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Spatio-Temporal Dynamics of Urbanising Landscape in Twin Cities in Karnataka, India

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***Abstract*— Urbanisation is a form of metropolitan growth fuelled by sets of economic, social, and political forces apart from the physical geography of an area. As population and activities increases in a city, the boundary of the city expands to accommodate the growth on the urban fringes, which is referred as sprawl. Sprawl generally infers to the regions with highly fragmented urban morphology impacting ecologically sensitive habitats. Cities in India have become a centre of urban agglomerations and have already attracted considerable attention because of their growth, population size, environmental influence and associated infrastructure, mobility issues. This is evident from the increase of mega urban centers (with more than 1 million inhabitants), which were four in 1990's has increased to 48 cities (post 2010). There has been 2.1% increase in urban population during the last decade and the current share is about 27.8%. As per 2011 census there has been tremendous increase in the population and most of urban areas have reached the threshold. Tier II cities in India are also undergoing rapid changes in recent times which necessitates planned interventions to minimize the impacts of unplanned urbanization and consequent impacts on natural resources including basic amenities. This communication analyses the spatio-temporal patterns of urbanisation in the tier II twin cities of Karnataka state: Hubli and Dharwad. The urbanization dynamics of the region with 5 km buffer from the city boundary has been studied considering the temporal remote sensing data of five decades. Five km buffer has been chosen to account for possible urban sprawl regions. A gradient-oriented approach using multi-temporal remotely sensed data was adopted to systematically monitor the spatiotemporal dynamics of the twin cities. Land cover analysis shows that area under vegetation (cultivation and forests) has declined from 97% (1989) to 78% (2010) in Hubli and from 98% (1989) to 86% (2010) in Dharwad. Urban area has increased from 1.08 (1989) to 14.62 (2010)%. Shannon entropy shows that Hubli-Dharwad is experiencing the tendency of sprawl in all directions. Spatial metrics reveal that the urban core of Hubli - Dharwad changed moderately over time and exhibited a spread out pattern of urban development with a moderate to low concentration of urban area towards the periphery. The new urban areas of developed rapidly along major transportation route connecting Hubli - Dharwad, resulting in urban development assuming an unusual outgrowth pattern.**

***Keywords*– Land use, Land Cover, Remote Sensing, Image Classification, Spatial Metrics, Twin Cities, Tier II cities.**

I. Introduction

Urbanization is a dynamic process involving the spatial and demographic changes leading to the increase in urban area with the concentration of population mainly due to migration ([1], [2],[3],[4]) and anthropogenic activities. Problems of urbanisation, which include inadequate housing and infrastructure, lack of basic amenities (water and sanitation), enhanced levels of pollution (water, air and land) are the manifestations of unplanned urbanisation, regions with poor economic base, lopsided urbanisation. This involves radical changes in land uses resulting in the alterations in spatial structure and configurations of the landscape affecting its functional ([1],[5]). The spatio-temporal analysis of land use dynamics helps in understanding various processes and interactions of the study area. Evaluating these processes that change temporally helps in understanding the complex dynamics that aid in understanding and visualizing the future spatial and temporal changes and in identification of local forces ([6],[7], [8]).

Urban population in India is increasing at about 2.3% per annum and the global urban population has increased 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 [9]. India has been experiencing rapid urbanisation with globalization and consequent opening of markets. 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 natural resources (water, electricity, infrastructure), higher levels of pollution (crossing the assimilative and supportive capacity of ecosystems), having higher traffic bottlenecks, higher crime rates due to burgeoning population. This has necessitated the focus shift from Tier 1 urban areas to Tier 2 cities that offer humongous potential with the scope for meeting the basic amenities with appropriate urban planning. 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. This is conceivable with modeling and visualization of urban growth using the historical spatio-temporal data. Failing to visualise and plan such growth would again lead to urban outgrowth depriving the local population with the basic amenities.

In this backdrop, current study focuses on urban growth and its forms and transition of rural area to urban forms in terms of urban land-use classes. Urban sprawl, also known as Peri urban area is defined as a low-density development pattern of urban growth having various social, environmental disadvantages ([10],[11],[12],[13], [14]). It is important to characterize urban sprawl in order to develop a comprehensive understanding of the causes and effects of urbanization processes. Urban sprawl is often evaluated and characterized exclusively based on major socioeconomic indicators such as population growth, commuting costs, employment shifts, city revenue change, and number of commercial establishments [15]. However, this approach does not portray the spatial dynamic of urban sprawl. Land use spatial variability and urban sprawl have been monitored by transition patterns of spatial configurations reflecting dynamics of land uses using temporal remote sensing data ([16], [17], [1]). Subsequent contributions include gradient analyses, geospatial tool applications such as landscape metrics to understand the process urban growth pattern ([18], [19], [1]). Mapping urban areas remains a complex challenge, thus a multitude of indicators have been created in order to characterize landscape structure and landscape pattern. One such indicator is Landscape metrics. Landscape metrics quantify spatial patterning of land use patches of a geographic area [20]. It provides both a quantitative and qualitative data and information on urban forms ([1], [21]; [22]). Changes of landscape pattern have been detected and described by spatial metrics which aided in quantifying and categorizing complex landscapes ([23],[24], [25], [26],[21],[1]). Applications of landscape metrics include landscape ecology (number of patches, mean patch size, total edge and mean shape), geographical applications [27], etc.

Tier II twin cities Hubli Dharwad was considered for the current analysis and the objectives of the study are to (a) quantify urban growth dynamics considering the administrative boundary with 5 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. Such information can support policy-making in urban planning and natural resource conservation.

II. Study Area

Hubli - Dharwad are twin cities in Indian state of Karnataka. Hubli-Dharwad is the second-largest urbanized centers in Karnataka. The twin cities have common governance and are governed by Hubli - Dharwad Municipal Corporation (HDMC) with a corporation governing area of 202.3Sq km. The population of the Twin cities is about 1 million (Census 2011). Hubli is a commercial and industrial hub with various commercial establishments. Dharwad is an educational and administrative centre with numerous colleges, universities and government offices. Hubli-Dharwad District encompasses an area of 4263 sq. kms lying between the latitudinal parallels of 15002' and 15051' N and longitudes of 73043' and 75035' E (Figure 1) with an altitude of about 800 m above the sea level. The district is bounded on the North by Belgaum, on the East by Gadag, on the South Haveri and on the West by Uttara Kannada. The district enjoys a moderate and healthy climate. The district has an agro-based economy to a large extent, trade and commerce are completely dependent on agriculture. In order to understand the influence of urban system in the rural vicinity, 5 km buffer is considered from each city boundary. Hubli city boundary is 7km in radius and Dharwad has a boundary of 2.45km in radius.

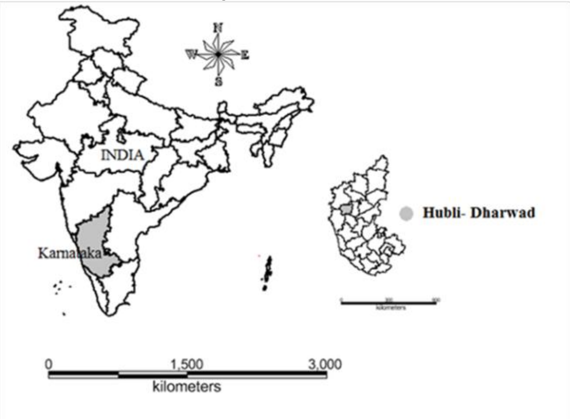

Figure 1: Showing the geographical location of Hubli Dharwad district

III. Materials and Methods

Urban dynamics was analysed using temporal remote sensing data of the period 1989 to 2010. The time series spatial data acquired from Landsat Series Thematic mapper (28.5m) sensors for the period 1989 and 2000were downloaded from public domain (http://glcf.umiacs.umd.edu/data). IRS LISS III data (24 m) for 2005 and 2010 were procured from the National remote Sensing Centre (http://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 were digitized from the city administration map. Population data was collected from the Directorate of Census Operations, Bangalore region (http://censuskarnataka.gov.in). 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 toposheet and Google earth (http://earth.google.com, http://bhuvan.nrsc.gov.in).

Table I: Materials used in Analysis

DATA	Year	Purpose
Landsat Series TM (28.5m) and ETM	1989, 2000	Landcover and Land use analysis
IRS LISS III (24m)	2005, 2010	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

A three-step approach was adopted to understand the dynamics of the urbanizing city (Figure 2), 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

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decades, (iii) spatial metrics analysis for quantifying the growth. Various stages in the data analysis are:

A. Preprocessing: The remote sensing data of Landsat were downloaded from GLCF (Global Land Cover Facility; http://glcf.umiacs.umd.edu/data)) 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.

B. 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 change in the temporal dynamics of the vegetation cover in the study region. NDVI value ranges from values -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).

C. Land use analysis: Further to investigate the changes in the landscape land use analysis was performed. Categories included are 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, vi) 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 (www.googleearth.com) and Bhuvan (bhuvan.nrsc.gov.in) v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

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 [28] 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. 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 demonstrate the effectiveness of the classifiers ([29][30]).

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.

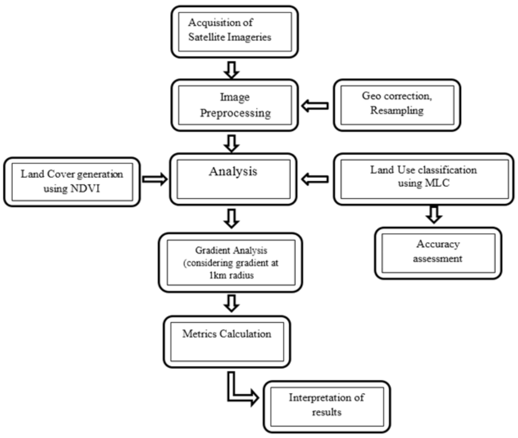

Fig.2. Procedure followed to understand the spatial pattern of landscape change

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, Cropland, nurseries.
Others	Rocks, quarry pits, open ground at building sites, kaccha roads.

a) Urban sprawl analysis: Direction-wise Shannon's entropy (H_n) is computed (equation 1) to understand the extent of growth: compact or divergent ([31], [1]). This provides an insight into the development (clumped or disaggregated) with respect to the geographical parameters across 'n' concentric regions in the respective zones.

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

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, zonewise using classified landuse data at the landscape level with the help of FRAGSTATS [12]. 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 III.

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Hubli city with 1km buffer, Dharwad city with 1km buffer
Fig.3. Google earth representation of the study region

Table III: Landscape metrics analysed

	Indicators	Formula
1	Number of Urban Patches (NPU)	$NPU = n$ NP equals the number of patches in the landscape.
2	Patch density (PD)	f(sample area) = (Patch Number/Area) * 1000000
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. mine_i=minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces.
5	Clumpiness	$CLUMPY = \left[\begin{array}{l} \frac{G_i - P_i}{P_i} \; for G_i < P_i \,\&\, P_i < 5, else \\ \frac{G_i - P_i}{1 - P_i} \end{array} \right]$ $G_{i=} \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right) - \min e_i} \right) g_{ii}$ =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.
6	Percentage of Like Adjacencies (PLADJ)	$PLADj = \left(g_{ij} / \sum_{k=1}^{m} g_{ik} \right) (100)$ 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
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.

IV. Results

I. Land use Land Cover analysis:

a) Vegetation cover analysis: Both Hubli and Dharwad being dominated by cultivable land area has a huge green area which includes both Green cover and cultivation. Temporal NDVI values are listed in Table IV. Vegetation cover of the study area assessed through NDVI (Figure 4), shows that area under vegetation has declined from 97% (1989) to 78% (2010) in Hubli and from 98% (1989) to 86% (2010) in Dharwad.

b) Land use analysis: Land use assessed for the period 1973 to 2009 using Gaussian maximum likelihood classifier is listed Table V and the same is depicted in figure 5. The overall accuracy of the classification ranges from 76% (1989), 83% (2000), 81% (2005) to 94% (2010) respectively. Kappa statistics and overall accuracy was calculated and is as listed in Table VI. There has been a significant increase in built-up area during the last decade evident from table IV. Other category covers major portion of the land use. Consequent to these, there has been a slight decrease of vegetation cover especially in the Dharwad region during the past three decades.

Table IV: Temporal Land cover details.

Year	Hubli - Vegetation %	Hubli - Non-Vegetation %	Dharwad-vegetation %	Dharwad Non - vegetation %
1989	97.0	3.0	98.12	1.88
2000	94.35	5.65	96.48	3.52
2005	89.73	10.27	92.21	7.79
2010	78.31	21.69	86.43	13.57

Table V (a): Temporal land use details for Hubli

Land use -Hubli Year	Urban	Vegetation	Water	Others
1989	1.08	0.22	0.64	98.06
2000	2.25	0.45	0.98	96.31
2005	9.85	0.71	0.74	88.70
2010	14.62	0.42	0.65	84.30

Table V (b): Temporal land use details for Dharwad

Land use - Dharwad Year	Urban	Vegetation	Water	Others
1989	0.62	1.43	0.51	97.45
2000	1.93	1.41	1.13	95.52
2005	3.75	1.29	0.25	94.71
2010	6.47	0.69	0.47	92.36

Table VI: Kappa statistics and overall accuracy

Year	Kappa coefficient	Overall accuracy (%)
1989	0.82	76.34
2000	0.89	83.54
2005	0.83	81.62
2010	0.91	94.86

c) Urban sprawl analysis: Shannon entropy computed using temporal data are listed in Table VII. Hubli-Dharwad is exhibiting the tendency of sprawl in all directions in recent times, as entropy values are inching closer to the threshold value (for Hubli: log (12) = 1.07. For Dharwad: log (7) = 0.845). Lower entropy values of 0.02 (NW), 0.011 (SW) during late 80's shows an aggregated growth as most of urbanization were concentrated at city center.

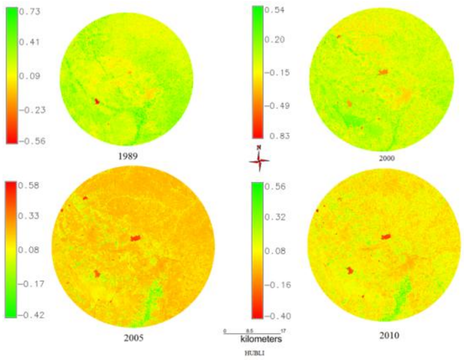

Fig.4.a. Temporal Land cover changes in Hubli during Past three Decades

However, the region experienced dispersed growth in 90's reaching higher values of 0.36 (NE), 0.49 (SE) in 2010 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.

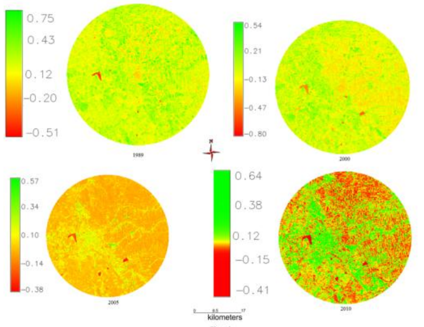

Fig.4.b. Temporal Land cover changes in Dharwad during Past three Decades

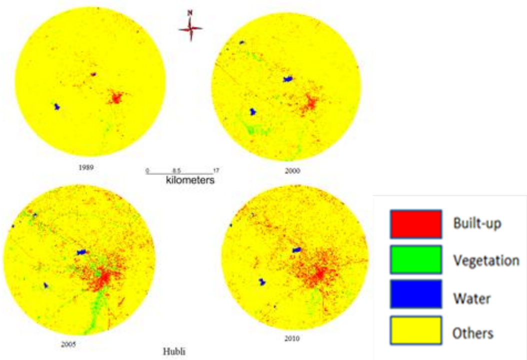

Fig.5.a. Classification output of Hubli

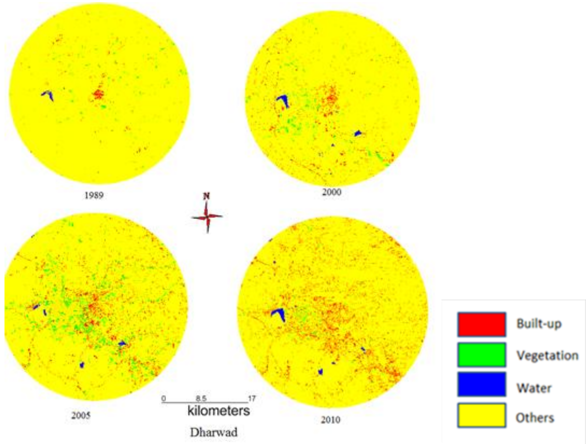

Fig.5.b. Classification output of Dharwad

Table VII: Shannon Entropy Index

Hubli	**NE**	**NW**	**SE**	**SW**
1989	0.027	0.02	0.055	0.011
2000	0.029	0.053	0.102	0.042
2005	0.146	0.09	0.21	0.059
2010	0.369	0.134	0.49	0.128
Dharwad	**NE**	**NW**	**SE**	**SW**
1989	0.011	0.013	0.008	0.006
2000	0.016	0.023	0.014	0.018
2005	0.08	0.086	0.09	0.0745
2010	0.168	0.164	0.213	0.216

d) Spatial patterns of urbanisation: In order to understand the spatial pattern of urbanization, ten landscape level metrics were computed zone wise 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 6a illustrates that the Hubli city is forming patched that are clumped at the center but is relatively disaggregated at the outskirts, but compared to the year 2005, 2010 results is indicative of clumped urban patch in the city and is directive of forming a single urban patch. Clumped patches are more prominent in NE and SW directions and patches is agglomerating to a single urban patch. The case with Dharwad is different as in case it has started to disaggregate in 2010, until 2010 there were less no of urban patches in the city, which have increased in 2010, which is indicative of sprawled growth in the city.

*The patch density (*Figure 6b) 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 in Hubli and Dharwad was higher in 2005 as the number of patches is higher in all directions and gradients due to increase in the urban built area, which remarkably increased post 1989 (SW, NE) and subsequently reduced in 2010, indicating the sprawl in the region in in early 90's and started to clump during 2010. The patch density is quite high in the outskirts also in both the cities.

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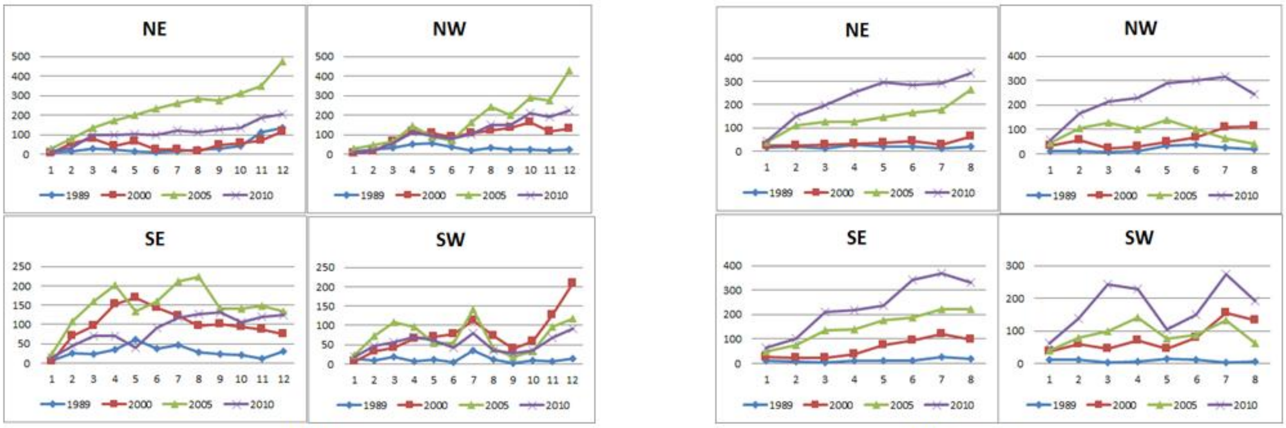
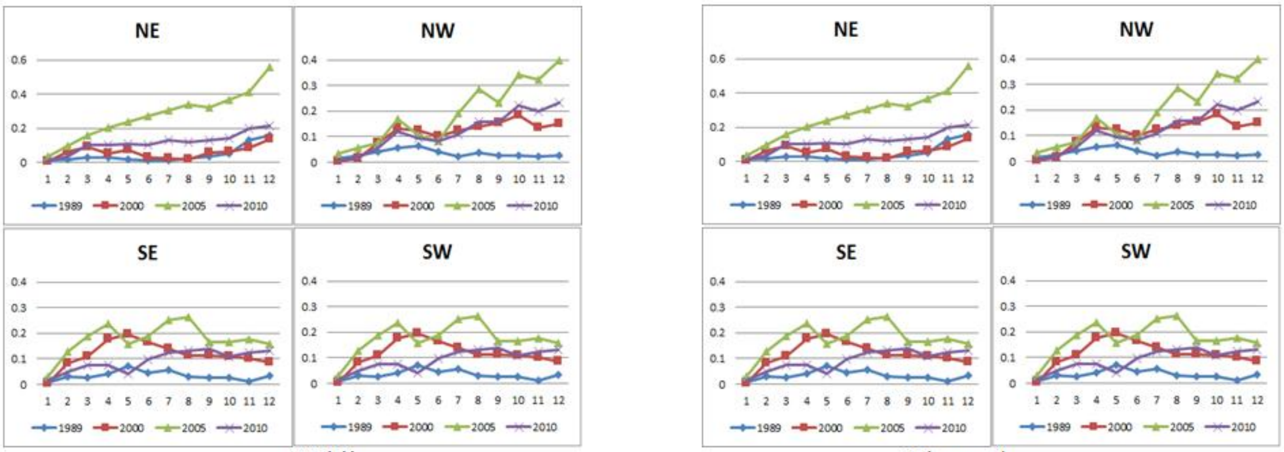
Landscape Shape Index (LSI): LSI equals to 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type and LSI increases without limit as the patch type becomes more disaggregated. Figure 6c indicate that there were low LSI values in 1989 as there was minimal urban areas in both Hubli and Dharwad which were mainly aggregated at the center. Since late 1990's both the city has been experiencing dispersed growth in all direction and circles and Hubli reached the peak of dispersed growth during 2005, towards 2010 it shows a aggregating trend in Hubli, whereas In Dharwad it is showing an dispersed growth.



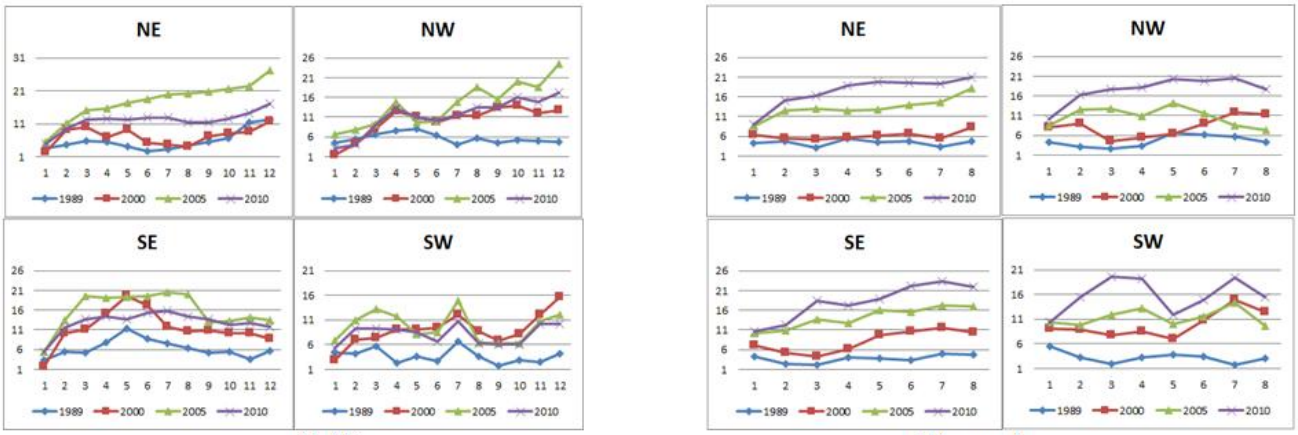
Hubli Dharwad

Fig.6.a. Number of urban patches (Directionwise, circlewise)



Hubli Dharwad

Fig.6.b. Patch Density (Directionwise, circlewise)



Hubli Dharwad

Fig.6.c. Landscape Shape Index (Directionwise, 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 of NLSI (Figure 6d) indicates that the landscape had a highly fragmented urban class, which became further fragmented during 2000 and started clumping to form a single square in late 2010 especially in NE and SW direction in all circle and few inner circles in SE and SW directions, conforming with the other landscape metrics.

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. Clumpiness index, Aggregation index highlights that the center of the both the cities is more compact in 2009 with more clumpiness and aggregation in SW and NE directions. In 1989 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 2000 and in 2010 we can observe large urban patches very close almost forming a single patch especially at the center and in SW direction in different gradients (Figure 6e and Figure 6f). Hubli in 2010 has become much aggregated while Dharwad is yet aggregating to form a single or maximally compact area.

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 explains the adjacencies of urban patches that the city center is getting more and more clumped with similar class (Urban) and outskirts are relatively sharing different internal adjacencies. Hubli city shows more adjacent clumped growth, whereas Dharwad shows more disaggregated growth (Figure 6g).

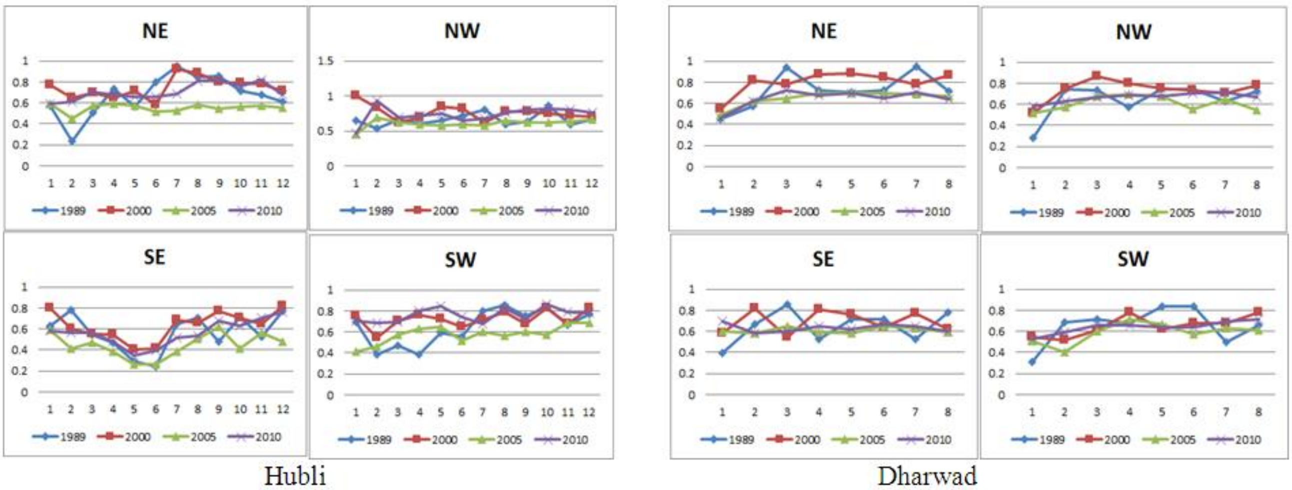


Fig.6.d. Normalized Landscape Shape Index (Direction wise, circle wise)

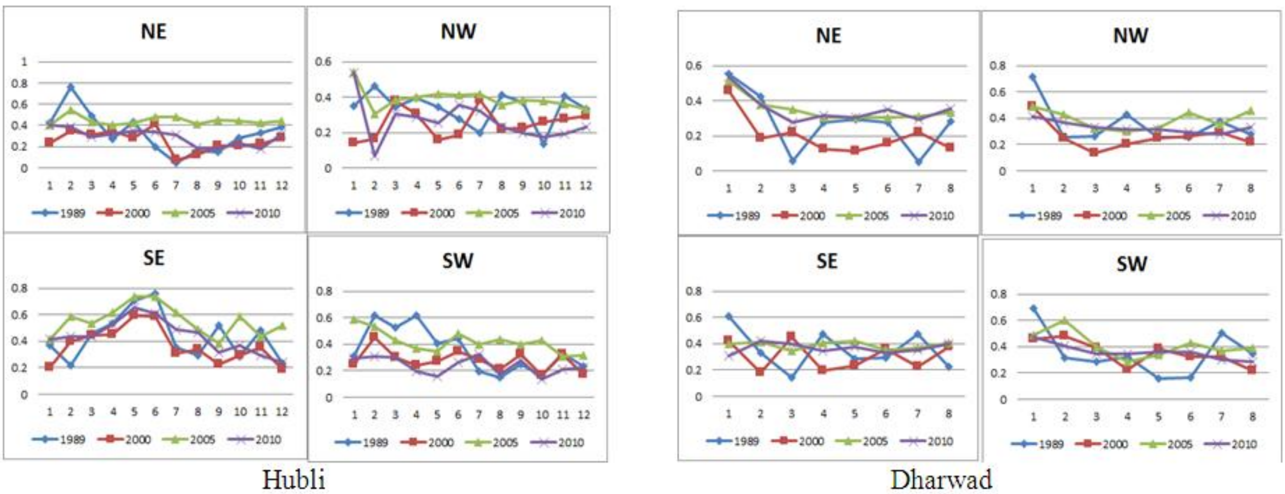
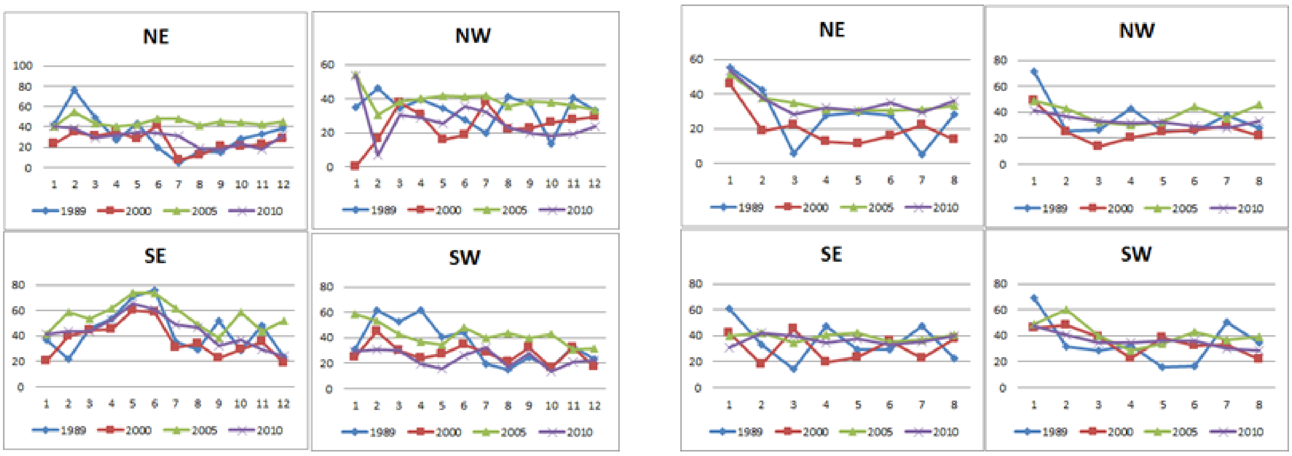
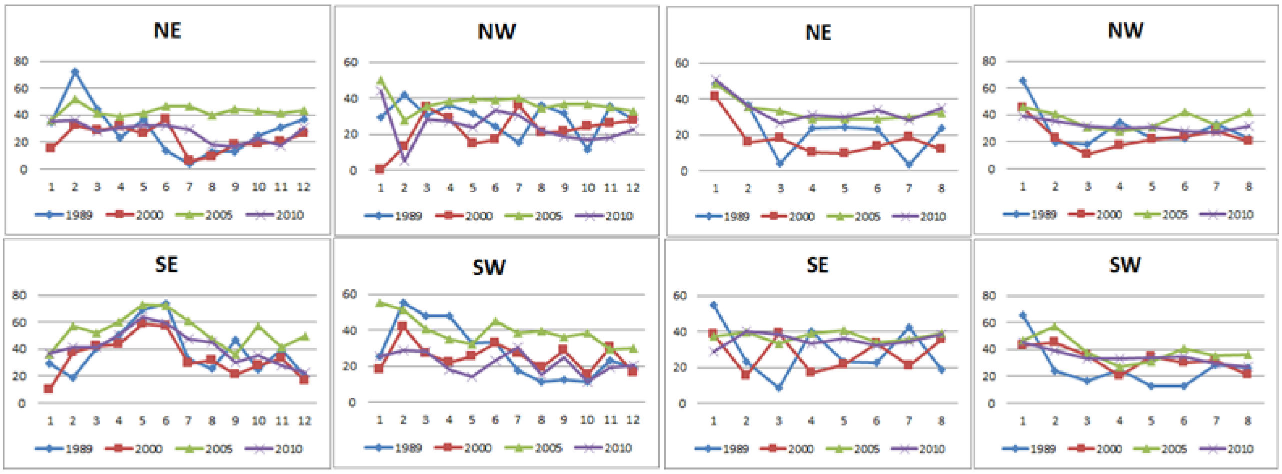


Fig.6.e. Clumpiness Index (Direction wise, circle wise)



Hubli Dharwad

Fig.6.f. Aggregation Index (Direction wise, circle wise).



Hubli Dharwad

Fig.6.g. Percentage of like Adjacencies (Direction wise, circle wise)

V. Conclusion

The analysis of land cover dynamics for the period of analysis 1989 - 2010 shows that area under vegetation (cultivation and forests) has declined from 97% (1989) to 78% (2010) in Hubli and from 98% (1989) to 86% (2010) in Dharwad. Urban area has increased from 1.08 (1989) to 14.62 (2010)%. Shannon entropy shows that Hubli-Dharwad is experiencing the tendency of sprawl in all directions. Spatial metrics reveal that the urban core of Hubli – Dharwad changed moderately over time and exhibited a spread out pattern of urban development with a moderate to low concentration of urban area towards the periphery.

Time series data analyses reveal the transformation for the urban sector along with different sectors, revealing the importance and use of detailed analysis of changes in land use. The evaluation also identified a continuous increase in the urban areas that is replacing the predominant agricultural areas in both the twin cities. The gradient pattern of analysis and the landscape metric analysis demonstrated distinct transformation phases and the complexity of changes in land use, indicating a transfer from agricultural dominated characteristics to an intensive process of peri-urbanisation or sprawl and finally, ending in urban consolidation.

Spatial metrics computed for gradients using temporal data aided in visualizing and modeling the patterns of urban growth which is required for planning framework associated with the future Master Plan for the evolution of systematic processes, and also to regulate abrupt transition processes, given their importance in urban growth. Results of the study produced very interesting results both qualitative and quantitative outputs, especially as inputs for the spatial decision-making support systems, to play a vital role in better decision-making.

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REFERENCES

[1] T.V. Ramachandra, A.H. Bharath, 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.

[2] 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.

[3] H.S. Sudhira, T.V. Ramachandra, K.S. Jagadish, "Urban sprawl: metrics, dynamics and modelling using G1S." Int. J Applied Earth Observation and Geoinformation, vol. 5, 2004. pp. 29-39.

[4] M. Luck, J. Wu, "A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan, Arizona, USA," Landsc. Ecol. Vol. 17, 2002, pp. 327–339.

[5] K.C. Seto, M. Fragkias, "Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics," Landsc. Ecol. Vol.20, 2005, pp. 871–888.

[6] E. F. Lambin, H. Geist, "Land-use and land-cover change: Local processes and global impacts" Berlin, Springer, 2006.

[7] M. Sherestha, A. York, C. Boone, S. Zhang, "Land fragmentation due to rapid urbanization in the Phoenix metropolitan area: analyzing the spatio-temporal patterns and drivers," Applied Geography, vol. 31, 2011, pp. 522-531.

[8] M.G. Turner, R.H. Gardner, "Quantitative method in landscape ecology: an introduction," Ecolog. Stud. Vol. 82, 1990, pp. 3–14.

[9] T. V. Ramachandra, U. Kumar, "Wetlands of Greater Bangalore, India: Automatic Delineation through Pattern Classifiers." Electronic Green Journal, vol. 26, 2008, pp. 1076-7975.

[10] B. Bhatta, S. Saraswati, D. Bandyopadhyay, "Urban sprawl measurement from remote sensing data," Applied Geography, vol. 30(4), 2010b, pp. 731–740.

[11] L. Petrov, C. Lavalle, M. Kasanko, "Urban land use scenarios for a tourist region in Europe: applying the MOLAND model to Algarve, Portugal," Landsc. Urban Plann. Vol. 92, 2009, pp. 10–23.

[12] A. Schneider, 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(3), 2008, pp. 659–692.

[13] R. Peiser, "Decomposing urban sprawl," Town Planning Review, vol. 72(3), 2001, pp. 275–298.

[14] M. P. Johnson, "Environmental Impacts of urban sprawl: a survey of the literature and proposed research agenda," Environment and Planning, vol. 33(4), 2001, pp. 717–735.

[15] J. K. Brueckner, "Urban Sprawl: Diagnosis and remedies," International Regional Science Review, vol. 23(2), 2000, pp. 160–171.

[16] J. Epstein, K. Payne, E. Kramer, "Techniques for mapping suburban sprawl," Photogrammetric Engineering and Remote Sensing, vol. 63(9), 2002, pp. 913 – 918.

[17] X. Li, A.G.O. Yeh, "Zoning land for Agricultural protection by the integration of remote sensing, GIS, and Cellular Automata," Photogramm. Engg. & Remote Sensing, vol. 67(4), 2001, pp. 471-477.

[18] C. Dietzel, M. Herold, J.J. Hemphell, K.C. Clarke, "Spatio-temporal dynamics in California's central valley: Empirical links to urban theory," Int. J. Geographic Information Science, vol. 19(2), 2005, pp. 175-195

[19] J. Peng, Y.L. Wang, Y. Zhang, J.S. Wu, W.F. Li, Y. You Li, "Evaluating the effectiveness of landscape metrics in quantifying spatial patterns," Ecological Indicators, vol. 10 (2), 2010, pp. 217–223.

[20] K. McGarigal, B. J. Marks, "FRAGSTATS: spatial pattern analysis program for quantifying landscape structure." USDA Forest Service General Technical Report PNW-351, 1995.'

[21] AninditaDasgupta, 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.

[22] 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.

[23] 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.

[24] M.G. Turner, R.H. Gardner, R.V. O'Neill, "Landscape Ecology in Theory and Practice," Springer-Verlag, New York. 2001

[25] M. Herold, H. Couclelis, K.C. Clarke, "The role of spatial metrics in the analysis and modelling of urban land use change," Computers, Environment and Urban Systems, vol. 29, 2005, pp. 369-399.

[26] H.S. Sudhira, T.V. Ramachandra, K.S. Raj, K.S. Jagadish, K.S, "Urban Growth Analysis using Spatial and Temporal Data," Photonirvachak, Journal of Indian Society of Remote Sensing, vol. 31(4), 2003, pp. 299-311.

[27] M. Pereira dos Santos Silva, G. Camara, M. Sobral I. Escada, R.C. Modesto de Souza, "Remote sensing image mining: detecting agents of land-use change in tropical forest areas." International Journal of Remote Sensing, vol. 29(16), 2008, pp. 4803-4822.

[28] R.O. Duda, P.E. Hart, D.G. Stork, "Pattern Classification", a Wiley-Interscience Publication, Second Edition, ISBN 9814-12-602-0, 2005.

[29] 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.

[30] R. G. Congalton, R. G. Oderwald, & R. A. Mead, "Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques," Photogrammetric Engineering and Remote Sensing, vol. 49, 1983, pp. 1671-1678.

[31] 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.

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