Urbanisation and sprawl in the Tier II City: Metrics, Dynamics and Modelling using Spatio-Temporal data.

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Abstract

Urbanisation is a dynamic complex phenomenon involving large scale changes in the land uses at local levels. Human induced land use and land cover (LULC) changes have been the major drivers of the changes in local and global environments. Urbanisation pattern has a direct influence on urban growth process, which extends its influence on the neighborhood resulting in the sprawl or peri-urban growth. Unplanned urbanization and consequent impacts on natural resources has necessitated the investigation and understanding of mechanisms and dynamics of land use and land-use change on a range of spatial scales as well as evaluation on the environmental consequences of these changes at the landscape scale. Rapid urbanization subsequent to globalization in Karnataka state shows dominant changes in land use during the last two decades. Urban regions are getting urbanized at much faster rates while peri-urban areas are experiencing sprawl. Rapid burgeoning population pressure has resulted in unplanned growth in the urban areas to accommodate these migrant people leading to sprawl. It is a growing concern for city planners during the past decade in India. This paper has analysed urbanisation pattern of Raichur-a Tier II city of Karnataka considering a buffer region of 5 km from the current administrative boundary to account for the likely urbanizing regions. Temporal land cover and land use analysis provide the temporal dynamics. The built-up area of the city has increased from 1.41% in 1973 to 8.51% in 2010. Shannon's Entropy (an urban sprawl index) shows that there is a remarkable urban sprawl in and around the city. As a result, the urban ecosystem has changed in the last four decades. Landscape metrics indicate a convoluted and a single patch urban growth at the center and a fragmented outgrowth near the boundary of the city and Buffer regions. This paper provides a valuable basis to understand the urban growth dynamics of Raichur City in India as a consequence of land use changes and helps the urban planners to visualize the developments for a sustainable future.

Keywords

Spatio temporal dynamics: Remote sensing: Shannon's entropy: Raichur: urban sprawl: spatial metrics.

Introduction

Urban growth is a spatial and demographic process, involving concentration of human population with higher level of economy [37]. Urbanisation is a dynamic complex phenomenon involving large scale changes in the land uses at local levels. Analyses of changes in land uses in urban environments provide a historical perspective of land use and an opportunity to assess the spatial patterns, correlation, trends, rate and impacts of the change, which would help in better regional planning and good governance of the region ([37] [7]). Structural composition and rate of growth of most Indian metropolitan cities or tier 1 cities have an aggregated core region and cities are expanding into the rural fringe areas. Due to burgeoning population and concentrated developmental activities, most of Tier 1 cities have exceeded their carrying capacities, which is evident from poor assimilative capacity (higher levels of pollutants in land, water and air), supportive capacity (lack of appropriate infrastructure, traffic bottlenecks) and lack of basic amenities (treated water supply, electricity and sanitation facilities. This necessitates policy measures to decongest tier I cities. This entails providing an alternative region for development and hence the current focus is on Tier II cities. Advance visualization of urbanisation process will aid in better regional planning to provide basic amenities and infrastructure. Urbanisation being the complex and dynamic process, planners and city developers need to monitor and visualize the growth pattern and land use dynamics in the urban and peri-urban areas of the Tier II cities. Otherwise, peri urban regions prone to the sprawl that would be devoid of basic amenities and inefficient and consumptive use of its associated resources.

Mapping and monitoring sprawl helps in identifying the environmental degradation process as well as to visualize the future sprawling growth patterns [3]. Several studies in this regard ([6] [36] [13] [5] [17] [15] [19] [11] [33] [25]), have quantified the sprawl through the diverse techniques. The most common approach is to consider the spatial and temporal dynamics of the regions with impervious surfaces [15].

Many studies have employed large number of indicators, including land-use conversion, population change and energy requirement [2]. Other researchers focused on measuring sprawl through the use of population data as an indicator [35] 37). These patterns of sprawl on landscapes can be detected, mapped and analyzed using remote sensing data along with certain image processing ([32] [14] [26] [12] 37). Thomas [29] considered Shannon's entropy model as a good measure of urban sprawl, i.e., the degree of spatial concentration and dispersion exhibited by a geographical variable. Various researchers have used shannon's entropy, ([1] [17] [10], [37], [7]) which reflects the concentration of dispersion of spatial variable in a specified area/zone, to measure and differentiate types of sprawl. This is why for this study Shannon's entropy has been used to assess the urban sprawl. Further, to understand the growth dynamics and the pattern Landscape, metrics as indicators have been used.

Landscape metrics or so called spatial metrics are numerical measurements that quantify spatial patterns in the form of compactness/edge/shape of land use patches of a geographic area [18]. There is a large number of studies that have used these spatial metrics in order to understand the pattern of urban landscape ([22] [23] [16] [8] [9] [37]). Landscape metrics currently used in satellite data analysis have a long history of usage in various fields such as ecological modeling ([20] [4]). Herold et al., [21] defined and described the function of spatial metrics as digital analysis measurements on the thematic-categorical maps that have a spatial heterogeneity at a particular resolution. Spatial metrics have found important applications in quantifying urban growth, sprawl, and fragmentation [34] [24]. Angel et al., [31] demonstrated five metrics for measurement of sprawl. Ramachandra et al., [37] have successfully applied the metrics and found very useful in understanding the urban growth process. Hence, spatial metrics have been used in the study to understand the process and pattern of growth

In the present study, an attempt has been made to study the impact of growing urbanization on the land-use and land-cover pattern of Raichur city and its effects on the rural fringe considering a 5 km buffer region. To examine the urban growth distribution and variation outward from the city center and model the growth, gradient approach and landscape metrics are employed.

Study area

Raichur district (Fig. 1) is one of major district in northern Karnataka, India, with 5 taluks and 37 hobli's and 120 hamlets, an area of 8386 sq. km and a population density of 181 persons per sq. km (2001). Raichur is drought prone, and falls in the northeast dry agro climatic zone. The normal annual rainfall of the district is 621 mm and the average temperature is 35^0C. Raichur urban city falls in this boundary of Raichur district, which has been considered for the analysis. Raichur city, located at $16^0$10′2″ and $16^0$14′ N latitude and $77^0$19′, is famous for its imposing Raichur Fort and has huge stone inscriptions in Persian and Arabic languages, referring to its construction in 1200's. Among the ruins of the immense fort, there are many tanks and old temples. Krishna and Tungabhadra are two water sources which cater to the needs of drinking water supply to Raichur city. Raichur is famous for its rice mills which exports high quality rice and has a production of pure cotton.

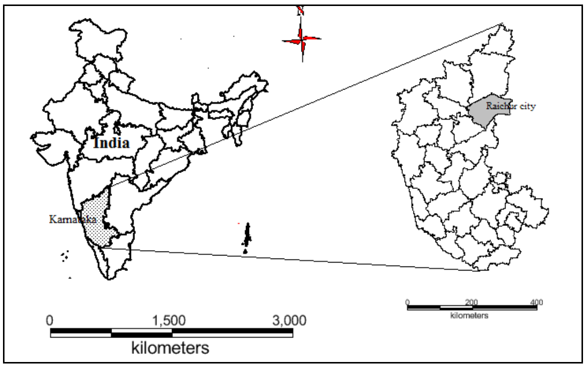

Fig. 1 Study area

Materials used

Urban dynamics was analysed using temporal remote sensing data during the period 1975 to 2010. The time series spatial data acquired from Landsat Series Thematic mapper (28.5m) and ETM sensors for the period 1975 to 1989 were downloaded from public domain (http://glcf.umiacs.umd.edu/data). Data pertaining IRS 1C of 2001 and 2010 (23.5m) were procured from the National remote Sensing Centre (http://www.nrsc.gov.in), Hyderabad. Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales were used to generate base layers of city boundary, etc. City map with ward boundaries was digitized based on the city administration map. Population data was collected from the Directorate of Census Operations, Bangalore region (http://censuskarnataka.gov.in). Table 1 lists the data used in the current analysis. Ground control points to register and geo-correct remote sensing data were collected using hand held pre-calibrated GPS (Global Positioning System), Survey of India toposheet and Google earth (http://earth.google.com, http://bhuvan.nrsc.gov.in).

Method

A stepwise normative gradient approach was adopted to understand the dynamics of the city, including (i) first step to derive land use and land cover (ii) a zonal-gradient approach of 4 zones and 1km radius gradients to understand the pattern of growth during the past 4 decades.(iii)understanding the change in the land use dynamics using Landscape metrics analysis. Various stages in the data analysis are as shown in Fig. 2.

Table 1. Materials used in Analysis

Data used	Year	Purpose
Landsat Series TM (28.5m) and ETM	1975, 1989	Land cover and Land use analysis
IRS LISS III (24m)	2001, 2010	Land cover 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

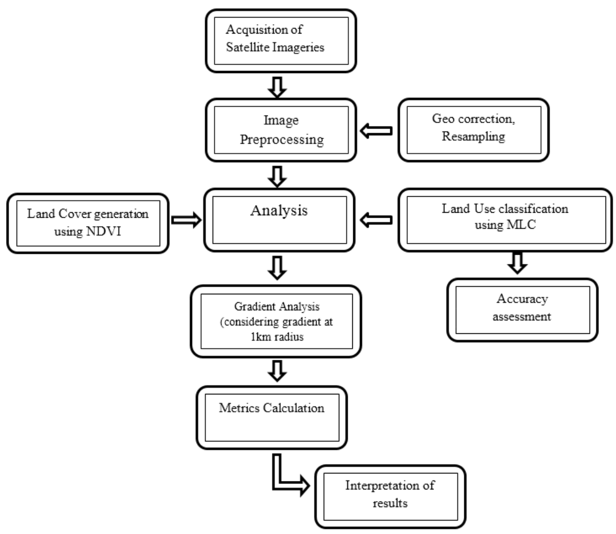

Figure 2: Procedure to understand the changes in spatial pattern and its dynamics

1) Preprocessing: The remote sensing data of landsat were downloaded from GLCF (Global Land Cover Facility) and IRS LISS III data were obtained from NRSC, Hyderabad. The data obtained were geo-referenced, rectified and cropped pertaining to the study area. The satellite data were enhanced using histogram equalization for the better interpretation and to achieve better classification accuracy. Furthermore, the images including topographical sheet and ward map were rectified to a common Universal Traverse Mercator (UTM) projection/co-ordinate system. All data sets were resampled to 30m spatial resolution using the nearest neighborhood re-sampling technique.

2) Vegetation Cover Analysis: Vegetation cover analysis was performed using the index Normalized Difference Vegetation index (NDVI) that was computed for all the years to understand the change in the temporal dynamics of the vegetation cover in the study region. NDVI value ranges from -1 to +1, where -0.1 and below indicates soil or barren areas of rock, sand, or urban built-up. 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).

3) Land use analysis: Further to investigate the different changes in the landscape land use analysis was performed. Categories listed in Table II, were classified with the training data (field data) using Gaussian maximum likelihood supervised classifier. This analysis includes generation of False Color Composite (bands – green, red and NIR), which basically helps in visualization of the different heterogeneous patches. The further use of the training data 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-calibrated 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 based on Google earth (www.googleearth.com) and Bhuvan (bhuvan.nrsc.gov.in). These polygons were overlaid on FCC to supplement the training data to classify landsat data.

Gaussian maximum likelihood classifier (GMLC) is applied to classify the data using the training data, in which various classification decisions are involved by means of probability and cost functions [30] 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 to classify the data and the balance 30% were used in validation and accuracy assessment. Thematic layers were generated for the study region corresponding to four land use categories.

Evaluation on the performance of classifiers has been done through accuracy assessment techniques to test the statistical significance of a difference, comparison of kappa coefficients and proportion of correctly allocated classes through computation of confusion matrix. These are most commonly used to demonstrate the effectiveness of the classifiers [27][28].

4) Further each zone was divided into concentric circle of increment radius of 1 km (Fig. 2.) from the center of the city to visualize 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.

Table II: 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.
Cultivation	Croplands, Nurseries, Rocky area.

5) Urban sprawl analysis: Shannon's entropy (H_n) is computed (equation 1) direction-wise to understand the extent of growth: compact or divergent. 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 i^{th} concentric circle and n is the number of circles/local regions in particular direction. Shannon's Entropy values ranges from zero (maximally concentrated) to log n (dispersed growth).

6) Spatial pattern analysis: Landscape metrics provide quantitative description on the composition and configuration of the urban landscape. These spatial metrics have been computed for each circle, zone wise with the help of FRAGSTATS [18] using classified land use data at the landscape level. Urban dynamics is characterized with 7 prominent spatial metrics chosen based on complexity, and density criteria. The metrics including the patch area, shape, epoch/contagion/dispersion are listed in Table III.

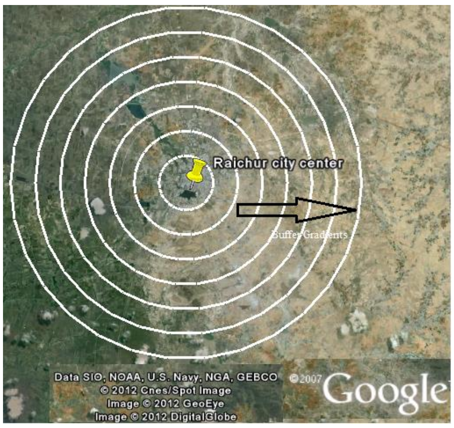

Fig. 2. Google earth representation of the study region along with the gradients

Results and Discussion

1. Land use Land Cover analysis:

Vegetation cover analysis: Vegetation cover of the study area assessed through NDVI (Fig. 3), shows that area under vegetation has declined by about 19%. Temporal NDVI values are listed in Table III, which shows that there has been a substantial increase in the Non Vegetative area. There has been an increase from 3 % to 17%, tells us that there has been staggering growth of impervious cover in the region resulting from decrease in vegetative cover.

Land use analysis: Land use assessed during the period from 1973 to 2010 by means of Gaussian maximum likelihood classifier is listed in Table IV and the same is depicted in Fig. 4. The overall accuracy of the classification ranges from 69.28% (1973) to 88.12% (2010). Kappa statistics and overall accuracy was calculated and listed in Table V. There has been a significant increase in built-up area during the last decade evident from 590% increase in urban area 1.44% in 1975 and has grown to 8.51% considering buffer area. Other category also had an enormous decrease in the land use. Consequently, cultivable area has come down drastically.

Table III: Temporal Land cover details.

Year	Vegetation	Non vegetation
	%	%
1975	96.32	3.68
1989	92.18	7.82
2001	89.36	10.64
2010	82.48	17.52

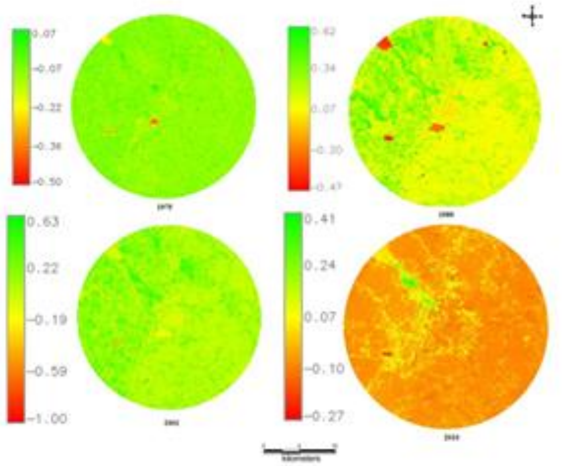

Fig. 3. Temporal Land cover changes during 1973 – 2010

Table III. Landscape metrics analysed

	Indicators	Formula	Range
1	Number of Urban Patches (NPU)	$NPU = n$ NP equals the number of patches in the landscape.	NPU>0, without limit.
2	Patch density(PD)	f(sample area) = (Patch Number/Area) * 1000000	PD>0
3	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≤NLSI<1
4	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
5	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≤ CLUMPY ≤1.
6	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
7	Aggregation index(AI)	$AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{\max \to g_{ii}} \right) P_i \right](100)$ g_{ii} =number of like adjacencies between pixels of patch type P_i= proportion of landscape comprised of patch type.	1≤AI≤100
8	Cohesion	$Cohesion = \left[1 - \frac{\sum_{j=1}^{m} p_{ij}}{\sum_{j=1}^{m} p_{ij} \sqrt[2]{a_{ij}}}\right] \left[1 - \frac{1}{\sqrt[2]{A}}\right]^{-1} * 100$	0≤cohesion<100

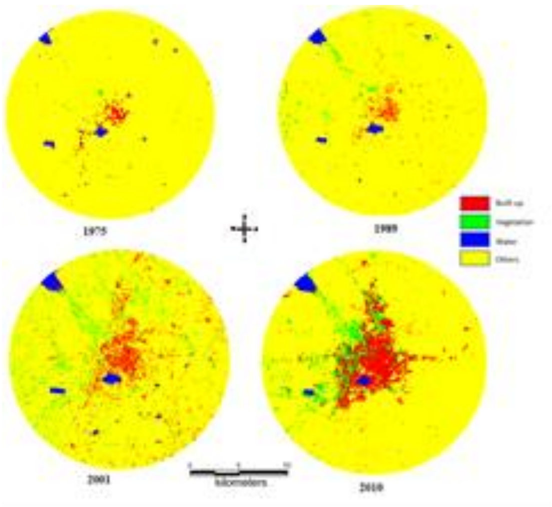

Fig. 4. Classification output of Raichur

Table IV: Temporal land use details for Raichur

Land use / Year	Urban	Vegetation	Water	Cultivation and others
2010	8.51	4.81	0.97	85.71
2002	5.21	3.58	1.36	89.85
1992	2.48	0.91	1.04	95.57
1973	1.44	1.62	0.88	96.16

Table V: Kappa statistics and overall accuracy

Year	Kappa coefficient	Overall accuracy (%)
1973	0.69	69.28
1989	0.83	81.69
1999	0.83	84.53
2010	0.89	88.12

Shannon's entropy: The entropy is calculated considering 7 gradients in 4 directions and listed in table VI. The reference value is taken as Log (7) which is 0.77 and the computed Shannon's entropy values are closer to this, indicating sprawl. Increasing entropy values from 1973 to 2010 shows the tendency of dispersed growth of built-up area in the city with respect to 4 directions as we move towards the outskirts and this phenomenon is most prominent in SE and SW directions.

Table VI: Shannon Entropy Index

	NE	NW	SE	SW
2010	0.135	0.146	0.168	0.194
2002	0.078	0.083	0.084	0.097
1992	0.023	0.026	0.026	0.027
1973	0.01	0.006	0.007	0.005

Spatial patterns of urbanisation: Spatial dynamic pattern of urban growth has been analyzed for 4 decades using eight landscape level metrics computed zone wise for each circle of 1 km radius. These metrics are discussed below:

Number of Urban Patch (Np) , a landscape metric indicates the level of fragmentation and ranges from 0 (fragment) to 100 (clumpiness).

Fig. 8a illustrates the temporal dynamics of number of patches. Urban patches are less at the center in 1970's as the growth was concentrated in central pockets. There is a gradual increase in the number of patches in 80's and further in 2001, but these patches form a single patch during 2010, indicating that the urban area get clumped as a single patch at the center, but in the buffer regions there has been a tremendous increase in 2001. Clumped patches at center are more prominent in NE and SE directions and patches are agglomerating to a single urban patch.

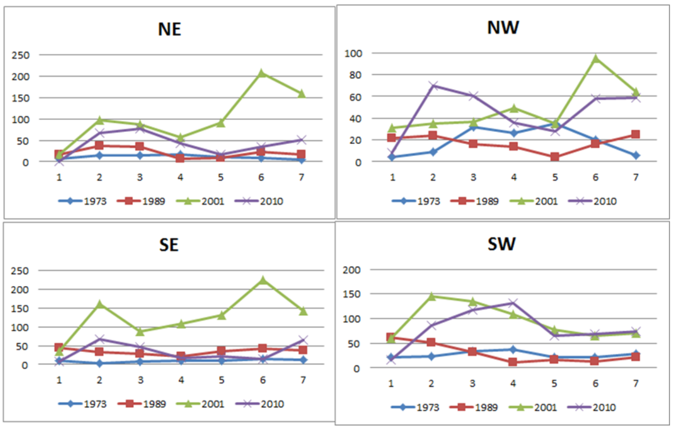

Fig. 8a. Number of urban patches (zonewise, circlewise)

The patch density (Fig. 8b) calculated on a raster map, using a 4 neighbor algorithm, increases with a greater number of patches within a reference area. Patch density was higher in 1989 and 2001 as the number of patches was higher all the directions. Density declined at the central gradients in 2010. In the outskirts the patch density has increased in early 2000's, which is indicative of sprawl in the region and PD is low at center indicating the clumped growth during late 2000's, which is in accordance with number of patches.

Landscape Shape Index (LSI): LSI is equal 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. 8c) indicated that there were low LSI values in 1973 due to minimal and concentrated urban areas in the center. Since 1990's the city has experienced dispersed growth in all direction and circles, towards 2010 it showed a aggregating trend at the center as the value was close to 1, whereas it was very high in the outskirts indicating the peri-urban development.

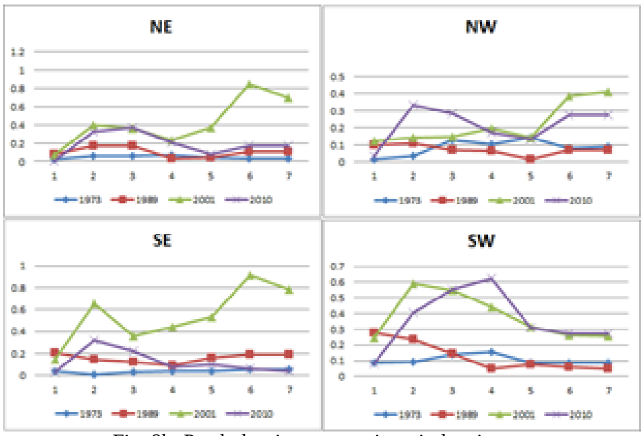

Fig. 8b. Patch density – zonewise, circle wise

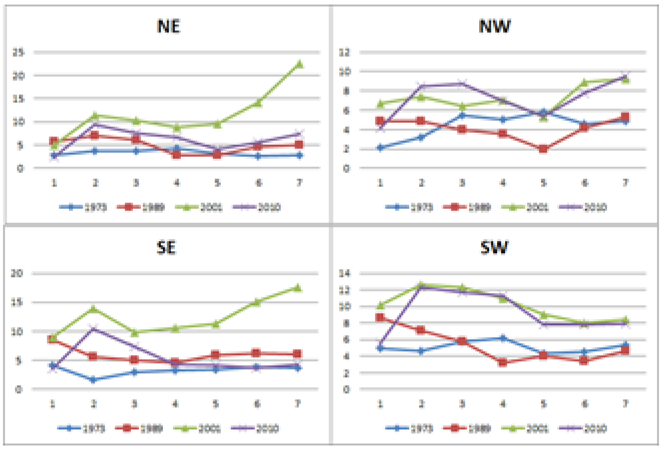

Fig. 8c. Landscape Shape index – zonewise, circlewise

Normalized Landscape Shape Index (NLSI): NLSI is 0 when the landscape consists of Single Square or maximally compact almost square, and increases as patch types becomes increasingly disaggregated while it is 1 when the patch type is maximally disaggregated. Results (Fig. 8d) indicate that the landscape in 2010 had a highly fragmented urban class in the buffer region and is aggregated class in the center, in accordance with the other landscape metrics.

Clumpiness index equals 0 when patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated. Aggregation index equals 0 when patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch.

Clumpiness and aggregation indices exhibit similar temporal trends and highlights that the center of the city is more compact in 2010 with more clumpiness and aggregation in NW and NE directions. In 1973 the results indicated that there were a small number of urban patches existing in all direction and in every circle. Post 2000 and in 2010, a large number of urban patches close to each other almost form a single patch especially at the center and in NW and NE direction in different gradients (Fig. 8e, Fig. 8f).

Lower values of these metrics in the outer circles indicate that there is a tendency of sprawl in the outskirts.

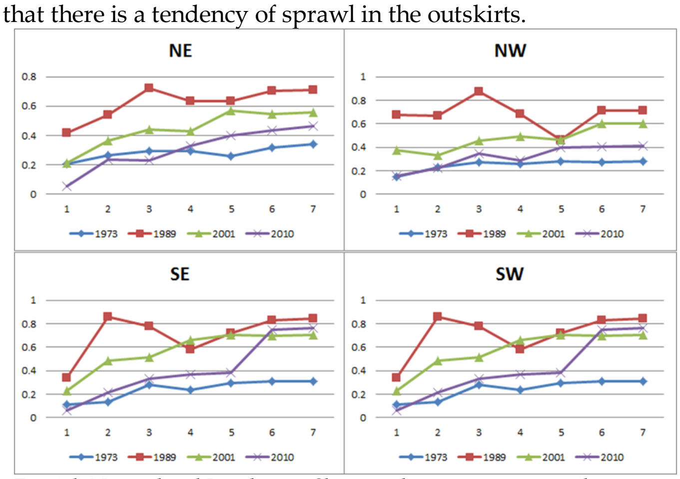

Fig. 8d. Normalised Landscape Shape index – zonewise, circlewise

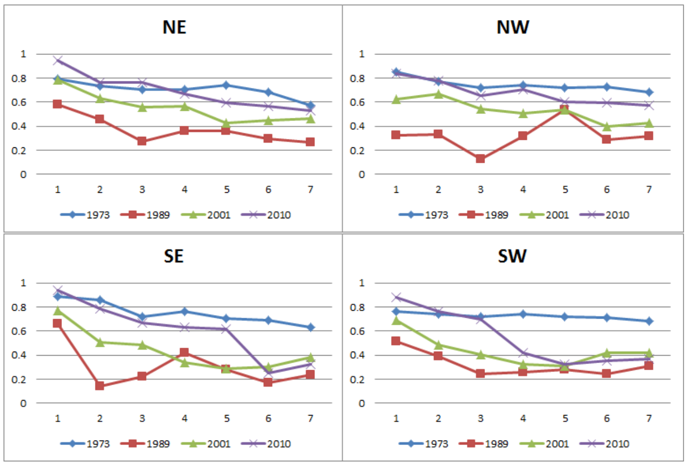

Fig. 8e. Clumpiness – zonewise, circle wise

Percentage of Like Adjacencies (Pladj), the percentage of cell adjacencies involving the corresponding patch type are like adjacent. This metrics also indicates (Fig. 8g) that the city center gets more and more clumped and the adjacent patches of urban much closer have formed a single patch in 2010 and outskirts relatively sharing different internal adjacencies with patches not immediately adjacent but have a trend to become adjacent to each other, which is also indicative of sprawl.

Patch cohesion index measures the physical connectedness of the corresponding patch type. Fig. 8h indicates physical connectedness of the urban patch with higher cohesion value (in 2010). Lower values in 1973 illustrated that the patches were rare in the landscape.

Conclusions

Urbanisation with its Spatio-temporal form, pattern and structure has been quantified for Raichur, atier II city in Karnataka through the gradient approach using temporal remote sensing data, land use analysis, Shannon's entropy, and spatial metrics. Land use analysis shows an increase of urban area from 1.44% (1973) to 8.51% (in 2010) in and around Raichur. The present land-use is predominantly cultivation or agriculture.

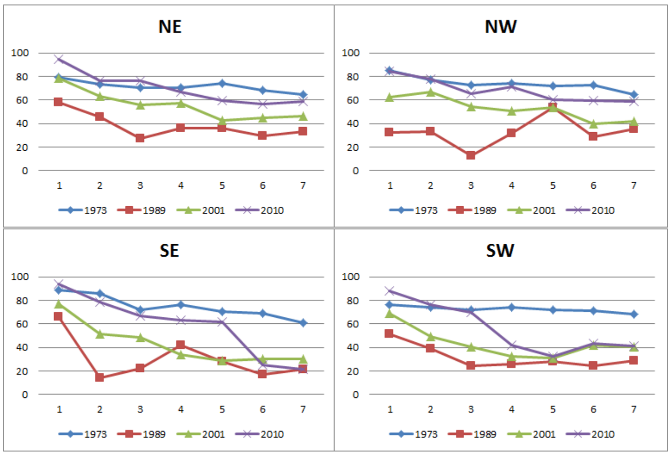

Figure 8f: Aggregation-zone and circle wise

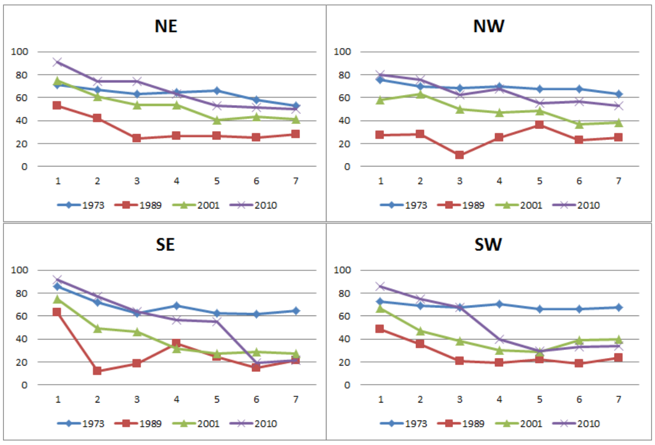

Figure 8g: Zone and circle wise: Pladj

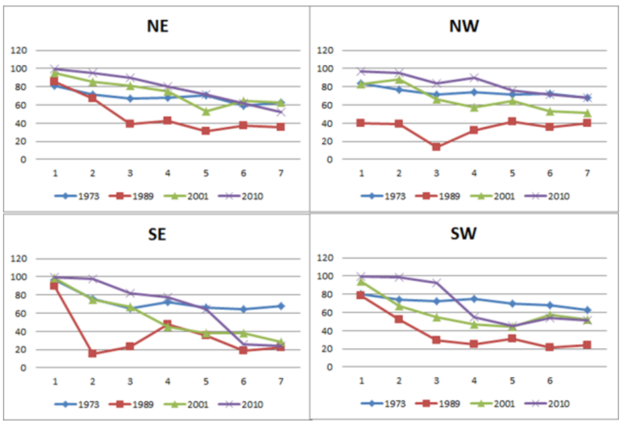

Figure 8h: Cohesion Index

Shannon's entropy, a measurement on the degree of sprawl in city, highlights the tendency of sprawl in recent times at outskirts. Spatial metrics in accordance with the Shannon's entropy indicates a clumped growth at city centre and dispersed growth at outskirts. This analysis visualizes the spatial patterns of urbanisation which helps in the regional planning to provide basic amenities and infrastructure. It is imperative to maintain the environmental quality through the judicious use of land by checking the haphazard growth of urbanization. Spatial models provide vital inputs for the decision makers and city planners to visualize and plan a sustainable growth process.

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