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Spatio temporal patterns of urban growth in Bellary, Tier II City of Karnataka State, India

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Abstract: Globalization and subsequent opening up of Indian markets has given impetus to the urbanization process in most urban pockets in India leading to large scale irreversible land cover changes. Tier II cities in Karnataka with spurt in urban activities are trying to be infrastructural competitive. However this approach has marginalized the planned interventions through the understanding and visualisation of the trends of future growth. In the absence of proper planning and visualization of growth trends, dispersed growth with lack of basic amenities is unabated in most of the metropolis of India. This communication analyses the growth patterns in one of the prominent tier II city in Karnataka –Bellary. The spatio–temporal analysis has been done for the past four decades considering buffer to account for the sprawl at outskirts. Land use and Land cover analysis with Shannon's entropy and Landscape metrics aided in visualizing the urban growth with the emerging spatial patterns. Land use analysis indicate the growth of urban areas in the city and Shannon's entropy indicates of sprawl and the need for appropriate strategies to manage natural resources while providing basic amenities . Landscape metrics highlight of aggregated growth at the centre with the tendency to form single clumped urban patch, whereas the city outskirts and the buffer region with fragmented landscapes reveal of dispersed growth. This analyses help city planners in understanding the urban growth and for institutionalizing the future developments

Keywords: Urbanisation, sprawl, Bellary city, landscape metrics, entropy.

I. Introduction

Unplanned urbanisation heralds the irreversible changes in the land cover threatening the sustence of natural resources and local; ecology. Indian cities underwent a rapid transition from the concentrated growth at city centre to very dispersed and fragmented model to accommodate the growth and demand of urban land that connects the major cities [42]. This has led to huge expansion around the urban area in an unplanned and uncontrolled manner [3]. Opening Indian markets during post 1990's due to globalization process has directly or indirectly led to the severe fragmentation of land in major urban Metropolis [40]. Major metropolitan cities experienced large scale land use changes with the compact or concentrated growth at city centre leading to a single land use urban class due to the availability of development conducive infrastructure and natural resources([1], [10], [42]). Most of the metropolitan urban fringe regions have experienced a rapid transition from rural cultivable land to urban area due to exurban development during post 2000 ([13], [7], [2], [11], [43]). Dispersed industrial and commercial units with human settlements in peri urban area of most metropolitan regions have linked the respective sprawl pockets with dense city road networks. These metropolitan regions have reached the growth threshold evident from the inability to meet the basic needs of the growing population in urban fringes [40]. Hence the focus is towards tier II cities to meet the requirements of further growth. The tier II cities have the adequate resources to meet the requirements of basic amenities of the dependent urban population. There has been an increased interest in recent times by the federal government agencies in giving further impetus as ubiquitous and self-sustained cities, since this has necessitated to understand and visualize the spatial patterns of the growth in these regions in order to plan and implement sustainable management of natural resources such as land, water, etc. Visualization and understanding of patterns of urbanisation is possible with the spatial data available at different time intervals. Remote-sensed data acquired through space borne sensors since 70's at regular intervals has aided mapping the compositions of cities and analyzing the changes over time ([18], [34], [33], [42]). The prominent characteristics of remotely sensed data, is availability in temporal mode and synoptic coverage of wide area, useful in analysing changes over the past four decades. This helps the planners and decision makers to visualise and understand the current patterns of urbanization processes ([5],[6]) apart from predicting the likely changes in future. The potential applications of remote sensing data in urban environmental research and policy has been well documented [35]. Further, the utility of multi resolution data for various environmental applications is reviewed by Sliuzas et al., 2010 [36]. Remote sensing data has been used to understand the spatio-temporal dynamics of urbanization, peri-urbanization, and urban morphology through land use land cover dynamics([32], [8], [41], [25], [9], [29], [12], [15], [16], [17], [14], [42], [40]). This forms the basis for current analysis of urban growth through remote sensing data through the temporal dynamics of land cover and land uses. Landscape metrics through Fragstat [26] are computed to detect and understand the patterns of variations in peri- urban or urban sprawl trends across the study region, along with multi-resolution remote sensing data. Landscape metrics aid in quantifying the spatial patterns of land use patches in a geographic area [26]. It provides both a quantitative and qualitative data and information on urban forms ([42], [4], [30]). Changes in landscape pattern have been detected and described through spatial metrics which aided in quantifying and categorizing complex landscapes ([28], [29], [31], [4], [19], [42]). Buffer region was considered in addition to the city's administrative boundary to account for the current and likely peri-urban development. Bellary a rapidly urbanising Tier II city of Karnataka, was considered for the current analysis and the objectives of the study are to (a) quantify urban growth dynamics considering the administrative boundary with 4 km buffer through Land cover and land use analyses, (b) to understand the pattern of urban growth through gradient approach, and (c) understand the dynamics of growth using spatial metrics. The qualitative and quantitative information support policy-making in urban planning and the sustainable management of natural resources.

II. Study Area

Bellary city is located at Latitude 15° 9' Longitude 76° 55' 60E in Karnataka State, India with a jurisdiction of about 82 Sq. Km (Figure 1). . Population is about 0.4 million as per recent 2011 population census (provisional). Gadag borders on the west, Andhra Pradesh on the East, Chitradurga and Davangere on the south and Raichur on the north. Temperature ranges from 25^0c to 45^0c and mean annual rainfall is about 700mm. The city is a hub industrial activities and is one of the major centers in the production of textiles in the country. Spatial extent of Bellary city is about 6km radius, and 4 km circular buffer is considered from the boundary for the analysis of spatio-temporal dynamics

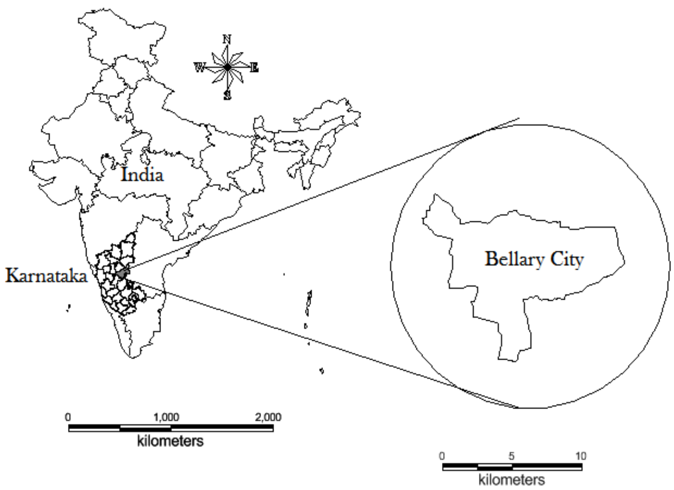

Figure 1: Study Area. Bellary City and 4 km buffer considered

Materials and methods

Urban dynamics has been assessed using remote sensing data of the period 1989 to 2010. Time series spatial data acquired from Landsat Series Thematic mapper (28.5m) sensors for the period 1989 and 2000were downloaded from public domain [23], IRS LISS III data (24 m) for 2005 and 2010 were procured from the National remote Sensing Centre [24], 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 were digitized from the city administration map. Population data was collected from the Directorate of Census Operations, Bangalore region [21]. Table I 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 toposheets (1:50000, 1:250000 scale), and virtual spatial maps - Google earth and Bhuvan ([22], [20]). See table1.

DATA	Year	Purpose
Landsat Series TM (28.5m) and ETM	1973	Land cover and Land use analysis
IRS LISS III (24m)	2001,2005, 2010	Land cover and Land use analysis
Survey of India (SOI) topo-sheet of 1:50000 and 1:250000 scales		To generate base layer maps (city boundary, etc.).
Field visit data –captured using GPS		For geo-correcting and generating validation dataset

Table 1. Materials used in Analysis

A three-step approach, illustrated in Figure 2 was adopted to understand the urban dynamics , which includes (i) a normative approach to understand the land use and land cover, (ii) a gradient approach of 1km radius to understand the pattern of growth during the past 4 decades, (iii) spatial metrics analysis for quantifying the growth. Various stages in the data analysis are:

i. 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 Landsat satellites have a spatial resolution of 28.5 m x 28.5 m (nominal resolution) were resampled to uniform 24 m for intra temporal comparisons.

ii. Vegetation Cover Analysis: Vegetation cover analysis was performed using the index Normalized Difference Vegetation index (NDVI) was computed for all the years to understand the temporal dynamics of the vegetation cover. NDVI values range from -1 to +1, where -0.1 and below indicate 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).

iii. Land use analysis: Further land use analysis was performed to investigate the changes in the landscape. Categories as listed in Table II, were classified with the training data (field data) using Gaussian maximum likelihood supervised classifier. The method involves i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS and collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth and Bhuvan v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

iv. Gaussian maximum likelihood classifier (GMLC) is applied to classify the remote sensing data of the study region using the training data. GMLC uses various classification decisions using probability and cost functions [39] 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). 60% of field data were used for classifying the data and the balance 40% were used in validation and accuracy assessment. Thematic layers were generated of classifies data corresponding to four land use categories (Table 2). Evaluation of the performance of classifiers is done through accuracy assessment techniques of testing 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 assess the effectiveness of the classifiers ([37], [38]).

Further each zone was divided into concentric circle of incrementing radius of 1 km (figure 3) 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.

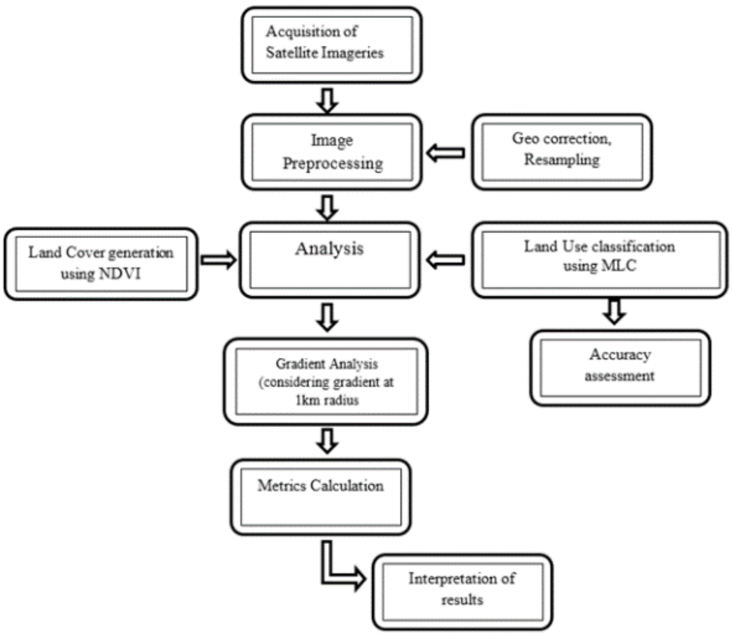

Figure 2: Procedure followed to understand the spatial pattern of landscape change

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.

Table 2. Land use categories

a) ***Urban sprawl analysis***: Direction-wise Shannon's entropy (H_n) is computed (equation 1) to understand the extent of growth: compact or divergent ([27], [42], [40]). This provides an insight into the development (clumped or disaggregated) with respect to the geographical parameters across 'n' concentric regions in the respective zones.

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

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 the particular direction. Shannon's Entropy values ranges from zero (maximally concentrated) to log n (dispersed growth).

b) ***Spatial pattern analysis***: Landscape metrics provide quantitative description of the composition and configuration of urban landscape. These metrics were computed for each circle, zone-wise using classified landuse data at the landscape level with the help of FRAGSTATS. Urban dynamics is characterised by 7 prominent spatial metrics chosen based on complexity, and density criteria. The metrics include the patch area shape, epoch/contagion/ dispersion and are listed in Table 3.

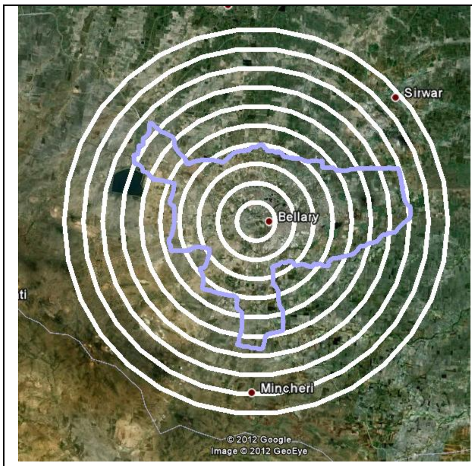

Figure 3. Google earth representation of Bellary

	Indicators	Formula
1	Number of Urban Patches (NPU)	$NPU = n$ NP equals the number of patches in the landscape.
2	Largest Patch Index (Percentage of built up)	$LPI = \frac{\max_{i=1}^{n}(a_i)}{A}(100)$ a_i = area (m^2) of patch i A= total landscape area
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.
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.

5	Clumpiness	$CLUMPY = \begin{bmatrix} \frac{G_i - P_i}{P_i} \; for G_i < P_i \; \& \; P_i < 5, else \\ \frac{G_i - P_i}{1 - P_i} \end{bmatrix}$ $G_{i=} \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right) - \min e_i} \right)$ gii $= number\ of\ like\ adjacencies\ between\ pixels\ of\ patch\ type\ gik$ $= number\ of\ adjacencies\ between\ pixels\ of\ patch\ types\ \ i\ and\ k.$ $Pi\ = proportion\ of\ the\ landscape\ occupied\ by\ patch\ type\ (class)\ i.$
6	Percentage of Like Adjacencies (PLADJ)	$PLADJ = \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right)} \right)(100)$ $gii\ = \quad number\ of\ like\ adjacencies\ (joins) between\ pixels\ of\ patch\ type$ $gik\ = \quad number\ of\ adjacencies\ between\ pixels\ of\ patch\ types\ i\ and\ k$
7	Cohesion	$Cohesion = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{IJ} \sqrt[2]{a_{ij}}} \right] \left[1 - \frac{1}{\sqrt[2]{A}} \right]^{-1} * 100$

Table 3. Landscape metrics analysed

RESULTS AND DISCUSSION

Land use Land Cover analysis:

Land cover analysis: Vegetation cover of the study area assessed with the temporal remote sensing data through NDVI is given in Figure 4. NDVI values indicate the spatial extent of vegetation and non-vegetation in the region. This is based on the reflectances of earth features (such as trees, agriculture, and scrub vegetation) which have higher values in Near IR region. The area under vegetation in 1973 is 57.53% mainly composed of cultivated vegetative area and the balance are open soil. During 1973-2001 there was an increase in the area under cultivation and some increments in urban pockets evident from the land cover of 2001, 2005 and 2010. Land use investigation was carried out to understand the dynamics under respective land use categories. Temporal NDVI values are listed in Table 4.

Year	Vegetation %	Non-Vegetation %
1973	57.51	42.47
2001	94.87	5.13
2005	94.8	5.2
2010	93.7	6.27

Table 4: Temporal Land cover details.

Land use analysis*:* Land uses assessed for the period 1973 to 2010 using Gaussian maximum likelihood classifier are listed Table 5 and in figure 5. The overall accuracy of the classification ranges from 78% (1973), 86% (2001), 84% (2005) to 89% (2010) respectively. Kappa statistics and overall accuracy was calculated and is as listed in Table 6. There has been a significant increase in built-up area during the last decade evident from table 5. There has been a decrease in tree vegetation cover in the region during the past four decades. Significant increase in other land use categories including urban class was observed.

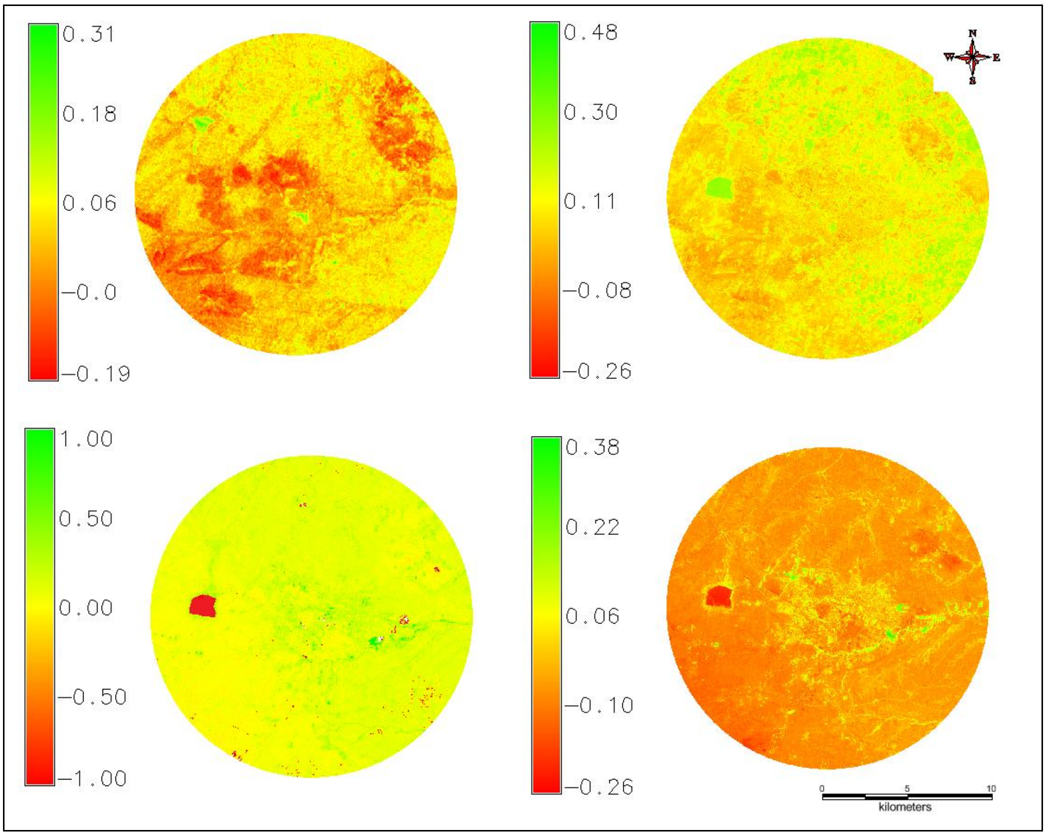

Figure 4: Temporal Land cover changes during Past three Decades

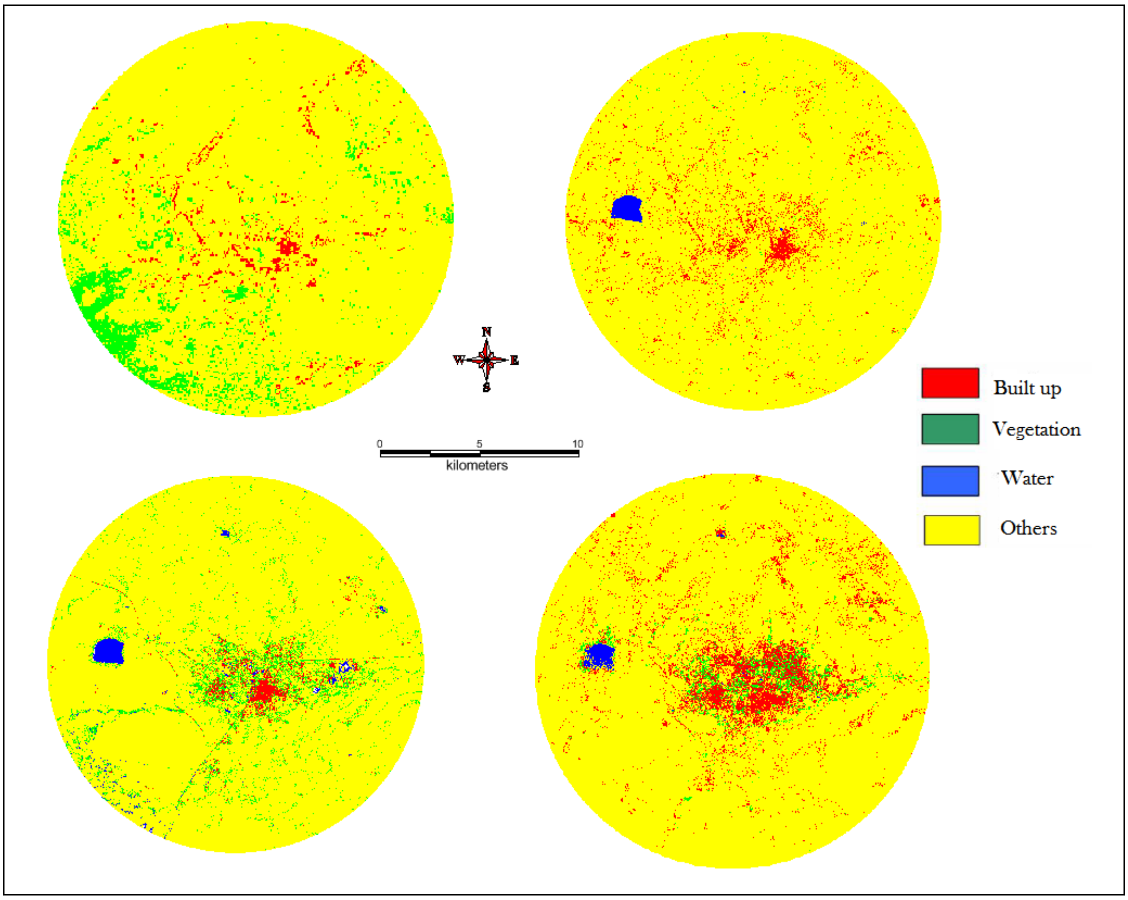

Figure 5:Classification output of Bellary

Land use / Year	**Urban**	**Vegetation**	**Water**	**Cultivation and others**
2010	7.42	0.48	2.04	90.07
2005	4.23	0.92	4.73	90.12
2001	2.64	0.41	2.01	94.94
1973	2.12	4.61	2.35	90.92

Table 5: Temporal land use details for Bellary

Year	**Kappa coefficient**	**Overall accuracy (%)**
1973	0.69	78.32
2001	0.84	86.94
2005	0.82	84.53
2010	0.86	89.69

Table 6: Kappa statistics and overall accuracy

Shannon's entropy: The entropy is calculated considering 10 gradients in 4 directions and are listed in table 7. The reference value is taken as Log (10) which is 1 and the computed Shannon's entropy values are inching closer to the threshold value, indicating tendency of sprawl. Consistently 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 NE directions**.**

	NE	**NW**	**SE**	**SW**
2010	0.37	0.32	0.389	0.33
2005	0.23	0.25	0.26	0.24
2001	0.1	0.09	0.12	0.14
1973	0.04	0.03	0.08	0.06

Table 7: Shannon Entropy Index

Spatial patterns of urbanisation: Spatial dynamic pattern of urban growth was analysed for 4 decades using eight landscape level metrics that were computed zone wise for each circle of 1 km radius. 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 6a illustrates the temporal dynamics of number of patches. Increase in number of patches indicates the land fragmentation, while decline in patches indicates the fragmented landscape forming a single land use patch. As observed from the figure, urban patches are least in the landscape in 1970's as the growth was concentrated on at the city center. In 2000's Bellary city saw a gradual increase in the number of patches, which can be understood as features of fragmented landscape, further in 2010, these patches are increasingly forming a single patch at the center during 2010 indicative that the urban area forming a single clump patch destroying all other land uses, but the case in the buffer regions has been indicative of higher fragmentation during the latter years. Clumped patches at center are more prominent in NE and SE directions and patches are agglomerating to a single urban patch.

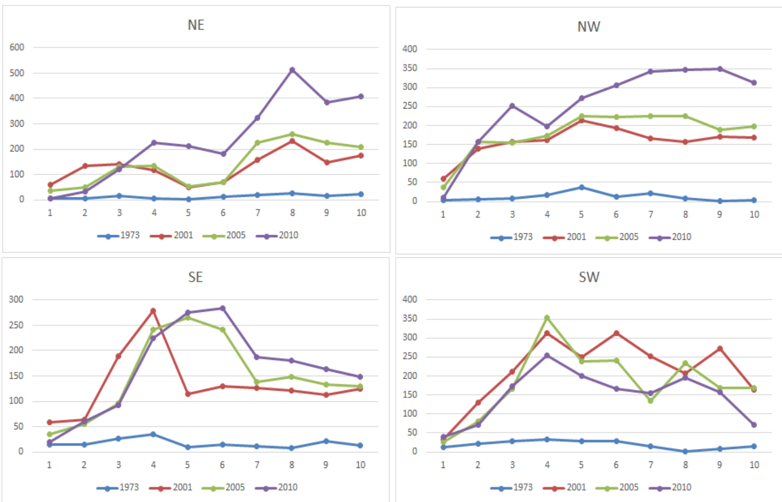

Figure 6a: Number of urban patches (zonewise, circlewise)

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 6b) indicate that there were low LSI values in 1973 as there were minimal urban areas and were concentrated in the center. The city since 2001 has been experiencing dispersed growth in all direction and in every gradient, towards 2010 it shows aggregating urban land use at the center forming a simple shaped single patch as the value is close to 1, whereas, the values of LSI are very high in the outskirts indicating a complex shaped growth with also is indicative of fragmented landscape in the buffer zone.

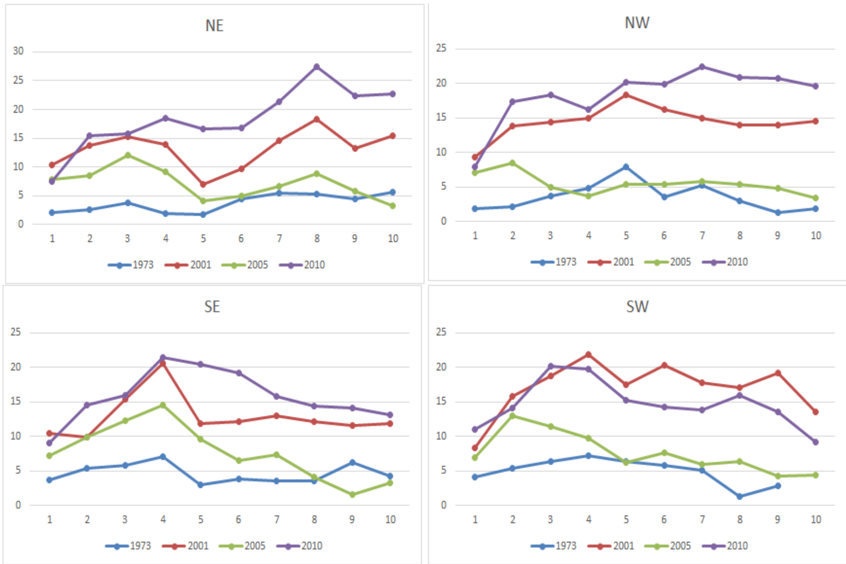

Fig 6b: Landscape Shape index – zonewise, circlewise

Normalized Landscape Shape Index (NLSI): NLSI is 0 when the landscape consists of single square or maximally compact almost square, it increases as patch types becomes increasingly disaggregated and is 1 when the patch type is maximally disaggregated. Results (Fig 6c) indicate that the landscape post 2000 is fragmented and in 2010, the landscape has a highly fragmented urban class in the buffer region and is aggregated class in the center, conforming to the other landscape metrics. Clumpiness index equals 0 when patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated. Clumpiness 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 indicate that there were a small number of urban patches existing in all direction and in every circle. Post 2000's and in 2010 large number of urban patches are close to each other almost forming a single patch especially at the center and in NW and NE direction in different gradients (Fig 6d). Lower values of these metrics in the outer circles indicate that there is a tendency of sprawl in the outskirts since non clumped patches exist in this region.

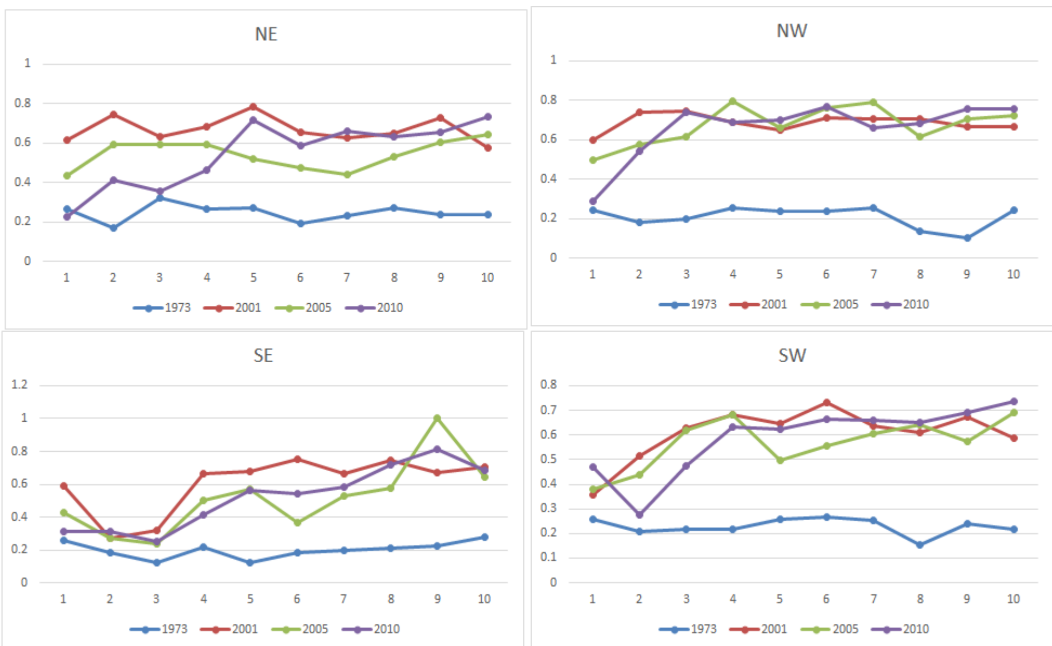

Fig 6c: Normalised Landscape Shape index – zonewise, circlewise

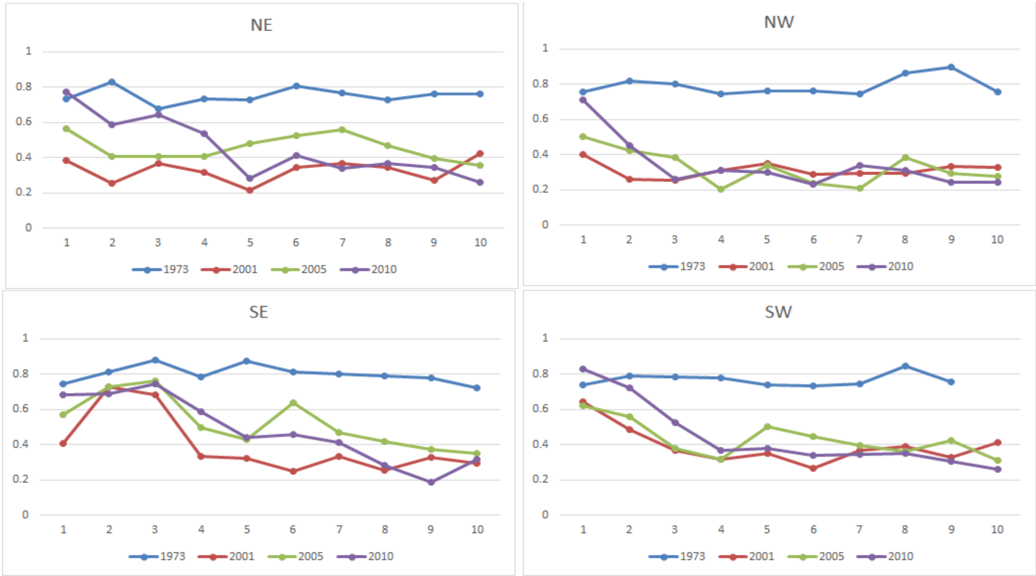

Figure 6d: Clumpiness – zonewise, circle wise

Percentage of like adjacencies (Pladj) is the percentage of cell adjacencies involving the corresponding similar patch type those are adjacent. The analysis of results of this metrics also indicates (Figure 6e) clumped urban single land use growth at the city center in 2010, adjacent patches of urban are much closer and are forming a single patch in 2010 and outskirts are relatively sharing different internal adjacencies with patches not immediately adjacent but have since these have a relatively small adjacency value it can be understood as a trend to become adjacent to each other, which is also indicative of sprawl.

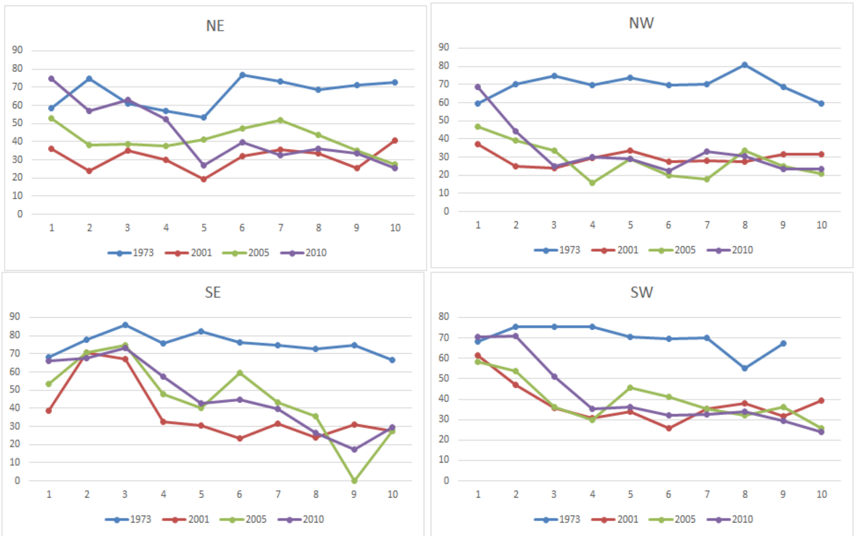

Figure 6e: Zone and circle wise: Pladj

Patch cohesion index measures the physical connectedness of the corresponding patch type. Figure 6f describes the results of the analysis of physical connectedness of the urban patch with the higher cohesion value (in 2010) indicating that the urban count is higher in the considered study region. Lower values in 1973 illustrate that the urban patches were rare in the landscape.

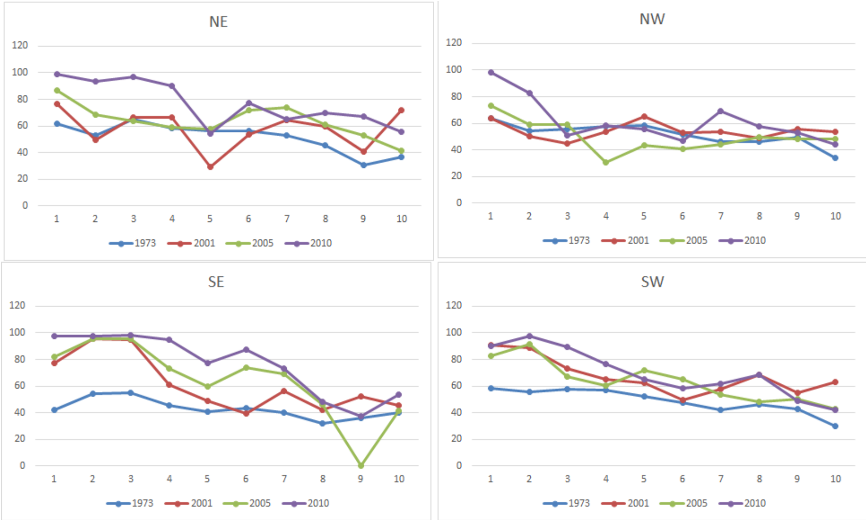

Figure 6f: Cohesion Index

Largest Patch Index (LPI): This metric reveals information about the largest patches in the Landscape and its native existence. Urban patch again counted as a largest patch in 2010 in the central area of Bellary, whereas the buffer zones had a mixture of other patches. Figure 6g is illustrative of results of this analysis.

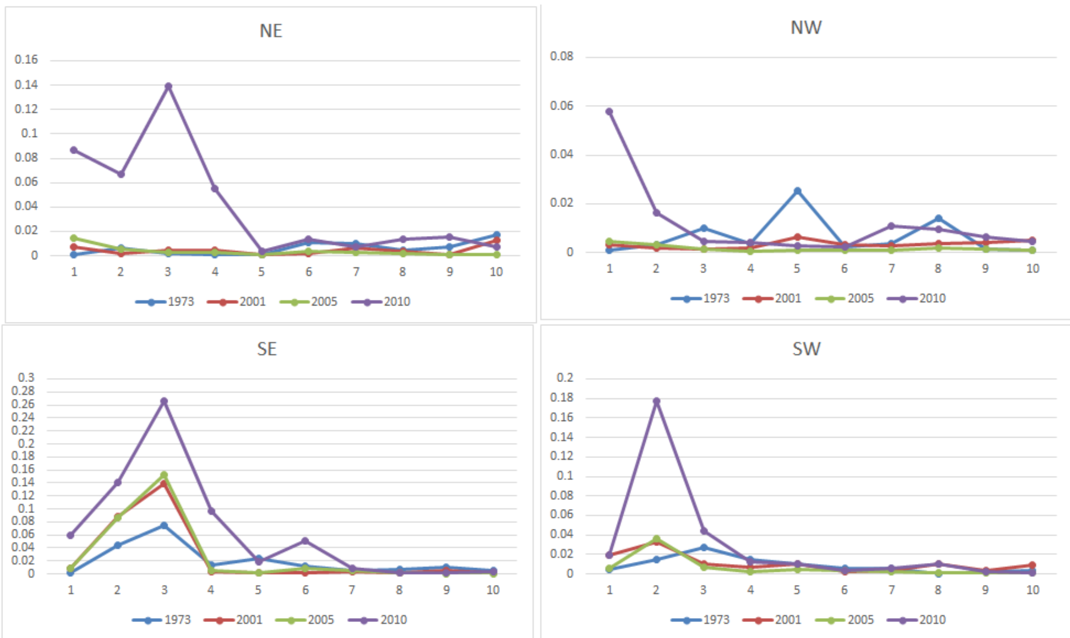

Figure 6g: Largest patch index

The trends of landscape metrics aided in quantifying the density and the shape of the urban growth, which is useful in the regional planning for provision of basic amenities and infrastructure in the region.

CONCLUSION

Multi resolution spatial data acquired through satellite borne sensors provided vital inputs of land use and land cover in Bellary, Tier II city in Karnataka, India. Analysis reveals that urbanization is in progress but neither uniform in space nor planned , Land use analysis show an increase of urban area from 2.12% (1973) to 7.42% (in 2010) in and around Bellary. The present land-use is predominantly cultivation or agriculture and open area. Shannon entropy illustrated the tendency of urban sprawl in and around the periphery and buffer zones. Further the zonal approach with gradients supplemented with landscape metrics brought out the fact that during the past four decades the center of the city is forming a clumped urban patch, while the periphery and the buffer regions are experiencing dispersed growth or sprawl. The judicious use of land by checking the haphazard growth of urbanization is imperative to maintain he environmental quality and health in the region. . Spatial models provide vital inputs for the decision makers and city planners to visualize and plan a sustainable management strategies.

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References

[1] A. Gospodini, "Portraying, classifying and understanding the emerging landscapes in the post-industrial city", Cities, vol. 23, 2006, pp. 311–330.
[2] A. Gospodini, "Post-industrial trajectories of Mediterranean European cities: the case of post-Olympics Athens", Urban Studies, vol. 46, 2009, pp. 1157–1186.
[3] A. Schneider, and C. E. Woodcock, "Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information". Urban Studies, vol. 45, 2008, pp. 659–692
[4] Anindita Dasgupta, Uttam Kumar, T.V. Ramachandra., "Urban Landscape analysis through spatial metrics, In the proceedings of the Conference on Infrastructure, Sustainable Transportation and Urban Planning, CISTUP@CISTUP2010, 18 - 20 October, JN Tata Auditorium, Indian Institute of Science, Bangalore. 2010.
[5] B. Bhatta, S. Saraswati, D. Bandyopadhyay, "Quantifying the degree-of-freedom, degree-of-sprawl, and degree-of-goodness of urban growth from remote sensing data", Applied Geography, vol. 30(1), 2010a, pp. 96–111.
[6] B. Bhatta, S. Saraswati, D. Bandyopadhyay, "Urban sprawl measurement from remote sensing data". Applied Geography, vol. 30(4), 2010b, pp.731–740.
[7] B. Catalan, D. Sauri, and P. Serra, "Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993– 2000.Landscape and Urban Planning, vol.85, 2008, pp. 174–184
[8] D. Lu and Q. Weng, "Spectral mixture analysis of the urban landscape in Indianapolis with Landsat ETM+ imagery". Photogrammetric Engineering and Remote Sensing, vol.70 (9), 2004, 1053–1062.
[9] D. Yu, C. Wu, "Incorporating remote sensing information in modeling house values: A regression tree approach", Photogrammetric Engineering and Remote Sensing, vol. 72(2), 2006, pp. 129–138.
[10] D.L. Johnson and L.A. Lewis, "Land degradation. Creation and destruction". Lanham: Rowman & Littlefield Publishers, 2007
[11] F. Munoz, "Lock living: Urban sprawl in Mediterranean cities". Cities, vol.20, 2003, pp. 381–385.
[12] F.A. Galeon, "Estimation of population in informal settlement communities using high resolution satellite image", The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 37(Part B4), 2008, pp.1377–1382.
[13] G. Cakir, C. Un, E. Z., Baskent, S. Kose, F. Sivrikaya, S. Keles, S., "Evaluating urbanization, fragmentation and land use/cover change pattern in Istanbul city, Turkey from 1971 to 2002". Land Degradation and Development, vol. 19, 2008, pp. 663–675.
[14] G. Tian, J. Jiang, Z. Yang, and Y. Zhang, "The urban growth, size distribution and spatio-temporal dynamic pattern of the Yangtze River Delta megalopolitan region, China", Ecological Modelling, vol.222(3), 2011, pp. 865–878.
[15] H. Taubenböck, M. Wegmann, A. Roth, H.Mehl, and S.Dech, "Urbanization in India: Spatiotemporal analysis using remote sensing data". Computers, Environment and Urban Systems, vol.33 (3), 2009a, pp. 179–188.
[16] H. Taubenböck, M. Wurm, N. Setiadi, N. Gebert, A. Roth, G. Strunz, et al. Integrating remote sensing and social science – The correlation of urban morphology with socioeconomic parameters. In IEEE, editor, urban remote sensing joint event, London, 2009b.
[17] H. Taubenböck, T. Esch, A. Felbier, M. Wiesner, A. Roth, and S. Dech , "Monitoring urbanization in mega cities from space" ,Remote sensing of Environment, vol.117, 2012, pp. 162–176.
[18] H.S. Sudhira, T.V. Ramachandra, and K.S. Jagadish, "Urban sprawl: metrics, dynamics and modelling using GIS". Int. J. Appl. Earth Observ. Geoinform. vol.5, 2004, pp. 29–39.
[19] H.S. Sudhira, T.V. Ramachandra, K.S. Raj, and K.S. Jagadish, "Urban Growth Analysis using Spatial and Temporal Data," Photonirvachak", Journal of Indian Society of Remote Sensing, vol. 31(4), 2003, pp. 299-311.
[20] http://bhuvan.nrsc.gov.in
[21] http://censuskarnataka.gov.in
[22] http://earth.google.com,
[23] http://glcf.umiacs.umd.edu/data
[24] http://nrsc.gov.in
[25] J. Mennis, and J. W. Liu, "Mining association rules in spatio-temporal data: An analysis of urban socioeconomic and land cover change", Transactions in GIS, vol. 9(1), 2005, pp. 5–17.
[26] K. McGarigal, B.J. Marks, "FRAGSTATS: spatial pattern analysis program for quantifying landscape structure." USDA Forest Service General Technical Report PNW-351, 1995
[27] K.M. Lata, C.H.S. Rao, V.K. Prasad, K.V.S. Badarianth, V. Raghavasamy, "Measuring Urban sprawl A case study of Hyderabad," gis@development, vol. 5(12), 2001, pp. 26-29.
[28] M. Antrop, V. Van Eetvelde, "Holistic aspects of suburban landscapes: visual image interpretation and landscape metrics," Landscape Urban Plan, Vol. 50 (1–3), 2000, pp. 43–58.
[29] M. Herold, H. Couclelis, and K.C. Clarke, "The role of spatial metrics in the analysis and modeling of urban land use change". Comput. Environ. Urban, vol.29, 2005, pp. 369–399.
[30] M. Herold, J. Scepan, K.C. Clarke, "The use of remote sensing and landscape metrics to describe structures and changes in urban land uses," Environ. and Plan. Vol. 34, 2002, pp. 1443–1458
[31] M.G. Turner, R.H. Gardner, R.V. O'Neill, "Landscape Ecology in Theory and Practice," Springer-Verlag, New York. 2001.
[32] P. Griffiths, P. Hostert, O. Gruebner, and S.V. der Linden, "Mapping megacity growth with multi-sensor data", Remote Sensing of Environment, vol. 114(2), 2010, pp. 426–439
[33] Q Weng, "Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends", Remote Sensing of Environment, vol.117, 2012. pp. 34–49.
[34] Q. Weng, D.A. Quattrochi, Urban remote sensing. Boca Raton: CRC Press –Taylor & Francis Group, 2006.
[35] R. B. Miller, and C. Small, "Cities from space: Potential applications of remote sensing in urban environmental research and policy". Environmental Science & Policy, vol. 6(2), 2003, pp.129–137.
[36] R. Sliuzas, M. Kuffer, and I. Masser "The spatial and temporal nature of urban objects. In T. Rashed & C. Jürgens (Eds.), Remote sensing of urban and suburban areas Netherlands", Dordrecht: Springer.2010, pp. 67–84.
[37] R.G. Congalton, "A review of assessing the accuracy of classifications of remotely sensed data," Remote Sensing of Environment, vol. 37, 1991, pp. 35-46.

[38] R.G. Congalton, R.G. Oderwald, and R.A. Mead, "Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques," Photogrammetric Engineering and Remote Sensing, vol. 49, 1983, pp. 1671-1678.
[39] R.O. Duda, P.E. Hart, D.G. Stork, "Pattern Classification", a Wiley-Interscience Publication, Second Edition, ISBN 9814-12-602-0, 2005.
[40] S. Bharath, H. A. Bharath, D. Sanna Durgappa, T.V. Ramachandra, "Landscape Dynamics through Spatial Metrics", Proceedings of India GeoSpatial Conference, Epicentre, Gurgaon, India, 7-9 February, 2012.
[41] T. Rashed, "Sustainable hazards mitigation. In M. Campagna (Ed.),GIS for sustainable Development: Bringing geographic information science into practice towards sustainability". New York: Taylor & Francis (CRC Press), 2005, pp. 287–309
[42] T.V. Ramachandra, A.H. Bharath and D.S. Durgappa, "Insights to urban dynamics through landscape spatial pattern analysis", Int. J Applied Earth Observation and Geoinformation, vol. 18, 2012, pp. 329-343.
[43] T.V. Ramachandra, A.H. Bharath, S. Sreekantha, "Spatial Metrics based Landscape Structure and Dynamics Assessment for an emerging Indian Megalopolis", International Journal of Advanced Research in Artificial Intelligence, vol.1(1), 2012b, pp 48-57.