Spatial Metrics based Landscape Structure and Dynamics Assessment for an emerging Indian Megalopolis

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Abstract—**Human-induced land use changes are considered the prime agents of the global environmental changes. Urbanisation and associated growth patterns (urban sprawl) are characteristic of spatial temporal changes that take place at regional levels. Unplanned urbanization and consequent impacts on natural resources including basic amenities has necessitated the investigations of spatial patterns of urbanization. A comprehensive assessment using quantitative methods and methodological understanding using rigorous methods is required to understand the patterns of change that occur as human processes transform the landscapes to help regional land use planners to easily identify, understand the necessary requirement. Tier II cities in India are undergoing rapid changes in recent times and need to be planned to minimize the impacts of unplanned urbanisation. Mysore is one of the rapidly urbanizing traditional regions of Karnataka, India. In this study, an integrated approach of remote sensing and spatial metrics with gradient analysis was used to identify the trends of urban land changes. The spatial and temporal dynamic pattern of the urbanization process of the megalopolis region considering the spatial data for the five decades with 3 km buffer from the city boundary has been studied, which help in the implementation of location specific mitigation measures.**

The time series of gradient analysis through landscape metrics helped in describing, quantifying and monitoring the spatial configuration of urbanization at landscape levels. Results indicated a significant increase of urban built-up area during the last four decades. Landscape metrics indicates the coalescence of urban areas occurred during the rapid urban growth from 2000 to 2009 indicating the clumped growth at the center with simple shapes and dispersed growth in the boundary region with convoluted shapes.

Keywords-Landscape Metrics; Urbanisation; Urban Sprawl; Remote sensing; Geoinformatics; Mysore City, India.

I. INTRODUCTION

Patterns and processes of globalization and consequent urbanization are the factors influencing contemporary land use trends and also posing challenges for sustainable land uses [9]. Analysis of landscape patterns and dynamics has become the primary objectives of landscape, geographical and ecological studies in recent times. Landscape changes involving large scale deforestation are the primary drivers of the climate change [52], [11] earth dynamics [51]. The spatial patterns of landscape transformation through time are undoubtedly related to changes in land uses [41].Landscape changes are diverse but very often influenced by regional policies [6]. The main driving factors for global environmental changes are been identified as agriculture intensification [17], [19], urbanisation [40] in the context of local policies[24,30,34]. The socio-economic impacts are often determinants of the type of land use within a given region, which in turn affect environmental issues [32], [35]. In order to address these urbanization challenges without compromising the environment values and their local sustainance, land use planning and necessary supporting data are crucial, especially to developing countries under severe environmental and demographic strains [12].

Urbanization is a irreversible process involving changes in vast expanse of land cover with the progressive concentration of human population. Urbanising landscapes will invariably have high population density that might lead to lack of infrastructure and provision of basic facilities. The urban population in India is growing at about 2.3% per annum with the global urban population increasing from 13% (220 million in 1900) to 49% (3.2 billion, in 2005) and is projected to escalate to 60% (4.9 billion) by 2030 [42]. Population of Mysore is 1 million as per census 2001 compared to 0.653 million (1991).

The increase in urban population is in response to the growth in urban areas due to migration from either rural area or other cities. There are 48 urban agglomerations (Mega cities, Tier I) having a population of more than one million in India (in 2011). Tier 1 cities have reached the saturation level evident from lack of basic amenities, traffic bottlenecks, higher concentrations of pollutants, higher crime rates due to burgeoning population. In this context, well planned Tier 2 cities offer humongous potential with the scope for meeting the basic amenities required. This entails the provision of basic infrastructure (like roads, air and rail connectivity), adequate social infrastructure (such as educational institutions, hospitals, etc.) along with other facilities. Modeling and visualization of urban growth based on the historical spatio-temporal data would help in identifying the probable regions of intense urbanization and sprawl.

Urban sprawl implies a sharp imbalance between urban spatial expansion and the underlying population growth [5]. Sprawl of human settlements is a major driving force of land use and land cover changes [3], [16] with detrimental impacts on natural resources and local ecology. Sprawl process entails the growth of the urban area from the urban center towards the periphery of the city municipal jurisdiction. These small pockets in the outskirts lack basic amenities like supply of treated water, electricity and sanitation facilities. Sprawl is associated with high negative impacts and especially the increasing dependency for basic amenities [50], the need for more infrastructure [5], the loss of agricultural and natural land, higher energy consumption, the degradation of peri-urban ecosystems etc., [23], [25], [27]. Understanding the sprawl over past few decades is crucial for the regional administration to handle the population growth and provide basic amenities while ensuring the sustainable management of local natural resources.

The information about the current and historical land cover/land use plays a major role for urban planning and management [54]. Mapping landscapes on temporal scale provide an opportunity to monitor the changes, which is important for natural resource management and sustainable planning activities. In this context, “Density Gradient” with the time series spatial data analysis is potentially useful in measuring urban development [50]. This article presents the temporal land use analysis and adopts the density gradient approach to evaluate and monitor landscape dynamics and further explains the landscape pattern through use of landscape metrics.

Knowledge of the spatio-temporal pattern of the urbanization is important to understand the size and functional changes in the landscape. Spatial metrics were computed to quantify the patterns of urban dynamics, that aid in understanding spatial patterns of various land cover features in the region [33]. Quantifying the landscape pattern and its change is essential for monitoring and assessing the urbanization process and its ecological consequences [31], [20], [27], [46]. Spatial metrics have been widely used to study the structure, dynamic pattern with the underlying social, economic and political processes of urbanization [21], [22], [45], [53]. This has provided useful information for implementing holistic approaches in the regional land-use planning [48]. [1] reviews the spatial characteristics of metropolitan growth including analysis [2], [4], [14], [28] the study of urban landscapes. Applications of landscape metrics include landscape ecology (number of patches, mean patch size, total edge, total edge and mean shape), geographical applications by taking advantage of the properties of these metrics [15], [39], [44] and measurement of ecological sustainability [43].

These studies also confirmed that Spatio-temporal data along with landscape metrics would help in understanding and evaluating the spatio temporal patterns of landscape dynamics required for appropriate management measures.

According to the City Development Plan (CDP), a 20-year vision document for Mysore, there has been a 70% increase in the city’s spatial extent since 2001, resulting in the higher degree of sprawl at outskirts. Objectives of this study are to understand and interpret the evolving landscape dynamics through temporal analysis of land use land cover pattern taking 3km buffer, through spatial metrics.

II. Study Area

Mysore city in Karnataka is one of the tier II cities and the cultural capital of India with a hub of industrial activities. It is designated as the 2nd capital of Karnataka. Mysore city is 128 sq. km in area and is one of the most preferred destinations for industries including IT hubs other than Bangalore.It is a main trading centre of silk and sandalwood. Mysore district is bounded by Mandya to the northeast, Chamrajnagar to the southeast, Kerala state to the south, Kodagu to the west, and Hassan to the north. It has an area of 128.42 km² and a population of about 1 million (2001 census). The district lies in the southern Deccan plateau, within the watershed region of Kaveri River, which flows through the northern and eastern parts of the district.

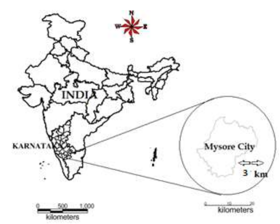


Figure 1. Study Area: Mysore city and 3 km buffer

III. Materials Used

DATA	Year	Purpose
Landsat Series MSS(57.5m)	1973	Landcover and Land use analysis
Landsat Series TM (28.5m) and ETM	1989, 1999,	Landcover and Land use analysis
IRS p6: Liss-4 MX data (5.6m)	2009	Landcover and Land use analysis
Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales		To Generate boundary and Base layer maps.
Field visit data – captured using GPS		For geo-correcting and generating validation dataset

TABLE I. Materials Used In Analysis

IV. Method

A two-step approach was adopted to chart the direction of the City’s development, which includes (i) a normative approach to understand the land use and (ii) a gradient approach of 1km radius to understand the pattern of growth during the past 4 decades. Various stages in the data analysis are:

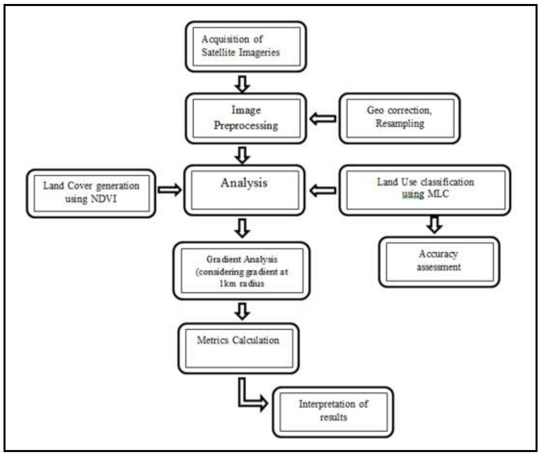


Figure 2. Procedure followed to understand the spatial pattern of landscape change

A. Preprocessing

The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. The Landsat satellite 1973 images have a spatial resolution of 57.5 m x 57.5 m (nominal resolution) and 1989 - 1999 data of 28.5 m x 28.5 m (nominal resolution) were resampled to uniform 30 m for intra temporal comparisons. Latest data of IRS P6 of spatial resolution 5.6 m was procured from NRSC, Hyderabad (http://www.nrsc.gov.in).

Vegetation Cover Analysis: Normalized Difference Vegetation index (NDVI) was computed to understand the temporal dynamics of the vegetation cover. NDVI value ranges from values -1 to +1, where -0.1 and below indicate soil or barren areas of rock, sand, or urban buildup. NDVI of zero indicates the water cover. Moderate values represent low density vegetation (0.1 to 0.3) and higher values indicate thick canopy vegetation (0.6 to 0.8).

B. Land use analysis

Land use categories listed in Table 2 were classified with the training data (field data) using Gaussian maximum likelihood supervised classier. The analysis included generation of False Color Composite (bands – green, red and NIR), which helped in identifying heterogeneous area. Polygons were digitized corresponding to the heterogeneous patches covering about 40% of the study region and uniformly distributed over the study region.

These training polygons were loaded in pre-calbrated GPS (Global position System). Attribute data (land use types) were collected from the field with the help of GPS corresponding to these polygons. In addition to this, polygons were digitized from Google earth (www.googleearth.com) and Bhuvan (bhuvan.nrsc.gov.in), which were used for classifying latest IRS P6 data. These polygons were overlaid on FCC to supplement the training data for classifying landsat data.

Gaussian maximum likelihood classifier (GMLC) is applied to classify the data using the training data. GMLC uses various classification decisions using probability and cost functions [10] and is proved superior compared to other techniques. Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Estimations of temporal land uses were done through open source GIS (Geographic Information System) - GRASS (Geographic Resource Analysis Support System, http://ces.iisc.ernet.in/grass).

70% of field data were used for classifying the satellite data and the balance 30% were used in validation and accuracy assessment. Thematic layers were generated of classified data corresponding to four land use categories.

Evaluation of the performance of classifiers [36], [37], [13] is done through accuracy assessment techniques of testing the statistical significance of a difference, comparison of kappa coefficients [8], [47] and proportion of correctly allocated classes [12] through computation of confusion matrix. These are most commonly used to demonstrate the effectiveness of the classifiers [8], [7], [29].

Further each zone was divided into concentric circle of incrementing radii of 1 km (figure 2) from the center of the city for visualising the changes at neighborhood levels. This also helped in identifying the causal factors and the degree of urbanization (in response to the economic, social and political forces) at local levels and visualizing the forms of urban sprawl. The temporal built up density in each circle is monitored through time series analysis.

TABLE I. a LAND USE CATEGORIES

Land use Class	Land uses included in the class
Urban	This category includes residential area, industrial area, and all paved surfaces and mixed pixels having built up area.
Water bodies	Tanks, Lakes, Reservoirs.
Vegetation	Forest, Cropland, nurseries.
Others	Rocks, quarry pits, open ground at building sites, kaccha roads.

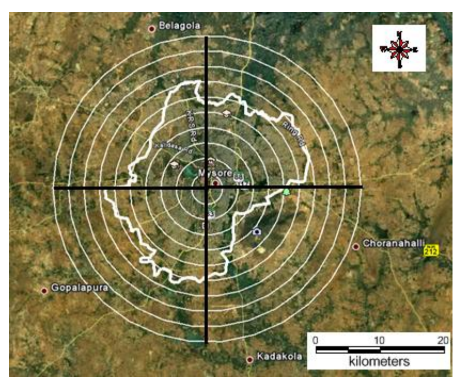


Figure 3. Google earth representation of the study region

C. Urban sprawl analysis

Direction-wise Shannon's entropy (Hn) is computed (equation 1) to understand the extent of growth: compact or divergent [26], [49], [38]. This provides an insight into the development (clumped or disaggregated) with respect to the geographical parameters across ‘n’ concentric regions in the respective zones.

$$Hn = -\sum_{i=1}^{n} Pi \log(Pi) \qquad \ldots\ldots \qquad (1)$$

Where Pi is the proportion of the built-up in the ith concentric circle and n is the number of circles/local regions in the particular direction. Shannon’s Entropy values ranges from zero (maximally concentrated) to log n (dispersed growth).

D. Spatial pattern analysis

Landscape metrics provide quantitative description of the composition and configuration of urban landscape. These metrics were computed for each circle, zonewise using classified landuse data at the landscape level with the help of FRAGSTATS [34].

Urban dynamics is characterised by 11 spatial metrics chosen based on complexity, centrality and density criteria. The metrics include the patch area, edge/border, shape, epoch/contagion/ dispersion and are listed in Table II.

V. Results & Discussion

1) Land use Land Cover analysis:

a) Vegetation cover analysis: Vegetation cover of the study area assessed through NDVI (Figure 3), shows that area under vegetation has declined to 9.24% (2009) from 51.09% (1973). Temporal NDVI values are listed in Table III.

b) Land use analysis: Land use assessed for the period 1973 to 2009 using Gaussian maximum likelihood classifier is listed Table IV and the same is depicted in figure 4. The overall accuracy of the classification ranges from 75% (1973), 79% (1989), 83% (1999) to 88% (2009) respectively. Kappa statistics and overall accuracy was calculated and is as listed in Table V.

c) There has been a significant increase in built-up area during the last decade evident from 514% increase in urban area. Other category also had an enormous increase and covers 166 % of the land use. Consequent to these, vegetation cover has declined drastically during the past four decades. The water spread area has increased due to the commissioning of waste water treatment plants (ex. Vidyaranyapura, Rayankere, Kesare) during late 90’s and early 2000.

Year	Vegetation		Non vegetation	
	%	Ha	%	Ha
1973	51.09	10255.554	48.81	9583.83
1989	57.58	34921.69	42.42	8529.8
1999	44.65	8978.2	55.35	11129.77
2009	09.24	1857.92	90.76	19625.41

TABLE II. TEMPORAL LAND COVER DETAILS.

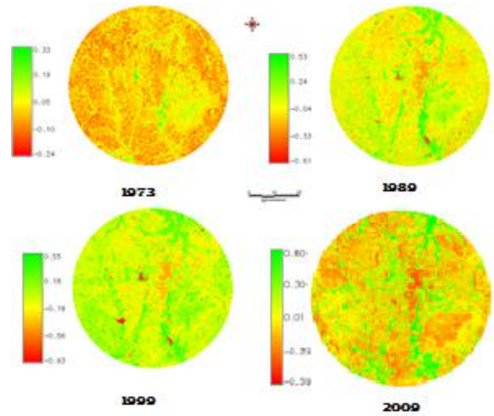


Figure 4. Temporal Land cover changes during 1973 – 2009

2) Built up Density Gradient Analysis: Built up density was minimal and the value ranges from 0.026 (considering 3km buffer) to 0.036 (without considering 3km buffer) in the North east direction (in 1973). The federal government’s policy in 1990’s to develop tier 2 cities led to the increase in urban area. There was a sharp growth in the region in almost all direction from 1999 till 2009, maximum value reaching 0.216 in the NE direction (considering 3km buffer) and 0.42 (without considering the buffer). This can be attributed to development of this region with the IT & BT industry which were earlier confined to Bangalore.

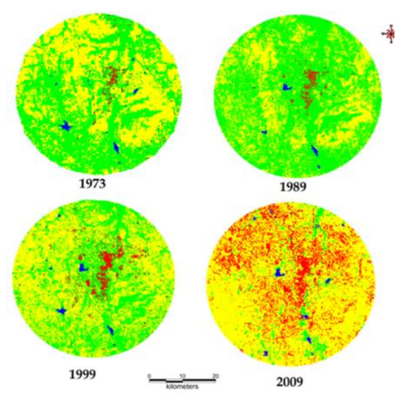


Figure 5. Classification output of Mysore

Land use / Year	Urban	Vegetation	Water	Others
1973	222.93	10705.68	124.47	9054.99
1989	229.41	13242.51	78.75	6557.4
1999	730.8	8360.1	117.9	10899.2
2009	3757.489	1159.336	142.58	15050.5
Total (Land in ha)		20108.91		

TABLE III. TEMPORAL LAND USE DETAILS FOR MYSORE

	Indicators	Formula	Range
	Category : Patch area metrics		
1	Largest Patch Index(Percentage of landscape)(LPI)	$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$ a_{ij} = area (m^2) of patch ij A= total landscape area	$0 \leq LPI \leq 100$
2	Number of Urban Patches (NPU)	$NPU = n$ NP equals the number of patches in the landscape.	NPU>0, without limit.
3	Patch density(PD)	f(sample area) = (Patch Number/Area) * 1000000	PD>0
4	Perimeter-Area Fractal Dimension (PAFRAC)	$\frac{2}{\frac{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}(\ln P_{ij}.\ln a_{ij})\right]-\left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}{\left(N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^{2}\right)-\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)}}$ Perimeter-Area Fractal Dimension a_{ij} = area (m^2) of patch ij. p_{ij}=perimeter (m) of patch ij. N= total number of patches in the landscape	$1 \leq PAFRAC \leq 2$
	Category : Shape metrics		
5	Normalized Landscape Shape Index (NLSI)	$NLSI = \frac{\sum_{i=1}^{i=N}\frac{p_i}{s_i}}{N}$ Where s_i and p_i are the area and perimeter of patch i, and N is the total number of patches.	$0 \leq NLSI < 1$
6	Landscape Shape Index (LSI)	$LSI = e_i / \min e_i$ e_i =total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i=minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces.	LSI>1, Without Limit
	Category: Compactness/ contagion / dispersion metrics		
7	Clumpiness	$CLUMPY = \left[\begin{matrix}\frac{G_i - P_i}{P_i} \; for G_i < P_i \, \& \, P_i < 5, else \\ \frac{G_i - P_i}{1 - P_i}\end{matrix}\right]$ $G_i = \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik}\right) - \min e_i}\right)$ g_{ii} =number of like adjacencies between pixels of patch type g_{ik} =number of adjacencies between pixels of patch types i and k. P_i =proportion of the landscape occupied by patch type (class) i.	$-1 \leq CLUMPY \leq 1.$
8	Percentage of Like Adjacencies (PLADJ)	$PLADJ = \left(\frac{g_{ii}}{\sum_{k=1}^{m} g_{ik}}\right)(100)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type g_{ik} = number of adjacencies between pixels of patch types i and k	0<=PLADJ<=100
9	Cohesion	$Cohesion = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{IJ} \sqrt[2]{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt[2]{A}}\right]^{-1} * 100$	$0 \leq cohesion < 100$

10	Aggregation index(AI)	$AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{\max \rightarrow g_{ii}} \right) P_i \right] (100)$ g_{ii} =number of like adjacencies between pixels of patch type P_i= proportion of landscape comprised of patch type.	1≤AI≤100
11	Interspersion and Juxtaposition(IJI)	$IJI = \frac{-\sum_{i=1}^{m} \sum_{k=i+1}^{m} \left[\left(\frac{e_{ik}}{E} \right) . \ln \left(\frac{e_{ik}}{E} \right) \right]}{\ln \left(0.5 [m(m-1)] \right)} (100)$ e_{ik} = total length (m) of edge between patch types E = total length (m) of edge in landscape, excluding background m = number of patch types (classes) present in the landscape.	0≤ IJI ≤100

TABLE IV. SPATIAL LANDSCAPE INDICES

TABLE V.

Year	Kappa coefficient	Overall accuracy (%)
1973	0.76	75.04
1989	0.72	79.52
1999	0.82	78.46
2009	0.86	84.58

TABLE VI. KAPPA STATISTICS AND OVERALL ACCURACY

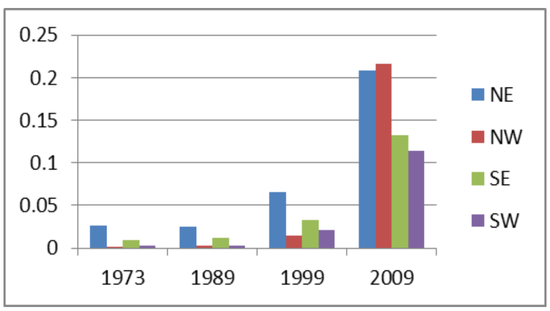


Figure 6. Urban density analysis of Mysore

3) Urban sprawl analysis: Shannon entropy computed using temporal data are listed in Table VI. Mysore is experiencing the sprawl in all directions as entropy values are closer to the threshold value (log (8) = 0.9). Lower entropy values of 0.007 (NW), 0.008 (SW) during 70's shows an aggregated growth as most of urbanization were concentrated at city centre. However, the region experienced dispersed growth in 90's reaching higher values of 0.452 (NE), 0.441 (NW) in 2009 during post 2000's.

The entropy computed for the city (without buffer regions) shows the sprawl phenomenon at outskirts. However, entropy values are comparatively lower when buffer region is considered. Shannon's entropy values of recent time confirms of minimal fragmented dispersed urban growth in the city. This also illustrates and establishes the influence of drivers of urbanization in various directions.

	NE	NW	SE	SW
2009	0.452	0.441	0.346	0.305
1999	0.139	0.043	0.0711	0.050
1992	0.060	0.010	0.0292	0.007
1973	0.067	0.007	0.0265	0.008

TABLE VII. SHANNON ENTROPY INDEX

4) Spatial patterns of urbanisation: In order to understand the spatial pattern of urbanization, eleven landscape level metrics were computed zonewise for each circle. These metrics are discussed below: Number of Urban Patch (Np) is a landscape metric indicates the level of fragmentation and ranges from 0 (fragment) to 100 (clumpiness).

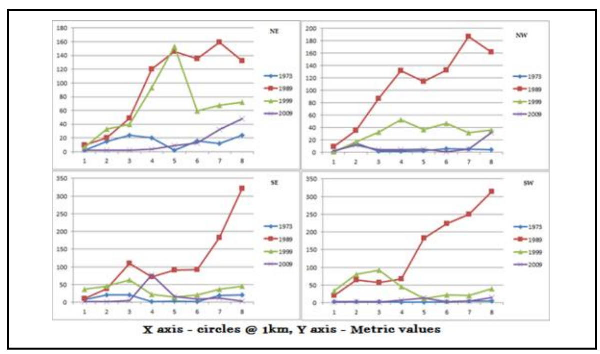


Figure 8.a Number of urban patches (zonewise, circlewise)

Figure 8a illustrates that the city is becoming clumped patch at the center, while outskirts are relatively fragmented. Clumped patches are more prominent in NE and NW directions and patches is agglomerating to a single urban patch. Largest patch index (Fig 8b) highlights that the city's landscape is fragmented in all direction (in 1973) due to heterogeneous landscapes, transformed a homogeneous single patch in 2009.The patch sizes given in figure 8c highlights that there were small urban patches in all directions (till 1999) and the increase in the LPI values implies increased urban patches during 2009 in the NE and SW. Higher values at the center indicates the aggregation at the center and in the verge of forming a single urban patch largest patches were found in NE and SW direction (2009).

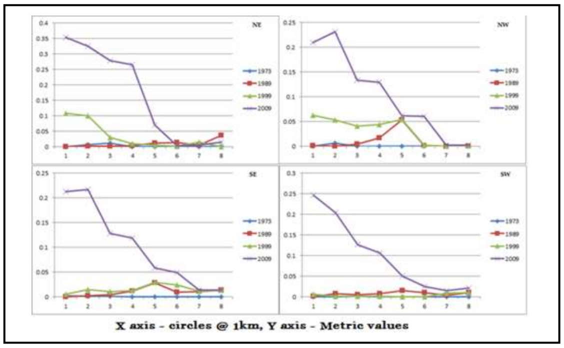


Figure 8.b Largest Patch – zonewise, circlewise

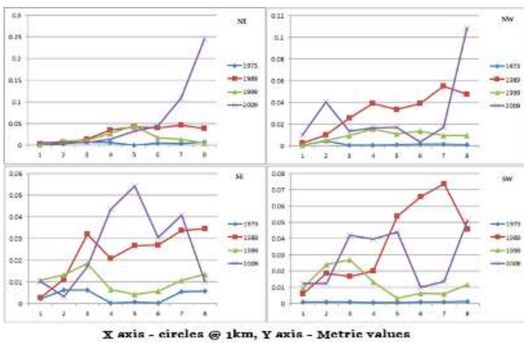


Figure 8.c Patch density – zonewise, circle wise

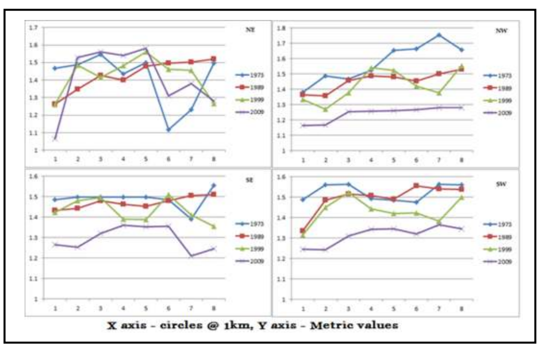


Figure 8.d PAFRAC – zonewise, circle wise

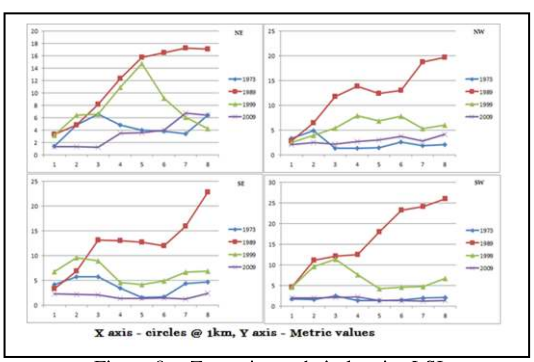


Figure 8.e Zonewise and circle wise LSI

The patch density (Fig 8c) is calculated on a raster map, using a 4 neighbor algorithm. Patch density increases with a greater number of patches within a reference area. Patch density was higher in 1973 as the number of patches is higher in all directions and gradients due to presence of diverse land use, which remarkably increased post 1989(NW) and subsequently reduced in 1999, indicating the sprawl in the region in in early 90's and started to clump during 2009, which was even confirmed by number of patches.

PAFRAC approaches 1 for shapes with very simple perimeters such as squares (indicating clumping of specific classes), and approaches 2 for shapes with highly convoluted, perimeters. PAFRAC requires patches to vary in size. Results (Fig 8d) indicate of dispersed development during 70's and 80's as PAFRAC highly convoluted. The value approaches 1 in 1990's and 2000's indicating aggregation leading to clumped region of urban land use.

Landscape Shape Index (LSI): LSI equals to 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type and LSI increases without limit as the patch type becomes more disaggregated. Results (Fig 8e) indicate that there were low LSI values in 1973 as there was minimal urban areas which were aggregated at the centre. Since 1990's the city has been experiencing dispersed growth in all direction and circles, towards 2009 it shows a aggregating trend as the value reaches 1.Normalized Landscape Shape Index (NLSI): NLSI is 0 when the landscape consists of single square or maximally compact almost square, it increases as patch types becomes increasingly disaggregated and is 1 when the patch type is maximally disaggregated. Results (Fig 8f) indicates that the landscape had a highly fragmented urban class, which became further fragmented during 80's and started clumping to form a single square in late 90's especially in NE and NW direction in all circle and few inner circles in SE and SW directions, conforming with the other landscape metrics.

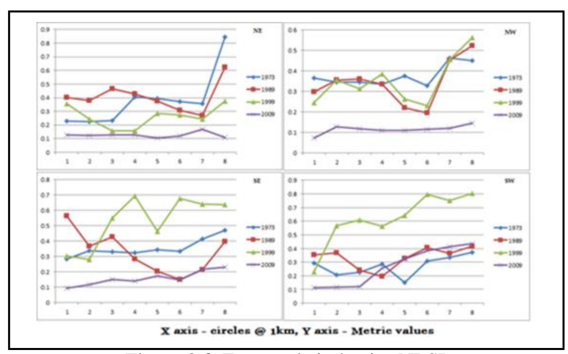


Figure 8.f Zone and circlewise NLSI

Clumpiness index equals 0 when the patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated. Aggregation index equals 0 when the patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch. IJI approaches 0 when distribution of adjacencies among unique patch types becomes increasingly uneven; is equal to 100 when all patch types are equally adjacent to all other patch types.

Clumpiness index, Aggregation index, Interspersion and Juxtaposition Index highlights that the center of the city is more compact in 2009 with more clumpiness and aggregation in NW and NE directions. In 1973 the results indicate that there were a small number of urban patches existing in all direction and in every circle and due to which disaggregation is more. Post 1999 and in 2009 it is observed that large urban patches are located closely almost forming a single patch especially at the center and in NW direction in different gradients (Fig 8g, Fig 8h and Fig 8i).

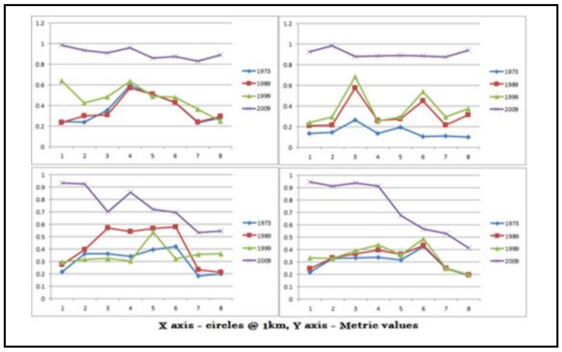
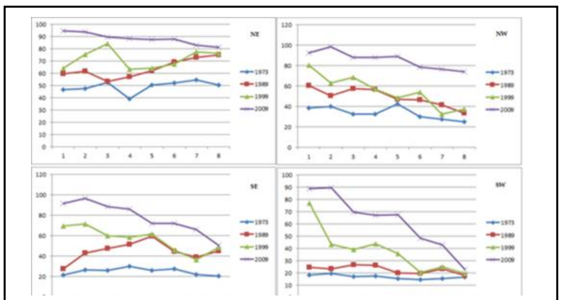


Figure 8.g Clumpiness – zonewise, circle wise



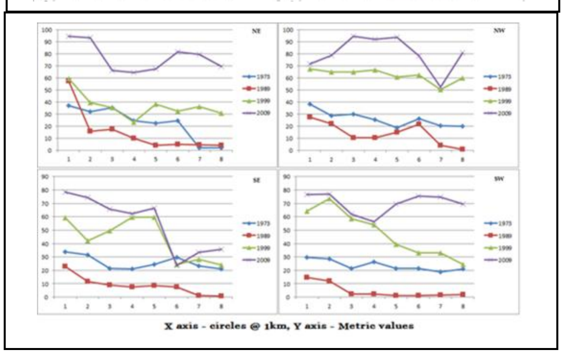


Figure 8.i Zone and circle wise - IJI

Percentage of Like Adjacencies (Pladj) is the percentage of cell adjacencies involving the corresponding patch type those are like adjacent. Cell adjacencies are tallied using the double-count method in which pixel order is preserved, at least for all internal adjacencies. This metrics also indicates the city center is getting more and more clumped with similar class (Urban) and outskirts are relatively sharing different internal adjacencies.

Patch cohesion index measures the physical connectedness of the corresponding patch type. This is sensitive to the aggregation of the focal class below the percolation threshold. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected. Above the percolation threshold, patch cohesion is not sensitive to patch configuration [18]. Figure 8k indicate of physical connectedness of the urban patch with the higher cohesion value (in 2009). Lower values in 1973 illustrate that the patches were rare in the landscape.

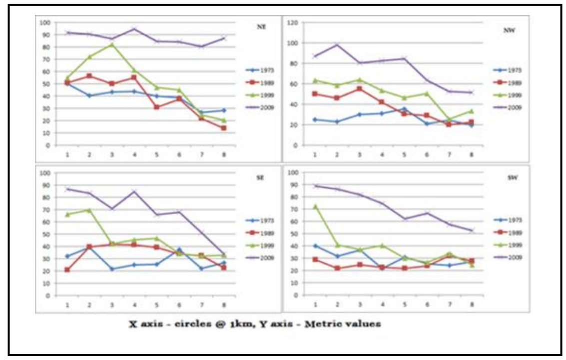


Figure 8.j Zone and circlewise Pladj

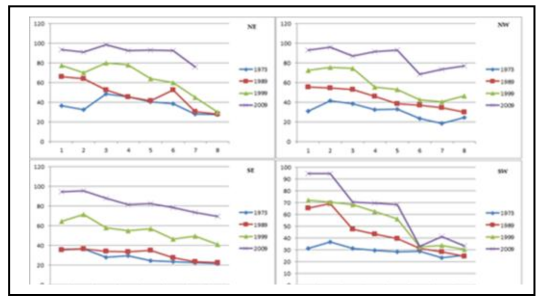


Figure 8.k Cohesion Index

VI. CONCLUSION

Karnataka government's current focus to develop tier 2 cities in order to decongest major cities, has posed a challenge as unplanned developmental activities is leading to urban sprawl impinging basic amenities to the common man in the outskirts. Availability of spatial data since 1970's has aided in the temporal land use dynamics. Spatial metrics in conjunction with the density gradient approach have been effective in capturing the patterns of urbanization at local levels. The techniques would aid as decision-support tools for unraveling the impacts of classical urban sprawl patterns in Mysore. A set of spatial metrics describing the morphology of unplanned areas have been extracted along with temporal land uses. The extracted indices have indicated the areas of high likelihood of 'unplannedness' considering the three dimensions (size/density/pattern).

Land use assessed for the period 1973 to 2009 using Gaussian maximum likelihood classifier highlight that there has been a significant increase (514%) in urban area, with consequent reduction in vegetation cover. Built up density was minimal and the value ranges from 0.026 (considering 3km buffer) to 0.036 (without considering 3km buffer) in the North east direction (in 1973). Shannon entropy computed using temporal data illustrates that Mysore city is experiencing the sprawl in all directions as entropy values are closer to the threshold. Spatial metrics at landscape level reveal that the landscape had a highly fragmented urban class and started clumping to form a single square in late 90's especially in NE and NW direction in all circle and few inner circles in SE and SW directions, conforming to the other landscape metrics.

Local urban and rural planners need to put forward effective implementable adaptive plans to improve basic amenities in the sprawl localities. Temporal land use analysis along with urban density gradient across four directions has helped in visualizing the growth along with the cultural and industrial evolution.

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