is located over ridges delineating four watersheds, viz. Hebbal, Koramangala, Challaghatta and Vrishabhavathi watersheds.

Bangalore has witnessed extensive growth in the last decade substantially by both globalization and urbanization. The demand on services and hence better quality of life in the city is not confined to the central core, the erstwhile Bangalore City Corporation jurisdiction alone, but spreads beyond into the peri-urban areas, the metropolitan area and outwards, into the Bangalore Metropolitan Region. The creation of Greater Bangalore City Corporation by the State Government in January 2007 was an acknowledgment of urban sprawl that resulted in the larger corporation by the agglomeration of erstwhile City Corporation with neighboring 8 municipal councils and 110 villages. With several other large-scale infrastructure development projects like the Bangalore-Mysore Infrastructure Corridor project, the Bangalore International Airport and the ring roads, the urban outgrowth is no longer confined to the city corporation limits but now spread beyond it.

The land-use policy for the urban areas in the state of Karnataka is guided by the Comprehensive Development Plans / Master Plans which indicates permissible land-use through zoning, building bye-laws and building height restrictions (through a specified floor-area ratio or the floor-space-index). The agency responsible for the preparation of such plans in Bangalore is the Bangalore Development Authority (BDA). In 2007, the State Government has notified the plan prepared by BDA for 2015 – Revised Master Plan (RMP). Accordingly in the RMP – 2015, as much as 55.94 km² of residential area has been opened up for mixed land usage, which means certain commercial activities would be allowed in these areas. About 42.3 per cent, that is 338.41 km², has been earmarked as residential area, up from 243 km² earmarked in the Comprehensive Development Plan 1995. However, the actual land-use currently is at variation to the previous CDP, deviations being regularised through penalties or otherwise and has been the major cause for uncontrolled outgrowth.

At the outset, the city's landscape is considered that extends up to the urban sprawl of Bangalore, beyond its administrative and planning jurisdictions. In the present study, two subsets are cropped one a smaller section in the north-east region and the other a significant portion of south-west region (Figure 1). The south-west subset mainly consist parts of the

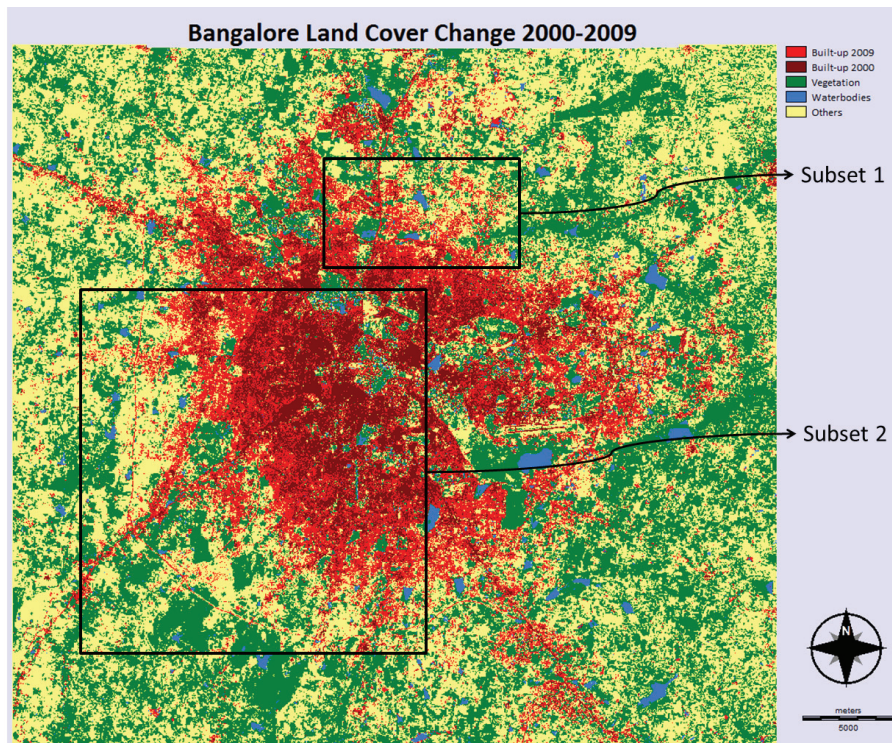


Figure 1. Bangalore Land Cover Change 2000-2009.

city's core areas of residential layouts, commercial areas and extends up to the suburbs like Kengeri, Rajarajeshwari Nagar, Malathalli, Sunkadakatte, Papareddipalya, Nagarbhavi and Govindraja Nagar. The water bodies present in this region are Kengeri tank, Hosakere, Komghatta tank, Ullal tank, Dubasipalya tank, Malathalli tank and Herohalli tank. It also consists of a number of educational institutions, prominently the Bangalore University, National Law School of India University (NLSIU), and Institute for Social and Economic Change (ISEC). The Bangalore University was established during 1973 in 'Jnana Bharathi' (JB) campus located on a sprawling 1,100 acres of land in the south-west region of Bangalore. Sixty years ago, the area was a sandalwood reserve and there used to be an elephant corridor (Kumar *et al.*, 2008) between what is now Bannerghatta National Park and Savanadurga State Forest. Due to rapid urbanization happening in the surrounding regions of the Jnana Bharathi campus the landscape is fast changing.

The northern part of Bangalore is experiencing rapid growth and is embarked for further development and expansion, mainly due to good transportation and other infrastructure facilities available along the corridor due to establishment of Bengaluru International Airport and the Bengaluru international Airport Area Planning Authority (BIAAPA) in its surrounding region at Devanahalli, a town situated at a distance of 39 km from Bangalore. This is one of the influencing factors for causing rapid growth in the northern region. The north-east subset considers primarily the small region east of this corridor to the new international airport, which used to be part of the green belt. Owing to these infrastructure developments, land prices have shot up in an

unprecedented manner and other commercial activities picking up all along the road resulting in unplanned and uncoordinated growth is having impacts on the hinterland.

3. Materials and Methods

3.1 Data Collection

The remote sensing data was obtained from the Global Land Cover Facility (GLCF – <http://www.landcover.org/>), and from the U.S. Geological Survey (USGS) and NASA's Landsat mission website. Beginning October 2008, the archived data of the Landsat missions are made available freely by USGS. Accordingly, the cloud free data corresponding to the years 2000 and 2009 were downloaded and processed.

3.2 Data Processing

The remote sensing data are processed to quantify the land cover broadly into 4 classes – built-up, water bodies, agriculture and vegetation, and others (including all other categories). The multi-spectral data of Landsat TM and Landsat ETM+ with a spatial resolution of 30 m each were analyzed using IDRISI Andes (Eastman, 2006; <http://www.clarklabs.org>). The image analyses included image registration, rectification and enhancement, false colour composite (FCC) generation, and classification.

3.3 Rectifying the SLC-off Images

The Scan Line Corrector (SLC), which compensates for the forward motion of Landsat 7, failed on 31st May 2003. It was

later found out that this was due to a mechanical failure and permanent in nature. The resulting images, called SLC-off, have the imaged area duplicated or lost, with width that increases toward the scene edge. It is noted that the SLC-off effects are most pronounced along the edge of the scene and gradually diminish toward the centre of the scene. The middle of the scene, approximately 22 kilometers wide on a Level 1 (L1G, L1Gt, L1T) product, contains very little duplication or data loss, and this region of each image is very similar in quality to previous ("SLC-on") Landsat 7 image data. An estimated 22 per cent of any given scene is lost because of the SLC failure. The maximum width of the data gaps along the edge of the image would be equivalent to one full scan line, or approximately 390 to 450 meters. The precise location of the missing scan lines will vary from scene to scene (USGS, 2009a).

The SLC-off images have posed pertinent challenges to satellite remote sensing analysts to make use of the data with appropriate corrections. Several approaches have been suggested for gap-filling including image segmentation approaches. A simple approach for gap-filling has been suggested by the USGS (2008).

Following the approach suggested for gap-filling by USGS mentioned above, the raw images after extraction are processed for correction. Coinciding with the date of acquisition of image selected for analysis, corresponding anniversary images are also selected for gap-filling. The anniversary images can correspond to the immediate previous month or the previous year. Caution is exercised for the selection of the anniversary images with respect to the corresponding season. Initially, the data corresponding to these two time periods is subjected to image enhancement through a combination of histogram equalization and linear stretching. Once the two images are matched, the gaps in the first image (acquired on 20th January 2009) are filled by that

of the second image (acquired on 5th February 2009) through a Boolean logic wherein, the first image covers the second image except where zero. The resultant image would have the gap-filled with the histogram equalized anniversary image.

3.4 Image Classification

The false color composite of the image are obtained by combining different band types depending upon the requirement, here bands 2, 3 and 4. Subsequently, the classification of the multi-spectral remote sensing data is carried through a multi-stage classification process: unsupervised and supervised. In the unsupervised classification the number of clusters for classification is 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 cover and some of the land cover features obtained from unsupervised classification. The signatures generated for each of the land cover were verified with the composite image. Further, the classified images were reclassified to note the expansion of built-up during 2000 and 2009 (Figure 1). First a cross-tabulation was produced to note the expansion of built-up during 2000 and 2009. This was then reclassified to depict the changes in built-up areas from 2000 to 2009.

3.5 Estimation of Landscape Metrics

The landscape metrics are estimated using Fragstats (McGarigal *et al.*, 2002), a popular software program used to analyze spatial pattern of categorical maps like land use and land cover maps. The landscape metrics considered for the study were class-level metrics like Total Class Area (CA), Percentage of Landscape (PLAND), Clumpiness Index (CLUMPY) Normalized Landscape Shape Index (nLSI),

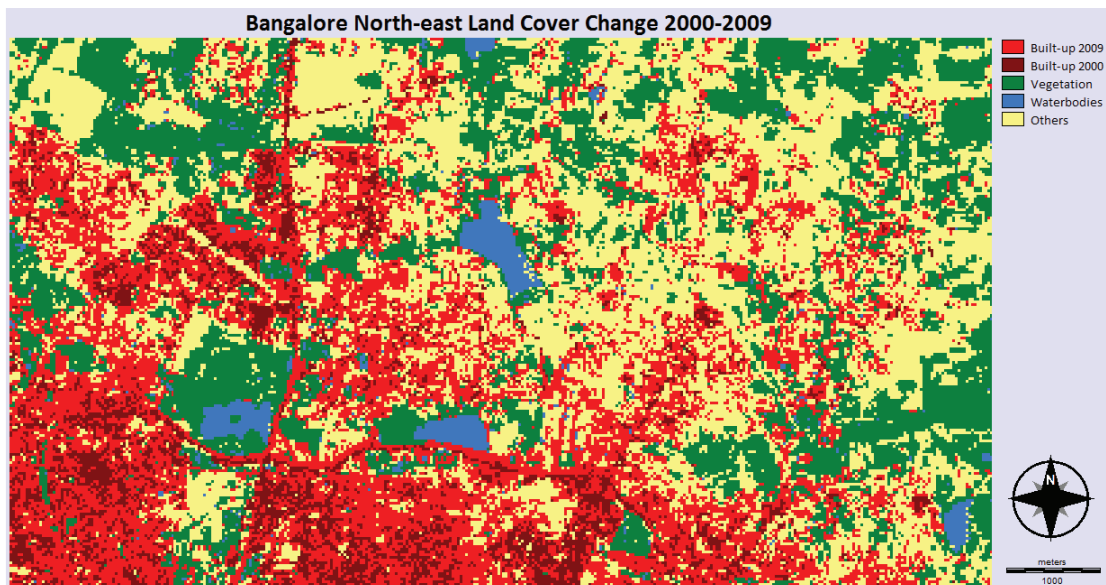


Figure 2. Bangalore North-east Land Cover Change 2000-2009.

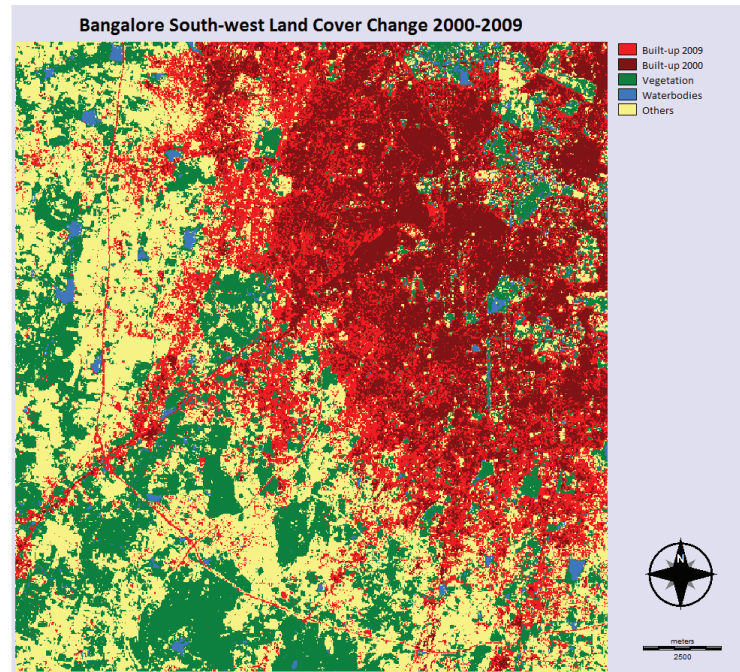


Figure 3. Bangalore South-west Land Cover Change 2000-2009.

while the landscape-level metrics were Largest Shape Index (LSI), Largest Patch Index (LPI), Shannon's Diversity Index (Entropy) and Contagion Index (CONTAG).

4. Results and Discussions

4.1 Land Cover Change

Based on the land cover classification for Bangalore over the two time periods (2000 and 2009) land cover change maps were prepared. Accordingly, a land cover change map for the entire Bangalore city landscape (Figure 1), a land cover change map for the north-east subset (Figure 2) and south-west subset (Figure 3) were also prepared. These classified outputs for these two periods were subjected to further analysis for estimation of metrics and evaluation.

The analysis revealed that increase in built-up area at the city level was by about 164.62 km², while the vegetation and water bodies decreased by about 285.72 km² and 7.2 km² respectively. In the south-west subset, the built-up area increased by 71.94 km² whereas the vegetation cover decreased from 166.29 km² to 91 km². The category 'others' includes all types of land cover other than built up, vegetation and water bodies, i.e. it includes open spaces, fallow land, rocky outcrop, abandoned quarry pits, etc. This category has decreased by 1.82 km². In the north-east subset the total built-up area has increased by 16.19 km², whereas the other non-built-up areas comprising of vegetation; water bodies; open spaces and others decreased by 15.45 km², 0.18 km², 1.3 km² respectively. The extents of land cover change although indicates the magnitude, doesn't throw light on the implications at landscape level. Hence, some of the landscape metrics was estimated to ascertain the implications of land

cover change at different scales.

4.1.1 Total Class Area (CA)

Class area is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular patch type. In addition to its direct interpretive value, class area is used in the computations for many of the class and landscape metrics. CA equals the sum of the areas (m²) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area. $CA > 0$, without limit.

The total class area of built-up in 2000 was 18540.48 Ha which has almost doubled in 2009 by 35002.47 Ha, whereas vegetation and water bodies have decreased during the period. In the south-west subset, the total class area of built-up increased from 8522.22 Ha to 15716.67 Ha, an increase of almost 84 %. However, in the north-east subset the increase of total class area of built-up has been 228 % from 711.23 Ha to 2330.74 Ha. Similarly in north-east and south-west subsets the total built-up area has increased from 2000 to 2009. This reveals that although the magnitude of change appeared marginal the proportional change has been significantly different for these two subsets.

4.1.2 Percentage of Landscape (PLAND)

PLAND equals the sum of the areas (m²) of all patches of the corresponding patch type, divided by total landscape area (m²), multiplied by 100 (to convert to a percentage). In other words, PLAND equals the percentage the landscape comprised of the corresponding patch type. Percentage of landscape quantifies the proportional abundance of each

Table 1. Class Metrics for 2000 and 2009.

| Region Subsets / | Time | 2000 | | | | 2009 | | | |
|------------------|--------|----------|------------|--------------|----------|----------|------------|--------------|----------|
| | Metric | Built-up | Vegetation | Water bodies | Others | Built-up | Vegetation | Water bodies | Others |
| Bangalore | CA | 18540.48 | 84063.40 | 4054.64 | 49385.76 | 35002.47 | 55490.48 | 3334.77 | 60893.63 |
| | PLAND | 11.88 | 53.87 | 2.60 | 31.65 | 22.59 | 35.81 | 2.15 | 39.30 |
| | LSI | 191.34 | 186.19 | 48.06 | 266.95 | 128.20 | 157.36 | 74.34 | 183.88 |
| | LPI | 5.66 | 46.13 | 0.30 | 2.08 | 17.85 | 5.69 | 0.10 | 6.77 |
| | CLUMPY | 0.54 | 0.60 | 0.78 | 0.49 | 0.74 | 0.70 | 0.62 | 0.65 |
| South-west (SW) | nLSI | 0.41 | 0.22 | 0.22 | 0.35 | 0.20 | 0.19 | 0.37 | 0.22 |
| | CA | 8522.33 | 16629.59 | 479.20 | 10960.54 | 15716.67 | 9132.09 | 709.03 | 10777.94 |
| | PLAND | 23.29 | 45.45 | 1.31 | 29.95 | 43.25 | 25.13 | 1.95 | 29.66 |
| | LSI | 94.06 | 93.16 | 25.32 | 131.34 | 57.21 | 68.41 | 43.54 | 83.63 |
| | LPI | 17.63 | 30.92 | 0.12 | 8.83 | 39.58 | 3.42 | 0.08 | 9.66 |
| North-east (NE) | CLUMPY | 0.62 | 0.62 | 0.67 | 0.48 | 0.77 | 0.73 | 0.52 | 0.67 |
| | nLSI | 0.29 | 0.21 | 0.33 | 0.36 | 0.13 | 0.21 | 0.47 | 0.23 |
| | CA | 711.23 | 3133.42 | 132.23 | 2330.63 | 2330.74 | 1588.40 | 150.23 | 2194.05 |
| | PLAND | 11.28 | 49.68 | 2.10 | 36.95 | 37.21 | 25.36 | 2.40 | 35.03 |
| | LSI | 50.52 | 40.44 | 8.83 | 57.77 | 39.17 | 31.89 | 13.42 | 48.31 |
| North-east (NE) | LPI | 1.05 | 38.20 | 0.70 | 5.68 | 29.48 | 3.55 | 0.64 | 18.23 |
| | CLUMPY | 0.38 | 0.59 | 0.79 | 0.45 | 0.63 | 0.70 | 0.69 | 0.54 |
| | nLSI | 0.55 | 0.21 | 0.21 | 0.34 | 0.23 | 0.23 | 0.30 | 0.30 |

patch type in the landscape. Like total class area, it is a measure of landscape composition important in many ecological applications. However, because PLAND is a relative measure, it may be a more appropriate measure of landscape composition than class area for comparing among landscapes of varying sizes.

When looking at Bangalore as a whole Table 1 indicates that the percentage of land cover type or the dominant patch type in 2000 included vegetation and other type of land cover with 53.87 % and 31.65 % of the landscape. However by 2009, the dominant patch type was vegetation comprising 39.3 % of the landscape, while built-up patches had doubled during the period. When analyzed for the north-east and south-west subsets, vegetation was the dominant patch type of the landscape in the year 2000 while it changed to built-up by the year 2009 for both the subsets. This indicates that the proportional change in land cover over the years, whether the open spaces, vegetation and water bodies, all have succumbed due to rapid urban growth.

4.1.3 Landscape Shape Index (LSI)

Landscape shape index provides a standardized measure of total edge or edge density that adjusts for the size of the landscape. LSI = 1 when the landscape consists of a single square (or almost square) patch; LSI increases without limit

as landscape shape becomes more irregular and/or as the length of edge within the landscape increases.

As the built-up area in the region increased, the landscape shape is getting more regular from 2000 to 2009, which was evident with the decreasing value of the index from 180.82 to 141.65 at the level of landscape metric (Table 2). The same trend was revealed for south-west and north-east subsets, indicating that the landscape is getting more regular over the duration. Further, even at the level of class metric (Table 1), LSI for built-up class decreased for the city level and the two subsets.

4.1.4 Largest Patch Index (LPI)

Largest patch index at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. LPI equals the area (m²) of the largest patch of the corresponding patch type divided by total landscape area (m²), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percentage of the landscape comprised by the largest patch.

The dominant patch type in 2000 for Bangalore was vegetation, which changed to built-up being the dominant patch type in 2009 having LPI of 17.85 % (Table 1). For south-west and north-east subsets the trend is similar,

Table 2. Landscape Metrics for 2000 and 2009.

| Metric / Region / Subsets | SHDI | | LSI | | LPI | | CONTAG | |
|---------------------------|------|------|--------|--------|-------|-------|--------|-------|
| | 2000 | 2009 | 2000 | 2009 | 2000 | 2009 | 2000 | 2009 |
| Bangalore | 1.05 | 1.16 | 180.82 | 141.65 | 46.13 | 17.85 | 35.95 | 43.32 |
| South-west (SW) | 1.12 | 1.15 | 92.04 | 62.27 | 30.92 | 39.58 | 31.76 | 36.27 |
| North-east (NE) | 1.04 | 1.17 | 41.50 | 35.87 | 38.20 | 29.48 | 34.61 | 30.72 |

wherein the dominant patch type in 2000 was vegetation and in 2009 it has made way for built-up being the dominant patch type for the entire landscape. LPI at the landscape level (Table 2) for Bangalore and north-east subset decreased during 2000 to 2009 indicating that the patches are getting more and more dispersed, resulting in sprawl in the region. However, for the south-west subset the LPI increased from 2000 to 2009 highlighting the fact that the patches are getting more compact.

4.1.5 Clumpiness Index (CLUMPY)

Clumpiness index is calculated from the adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch types) appear side-by-side on the map. The value is 0 when the class is maximally disaggregated (i.e., subdivided into one cell patches) and is 1 when the class is maximally clumped.

In the present case, the clumpiness of built-up patch type in the city was 0.54 implying scattered patches in 2000, but it is reached 0.74 suggesting significant aggregation by 2009. However, the water body patch type which was 0.78 was maximally aggregated in 2000 has reduced with a value 0.62 during 2009. The south-west and north-east subsets also show similar trend with increasing clumpiness index for built-up and decreasing index for water bodies.

4.1.6 Normalized Landscape Shape Index (nLSI)

Normalized landscape shape index (nLSI) is the normalized version of the landscape shape index (LSI) and as such, provides a simple measure of class aggregation or clumpiness. The normalization essentially rescales LSI to the minimum and maximum values possible for any class area. nLSI essentially measures the degree of aggregation given this variable range. The normalization essentially rescales LSI to the minimum and maximum values possible for any class area. When the patch type is relatively rare (say $P_i < 0.1$) or relative dominant (say $P_i > 0.5$), the range between the minimum and maximum total edge (or perimeter) is relatively small; whereas when the patch type is intermediate in abundance (say $P_i = 0.5$), the range is quite large. nLSI essentially measures the degree of aggregation given this variable range.

From the computation of nLSI for the Bangalore region (Table 1), it revealed that built-up patches compacted from 0.40 to 0.19 during 2000 to 2009. On the contrary, the index for water bodies increased from 0.21 in 2000 to 0.37 in 2009. Analyzing the same index for south-west and north-east subsets built-up patches have compacted for the period 2000 – 2009, from 0.29 to 0.13 and 0.54 to 0.23 respectively. However, the index for water bodies for all regions has increased, suggesting that this patch type became more dispersed or scattered across the landscape.

4.1.7 Shannon's Diversity Index (SHDI)

Shannon's diversity index is a popular measure of diversity in community ecology, applied here to patches in the landscape. SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SHDI increases as the number of different patch types (i.e. patch richness) increases and/or the proportional distribution of area among patch types becomes more equitable. Moreover, it is demonstrated that heterogeneity (pattern) and entropy can be considered as equivalent terms. In the present study, entropy is used as a measure of the fragmentation process, i.e. a measure of dispersion of built-up patches. Lower the index indicates compactness of the patches, while higher the index (not greater than $\log(n)$) indicates more dispersion of the patches.

Increasing degrees of fragmentation coincide with increasing entropy, increasing number of patches and decreasing habitat area. The landscape heterogeneity is assumed equivalent to uncertainty or entropy (Joshi *et al.*, 2006). In the present landscape for Bangalore, entropy has increased from 1.0453 in 2000 to 1.1631 in 2009 (Table 2). Similarly in the north-east subset the entropy increased by 0.1302 from 2000 to 2009, as for south-west subset the increase is 0.0312. This shows that in all parts of the city built-up patches increased with increased fragmentation of the vegetation but at varying degree. The north-east subset showed higher increasing value of entropy as the region is undergoing major changes due to significant increase in built-up areas while in the south-west subset there is marginal increase in entropy value as the growth has almost reached a level of saturation as far as increase in built-up areas is considered. This suggests that the heterogeneity of the landscape has increased during the study period.

4.1.8 Contagion (CONTAG)

When a single class occupies a very large percentage of the landscape, contagion is high, and vice versa. CONTAG approaches 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of all pair wise adjacencies). CONTAG = 100 when all patch types are maximally aggregated; i.e., when the landscape consists of single patch.

Contagion value for Bangalore landscape has increased from 35.95 in 2000 to 43.32 in 2009, also for the south-west subset the value has increased from 31.75 to 36.27 over the period indicating that the dominant patch type (built-up) is aggregating more, while in the north-east subset the value decreased from 34.60 in 2000 to 30.71 in 2009, depicting that this subset is experiencing a different transition.

4.2 Discussion

Bangalore has witnessed dramatic increase of built-up areas as revealed by the land cover change analyses wherein the

increase in built-up areas at the city landscape has been by almost 89 % or nearly doubled within less than a decade. The amount of land cover change gives evidence to magnitude of urban growth leading to sprawl on the outskirts and further densification in the inner parts as well. The increase of built-up areas has taken place taking toll of vegetation and other open spaces that is a cause of concern. As evident from the analysis of the two subsets, the proportional change of built-up has been significant in the north-east subset in comparison to the south-west subset. From the planning perspective, it would be imperative that such growth is anticipated in the land-use plans.

Further, on careful evaluation of the metrics applied to the city landscape and the two subsets, most of the metrics suggest similar trends while capturing respective variations in magnitude of the concerned parameters. However, two metrics: LPI and Contagion depict variations across the different extents and time. In the estimation of LPI for the class metrics, it clearly suggested for the three extents that the largest patch type changed from vegetation to built-up over the study period. However, on estimation of the LPI for the landscape metrics, the values of LPI decreased for the city landscape and north-east subset, while it increased for the south-west subset during 2000 to 2009. Thus, indicating the changing patch dominance across the different extents. In other words, although built-up patch emerged as the largest patch type by 2009 from 2000; the dominance of the largest patch types had actually decreased with the transition from vegetation to built-up at the city landscape and south-west subset, while the dominance of largest patch increased with the transition from vegetation to built-up for the north-east subset. The Contagion index too represents varied responses for the three extents. Interestingly, it suggests that for the city landscape and south-west subset, the value increased while it decreased marginally for the north-east subset. This clearly indicates that the dominant patch type is aggregating more for the city landscape and south-west subset and conversely for the north-east subset. Perhaps, this can be an early warning of the changing landscape structure that could suggest that if the present trend continues, the dominance of built-up patch would eventually increase at the city's landscape level too.

Despite best efforts, there are limitations to the present study. The analysis was confined to spatial resolution of satellite remote sensing data with 30 m and temporal resolution of about 9 years. It would be a worthwhile exploration to evaluate the effect of scale (say less 30 m) in the estimation of these metrics and their effectiveness in capturing the patterns. The computation of metrics rested on the land cover classification, which had an average accuracy of 70 % for both dates.

Another important aspect of this study was utilising the SLC-off Landsat ETM+ satellite remote sensing data. The data gap in the SLC-off data was compensated through histogram equalisation and image enhancement techniques

to the data obtained for the same region although with different pass (time of acquisition) and corresponding to the same season. Employing the methods described, it is demonstrated that despite the scan line corrector failure, the data loss is compensated by the near time data. However, there can be issues of calibration for the spectral reflectance captured by the SLC-off Landsat ETM+ sensors if the data fill is pursued using data obtained from different sensors. Furthermore, since late 2008 USGS has made available the archival data acquired by the Landsat missions at no charge (USGS, 2009b). This reduces the burden of data access especially for developing nations and opens up enormous opportunities for investigations on land-use and land-cover changes and their landscape characterisation.

5. Landscape Metrics in Land-Use Policy and Planning

An important aspect that was revealed in the land cover maps for the three extents was rapid increase of built-up areas, with increased dominance of built-up patch type and aggregation. In the south-west subset, with the increasing sprawl around the recently constructed ring roads and areas within has contributed to the land cover change significantly. Certain areas that harbored green cover adjoining the rural hinterland offered contiguity patches of natural landscape. However as a result of land cover changes; this has led to the isolation of the Bangalore University – Jnanabharathi campus amidst the urban (built-up) landscape. Among the causes for isolation of this campus amidst the urban outgrowth was also the creation of an outer ring road during 2003-05. Since then, there have been significant land cover changes along the ring road also factored by the real-estate boom and limited regulation on such external development. It is clearly evident that a poor land-use policy with any appreciation to landscape ecology has led to the isolation and fragmentation of habitats. As for the north-east subset of the city it is seen that the process of unplanned and uncoordinated growth is taking place at a very faster rate resulting in the dispersed urban patches in the radial form followed by the ribbon form all along the international airport corridor, having high impacts on the environment due to loss of vegetation and open spaces.

As noted earlier, land-use policy is governed by the preparation of development plans / master plans through zoning of land-use. The current process of planning is governed by the Karnataka Town and Country Planning (KTCP) Act and Karnataka Urban Development Authorities Act. According to the provisions of the act, the respective Development Authority is mandated to prepare land-use plans indicating the zoning for permissible land-uses once in every ten years. This is prepared based on projected future population and with allocations of land-use based on certain assumptions. This doesn't ascribe to the landscape level characterization including some of the sprawl and landscape specific spatial metrics. Moreover, the detailed master plans are drawn out at the scale of planning districts (Bangalore

Metropolitan Area is sub-divided into 47 planning districts), each of which is approximately the extent of the smaller subset – north-east subset.

Further, it is feared that in the absence of appreciation to landscape ecology further isolation and fragmentation of habitats and dispersed growth in the periphery of the city will be inevitable. It is thus argued that when landscape metrics are considered as potential instruments in the preparation of future land-use zoning plans, they can aid in guiding the land-use policy to avoid isolation and fragmentation of such habitats. The landscape metrics when used in conjunction with existing norms can facilitate land-use planning to acknowledge the landscape dynamics and avoid fragmentation of habitats.

6. Conclusion

It is imperative that future studies can attempt to address the growth pattern and landscape fragmentation at varied spatial scales. Furthermore, it would also be prudent to analyse the metrics in light of the comprehensive development plan – revised master plan prepared by Bangalore Development Authority and evaluate the implications. This study quantified the land cover change for Bangalore during 2000 to 2009 and studied the effect of varied spatial extents on the estimation of landscape metrics. Some of the landscape metrics were estimated to demonstrate their utility, combined with the spatial analysis to drive the point of considering landscape metrics as potential instruments in the preparation of land-use policy for future urban growth.

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