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SMART CITIES CHALLENGES

SMART ENVIRONMENT FOR SUSTAINABLE RESOURCE MANAGEMENT

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SMART CITIES CHALLENGES:

SMART ENVIRONMENT

FOR SUSTAINABLE RESOURCE MANAGEMENT

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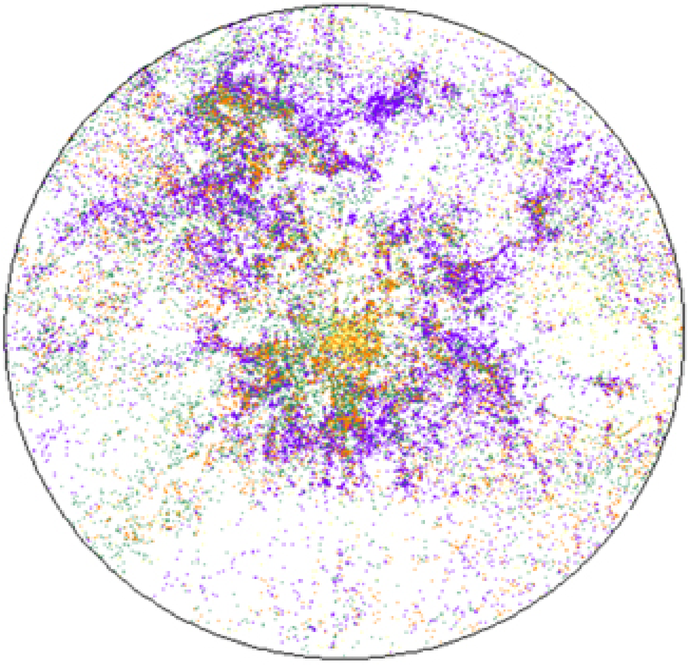

URBANISATION PATTERN OF INCIPIENT MEGA REGION IN INDIA

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ABSTRACT

Urbanisation refers to the growth of the towns and cities due to large proportion of the population living in urban areas and its suburbs at the expense of its rural areas. Unplanned urbanisation leads to the large scale land use changes affecting the sustenance of local natural resources. This necessitates an understanding of spatial patterns of urbanisation to implement appropriate mitigation measures. The focus of the current study is to analyse the spatial patterns of urbanisation and sprawl in Pune city with 10 km buffer using temporal remote sensing data through geo-informatics and spatial metrics. Land use analyses of the city with a buffer of 10km reveals that there has been a significant increase of built-up land from 2.96% (1977) to 20.4% (2013) with the reduction of vegetation from 22.49 to 17.96%. Shannon entropy reveal the tendency of sprawl in NW direction. Zone and Gradient-wise spatial metrics analysis is done to understand the spatial patterns of urbanisation at local levels. The analysis suggests that urbanisation has caused fragmentation with adjacencies in buffer zones. Spatial metrics substantiate rampant sprawl at the peri-urban regions and infilling at city centre. However, this value has reduced in 2013 indicating of reaching the threshold of urbanization. These analyses highlight of the significant changes in land cover with the decline in vegetation, water bodies, etc. This necessitates an integrated approaches in urban planning to ensure the sustenance of water, moderation of micro climate, etc. Conservative urban planning would take into account the sustenance of natural resources and people's livelihood aspects. Visualization of urban growth at local levels helps the urban planners and decision-makers in understanding the role of policy decisions (industrialization, etc.) on land use dynamics, which helps in evolving region specific development strategies to mitigate the potential impacts on the urban environment.
This research provides the details of land use and its development for guiding scientific-based decision support and policy making.

KEYWORDS: Pune, Urban sprawl, landscape metrics, Shannon entropy, India.

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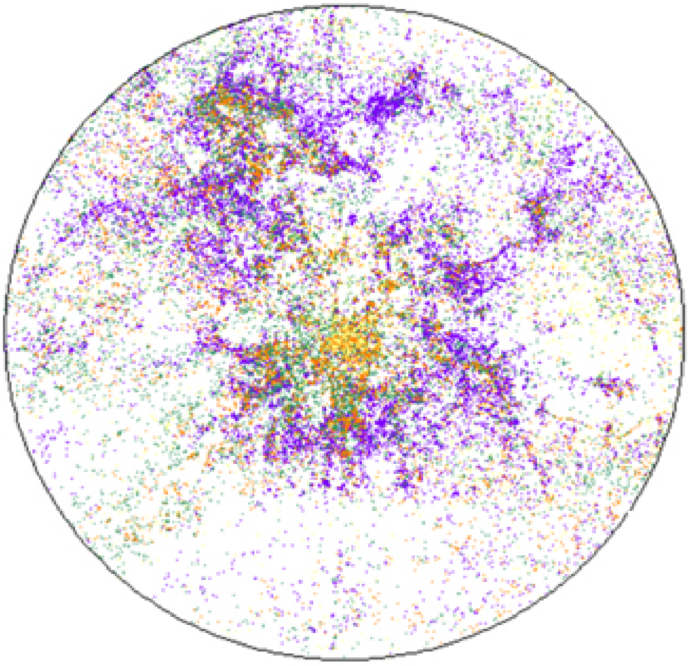

印度初期大都市圈的城市化模式

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摘要

城市化是指大部分人口居住在市区和郊区并以牺牲其农村地区利益为代价的城镇和城市的增长。无序的城市化可导致土地利用的大规模转变，从而造成当地的自然资源无法维系。因此，这就需要对城市化的空间模式有所了解，以便采取适当的缓解措施。此次研究的重点是分析普纳（Pune）市及其10公里缓冲带范围内的城市化和扩张的空间模式，采用的是通过地理信息学和空间测量得到的时相遥感数据。对该市及其10公里缓冲带范围内的土地利用分析发现，建设用地从2.96%（1977年）大幅增长至20.4%（2013年），而植被覆盖则从22.49%降至17.96%。香农熵揭示城市向西北方向蔓延的趋势。为了解局部层面的城市化空间模式，进行了区带和梯度式空间测量分。分析表明城市化已经在缓冲带内的毗邻区域造成破碎化。空间测量证实了城市化在城乡结合部的大肆蔓延和对城市中心的不断挤占。但此值在2013年已有所降低，表明城市化进程达到临界点。该项研究为科学决策和制定政策提供了土地利用和开发的详细资料。

关键词

GIS；熵；城市化； 大都市圈；普纳（Pune

1 INTRODUCTION

Cities origin can be traced back to the river valley civilizations of Mesopotamia, Egypt, Indus Valley and China. Initially these settlements were largely dependent upon agriculture, however with the growth of population the city size increased and the economic activity transformed to trading. The process of urbanisation gained impetus with industrial revolution 200 years ago and accelerated with globalization in 1990's.

Urbanisation refers to the growth of the towns and cities due to large proportion of the population living in urban areas and its suburbs at the expense of its rural areas. In most of the countries the total population living in the urban regions has extensively accelerated since the Second World War. Current global population is 7,057,075,000 billion (Population Reference Bureau, 2005; United Nations, 2011). The rapid urbanization of the world's population over the 20th century is evident (Revision of the UN World Urbanization Prospects report, 2005) from the dramatic increase in global urban population from 13% (220 million, in 1900), to 29% (732 million, in 1950), to 49% (3.2 billion, in 2005) and is expected to increase to 60% (4.9 billion) by 2030 (Ramachandra and Kumar, 2008; Ramachandra et. al., 2012) and 9.6 billion in 2050 (United Nations, 2011).Urban population has been increasing three times faster than the rural population, mainly due to migration in most parts of the world (Girardet 1996; Massey et. al., 1999).

People migrate to urban areas with the hope of a better living, considering relatively better infrastructural facilities (education, recreation, health centres, banking, transport and communication), and higher per capita income. However, rapid unplanned urbanization has led to serious problems in urban areas due to higher pollution (air, water, noise) inequitable distribution of natural traffic congestion, development of shanty towns and slums, unemployment, increased reliance on fossil fuels, and uncontrolled outgrowth or sprawl in the periphery

The direct implication of such urbanisation is the change in land use and land cover of the region. Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Sudhira, et al., 2003). The process of urbanisation contributed by infrastructure initiatives and consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros. However, in such a phenomenon for ecologically feasible development, planning requires an understanding of the growth dynamics. Nevertheless, in most cases there are lot of inadequacies to ascertain the nature of uncontrolled progression of urban sprawls.

Urban sprawl refers to the dispersed development along highways or surrounding the city and in rural countryside with implications such as loss of agricultural land, open space and ecologically sensitive habitats. Sprawl is thus a pattern and pace of land use in which the rate of land consumed for urban purposes exceeds the rate of population growth resulting in an inefficient and consumptive use of land and its associated resources. This phenomenon is characterized by an unplanned and uneven pattern of growth, driven by multitude of processes evident from lack of basic amenities. Urban sprawl is thus a term often used variously to mean the gluttonous use of land, uninterrupted monotonous development, leapfrog discontinuous development and inefficient use of land that are influenced by a myriad of factors, including land features, infrastructure, policies, and individual characteristics. This is characterised by low levels of some combination of eight distinct dimensions such as density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity (Sudhira, et al., 2004; Ramachandra, et al., 2012a).

Process of urbanisation bring the development of a region (Verzosa and Gonzalez, 2010), which could be planned (in the form of townships) or unplanned (organic). Unplanned urbanization leads to the haphazard or irregular growth with the loss of green spaces and water bodies. Dispersed urban growth without proper infrastructure and basic amenities is often referred as sprawl (Yeh and Li, 2001; Sudhira et al., 2004; Verzosa and Gonzalez, 2010, Bharath H A et al., 2012, Bharath S et al., 2012) and this phenomenon is widespread in developing countries (Bhatta et al., 2010a; 2010b). Implications of sprawl are excess demand on natural resources, improper allocation of basic amenities and infrastructure, (Ramachandra et al., 2012b), deteriorating water quality, an increased potential for harboring disease vectors, etc. Large scale land use and land cover (LULC) changes, such as the loss of forests to meet the urban demands of fuel and land (Ramachandra and Kumar, 2009) has led to the changes in the ecosystem structure, impacting its functioning and thereby threatening sustainable development (Yeh and Li, 1999; Ji et al., 2001; Chen et al., 2005; Xiao et al., 2006; Liu et al., 2007; Ramachandra et al., 2013).

Urban expansion is one of the most direct forms of land use change, and refers specifically to changes in land use patterns and urban space distribution resulting from the social and economic pressures (Pathan et al. 1989, 1991; Gillies et al., 2003; Alphan et al., 2009; Bhatta 2009; Ramachandra and Bharath, 2012a). Land cover changes involving the disappearance of ecologically vital natural systems is the major concern in developing countries (Taubenbock, 2009; Ramachandra et al., 2012a). This has necessitated the understanding of spatial patterns of urbanisation and quantification of changes. Several earlier studies have addressed issues relating to urbanisation in relation to energy, land use and climate (Roth et. al., 1989; Grimm et. al, 2000; Voogt and Oke, 2003; Bharath H. A et al., 2012, Vinay et al., 2012).

Analysis of the urbanisation process and provision of appropriate management strategies requires monitoring of the spatial extent of urbanisation with the location (Kong et. al., 2012).Availability of temporal data through space borne sensors with geographic information system (GIS)has aided in the understanding of spatial patterns and visualization of urbanization with environmental implications (Clapman, 2003; Sutton, 2003; Gillies et al., 2003; Martinuzzi et. al., 2007; Yang et al., 2003; Lopez et al., 2001; Ramachandra et al., 2012b). Remote sensing data provides a birds-eye view of urban land-use changes at regular intervals. Geographic information system (GIS) enables spatial analysis of temporal data, which aid in understanding land use dynamics. Land use (LU) indicates the socio-economic use of land (for example, agriculture, forestry, recreation or residential use), which implies the purpose for which land is employed (Codjoe, 2004) or activities humans undertake inducing a change or maintain it (Di Gregorio and Jansen, 1997; Jansen and Di Gregorio, 1998; Codjoe, 2004).

The spatial patterns elucidate the heterogeneity and complexity of the urban patches in the landscape (Uuemaa et al., 2009) that can be measured using spatial metrics that help in quantifying and monitoring the urban growth (Sudhira et al., 2003; Ramachandra and Bharath., 2012b; Ramachandra et al., 2012a).Landscape structure is a prime factor in analysing the pattern and effects the various natural processes (Molles, 2006), which is determined by size, shape, composition of land use patches within the landscape. The analysis of structure of the landscape is essential to understand the implications of land use changes. In this regard, spatial metrics with a robust mathematical framework help to understand and quantify the spatial patterns of urbanisation (Gustafson, 1998; Sudhira et al., 2004; Herold et al., 2003; Uuemaa et al., 2009; Bharath H.A et al., 2012). Spatial metrics can be computed using Fragstats and Patch Analyst. Fragstats is designed to compute a wide variety of spatial metrics to understand landscape dynamics (McGarigal and Marks, 1995). India has been experiencing urbanisation subsequent to globalisation and opening Indian markets during 1990's. Pune city is the eighth populated Indian city with higher economic growth, industrial development and IT sectors has been experiencing rampant land use changes. However, unplanned urbanisation in most cities in India including Pune has enhanced the environmental concerns in recent years (Bhaskar, 2012). Pune city with sprawl is facing lack of infrastructure and basic amenities such as sanitation, housing, improper drainages, transportation, etc. (Desai et al., 2009). This has necessitated the analysis of spatio temporal patterns of urbanisation for implementing appropriate policy measures to mitigate environmental consequences. The focus of the current paper is to understand the spatial patterns of urbanisation through (I) the analysis of land use dynamics, (ii) investigation of sprawl through Shannon's entropy and (iii) patterns of urbanisation through spatial metrics using gradient and zonal approach.

2 STUDY AREA

Pune, earlier known as Poona is the cultural capital of Maharashtra and is also known as “Queen of Deccan” as it is located atop the Deccan Plateau and also “Oxford of East” and “Detroit of India”. Pune is located in the western part of Maharashtra state between 18°32´ N and 72° 51´E at a height of 560 m above mean sea level. It lies near the confluence of the Mula-Mutha River. Rivers Pavana and Indrayani flows along the north-western outskirts of the urban area. The Pune Municipal Corporation covers an area of 243.84 sq. kms. Pune has a tropical wet and dry climate, with three distinct seasons- Summer(March to May), Monsoon (June to September) and Winter (November to January).The River Bhima flows through the city and provide water supply for the domestic, commercial and irrigation purpose. Rice, Jowar, Bajra, sugarcane, groundnut and sunflower are major crops grown in the Pune. Fig. 1 depicts the population dynamics during 1901 to 2011 showing an increase by 347% during the last 110 years. Pune being one among incipient mega cities in India has seen the large scale development in recent times. Population of Pune has increased by 2 million to 9 million (Census 2011) from 7 million in 2001 (Census 2001, JNNURM, 2006-2012). Fig. 1 shows the population statistics of Pune in last 100 years.

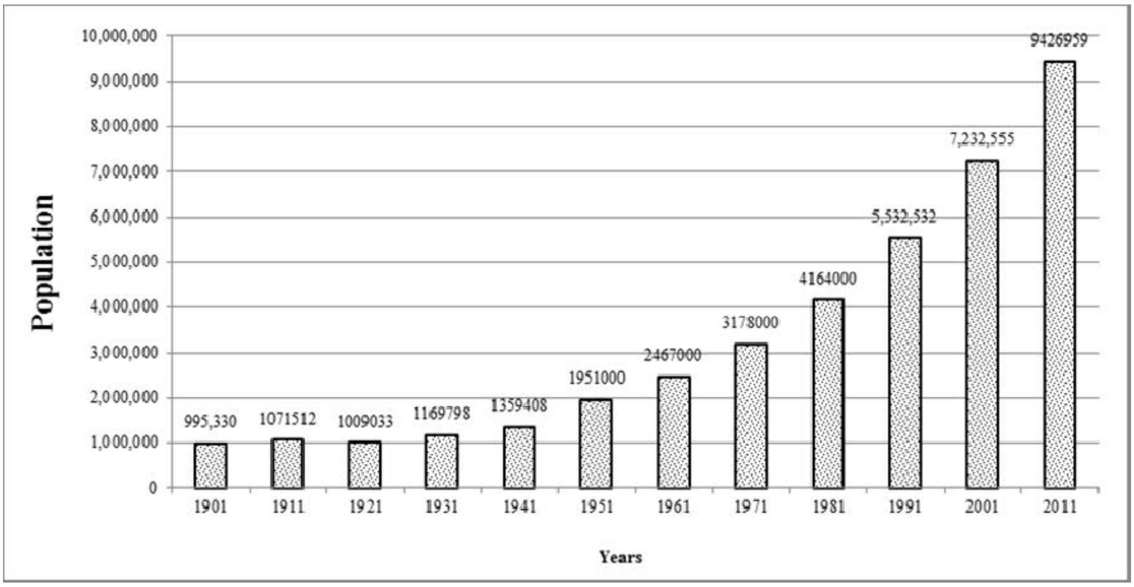


Fig. 1: Growth of population in Pune

Pune Municipal Corporation with forty-eight wards is the civic body that is responsible administration and infrastructure development of the city and it is known as the Pune Mahanagar Palika (PMP). The current study has been carried out in a region of 1524.4 sq. km consisting of municipal corporation administrative region with 10 km buffer. Buffer of 10 km is considered to account the growth in the peri-urban regions (Fig. 2). Time series spatial data acquired through Landsat Series Multispectral sensor (57.5m) and thematic mapper (30m) and Landsat 8 operational image scanner (30m) sensors for the period 1973 to 2013 were downloaded from a public domain Global Land Cover Facility (http://www.glcf.umd.edu/index.shtml) and (http://www.landcover.org/). Survey of India (SOI) topographic sheets of 1:50000 and 1:250000 scales were used to generate base layers of city boundary, training sites, etc.

3 METHOD

Spatial pattern of urbanisation is assessed using temporal remote sensing data of 1977 to 2013. The analysis is outlined in Fig. 3, which includes pre-processing, analysis of land cover and land use, and finally spatial patterns analysis through gradients and zones using spatial metrics.

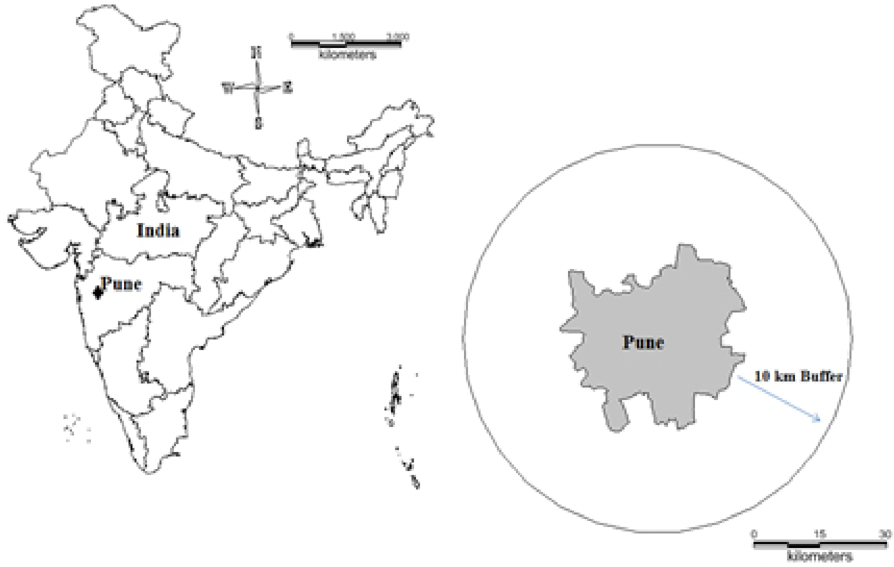


Fig. 2: Study area considered, Pune and 10km buffer.

The study region includes Pune administrative area with 10 km buffer to account pockets at city outskirts experiencing sprawl.

Pre-processing: Remote sensing data (Landsat series) for Pune, acquired for different time periods, were geo-corrected and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps of the Survey of India. The Landsat satellite data of 1977 (with spatial resolution of 57.5 m x 57.5 m (nominal resolution) were resampled to 30 m in order to maintain uniformity in spatial resolution of data across time periods 1992 - 2013 (30 m x 30 m (nominal resolution)).

Land Cover analysis: Land cover analysis was performed to understand the changes in the vegetation cover through Normalised Difference Vegetation Index (NDVI), which ranges from -1 to +1. Very low values of NDVI (-0.1 and below) correspond to soil or barren areas of rock, sand, or urban built up. Zero indicates water cover. Moderate values represent low density vegetation (0.1 to 0.3), while high values indicate thick canopied vegetation (0.6 to 0.8).

Land use analysis: 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, iv) 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, v) supplementing this information with Google Earth, vi) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. Land use analysis was carried out using supervised pattern classifier -Gaussian Maximum Likelihood Classifier (GMLC) algorithm using various classification decisions based on probability and cost functions (Duda et al., 2000, Ramachandra et al., 2012a, Ramachandra et al., 2012d). Remote sensing data was classified using training data of all land use types as detailed in table 1. Mean and covariance matrix are computed using estimate of maximum likelihood estimator.

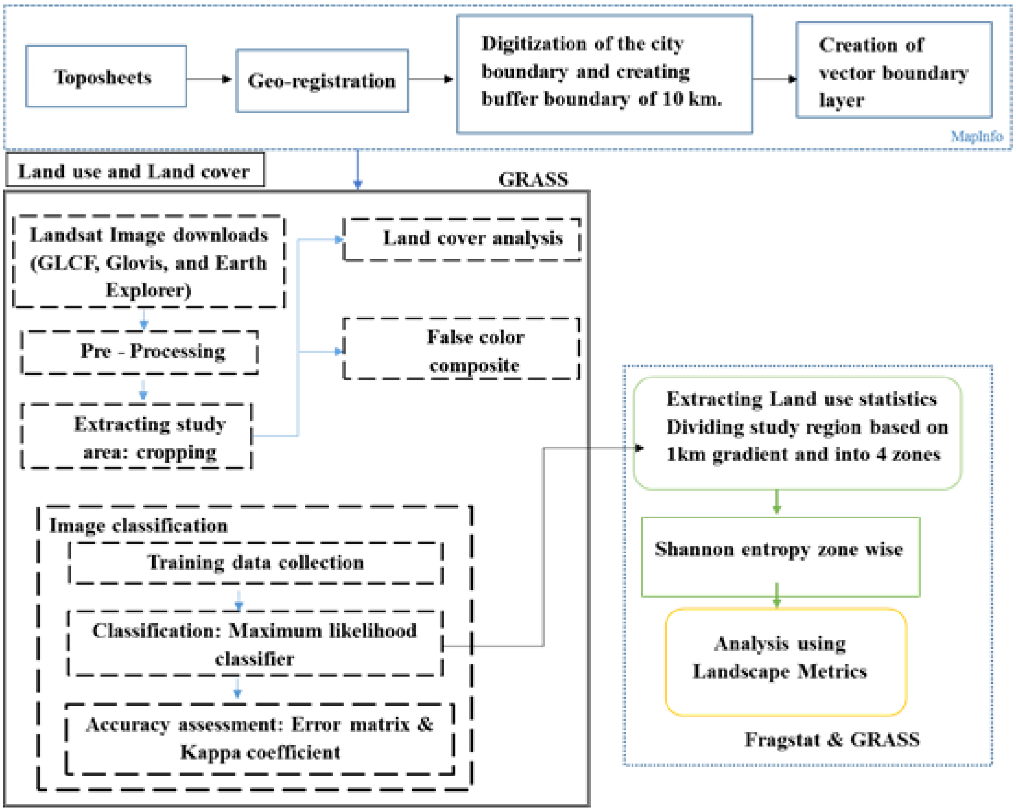


Fig. 3: Procedure followed in analysis

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 1: Land use classification categories

Land use was computed using the temporal data through the open source program GRASS - Geographic Resource Analysis Support System (http://ces.iisc.ernet.in/foss). Signatures were collected from field visits and with the help of Google Earth. 60% of the total generated signatures were used in classification, 40% signatures were used in validation and accuracy assessment.

Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies (Mitrakis et al., 2008, Congalton et al., 1983).

Accuracy assessment and Kappa coefficient indicate the effectiveness of the classifier (Congalton, 1991; Lillesand & Kiefer, 2005). Recent remote sensing data (2013) was classified using the training data collected from field using GPS and earlier time period, training polygon along with attribute details were compiled from the previously published topographic maps, vegetation maps, revenue maps, etc.

Division of these zones to concentric circles (Gradient Analysis): All of the zones were divided into concentric circles with a consecutive incrementing radius of 1 km from the centre of the city. This analysis helped in visualising the process of change at local levels and understand the agents responsible for the changes. This helps in identifying the causal factors and locations experiencing various levels (sprawl, compact growth, etc.) of urbanization in response to the economic, social and political forces. This approach (zones, concentric circles) also helps in visualizing the forms of urban sprawl (low density, ribbon, leaf-frog development).

The built up density in each circle is monitored over different time period through time series analysis. This helps the city administration in understanding the urbanization dynamics to provide appropriate infrastructure and basic amenities. Shannon's Entropy (Hn): Further to understand the growth of the urban area in a specific zone and to understand if the urban area is compact or divergent, Shannon's entropy (Lata et al., 2001; Ramachandra et al., 2012a) given in equation 1, was computed for each zone.

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

Where, Pi is the proportion of the built-up in the i^{th} concentric circle. If the distribution is maximally concentrated, the Shannon's Entropy (H_n), of zero is obtained. If distribution is evenly among the concentric circles, H_n will have maximum of log n.

Computation of spatial metrics: Spatial metrics are helpful to quantify spatial characteristics of the landscape. Select spatial metrics with details given in Table 2, were computed to analyse and understand the urban dynamics through FRAGSTATS (McGarigal and Marks in 1995) at three levels: patch, class and landscape levels.

Indicator	Formula
Number of patches(Built-up)(NP)	$N = n_i$; Range: NP≥ 1
Patch Density (PD)	$PD = \frac{n_i}{A}(10{,}000)(100)$; Range: PD> 0
Normalised landscape shape Index (NLSI)	$NLSI = \frac{e_i - \min e_i}{\max e_i - \min e_i}$; Range: 0 to 1
Total edge	TE=E, E=no of edges, TE ≥ 0, without limit.
Edge Density	$ED = \frac{E}{A}$: Range: ED $\geq$ 0
Clumpiness Index (Clumpy)	$G_i = \left[\frac{g_{ii}}{(\sum_{k=1}^{m} g_{ik}) - \min e_i}\right]$ $CLUMPY = \begin{pmatrix} \left[\frac{G_i - P_i}{P_i}\right] \text{ for } G_i < P_i P_i < 5; else \\ \frac{G_i - P_i}{1 - P_i} \end{pmatrix}$ Range: Clumpiness ranges from -1 to 1
Percentage of Land adjacencies (Pladj)	$PLADJ = \left(g_{ii}/\sum_{k=1}^{m} g_{ik}\right)(100)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *double-count* method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method. 0<=PLADJ<=100
Cohesion Index	$Cohesion = \left[1 - \left(\sum_{j=1}^{n} P_{ij} \Big/ \sum_{j=1}^{n} P_{ij}\sqrt{a_{ij}}\right)\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} * 100$ Range:0≤cohesion<100

Table 2. Landscape Metrics used in analysis

4 RESULTS

Land cover analysis: Land cover computed through NDVI, shows a decline of vegetation from 26.62% (1977) to 21.32% (2013) and year wise changes are tabulated in table 3 and depicted in Fig. 4.

Land use analysis: Land use analysis was performed to classify into four categories through GMLC using training data collected from the field, Google earth and SOI toposheets. Fig. 5.The statistics calculated is as tabulated in table 4. The results show that the urban paved surface increased by around 689 times from 3%

to 10%. The analysis showed the increase in vegetative cover which can be attributed to increase in agricultural area with crop. Water class remained fairly constant and other class which included open area, agricultural plots without crop decreased overtime from 73% to 60 %. Urban growth in past 4 decades in the study region can be seen in Fig. 6, this explains growth of urban land use in every decade. Assessment of land use dynamics helps in understanding the trends of urban expansions. This illustrates the maximum growth in South-East, North-East and North-West directions and occurs mainly in the gradients near the centre. Minimal growth or marginal growth compared to central gradients is seen in buffer zones and the periphery.

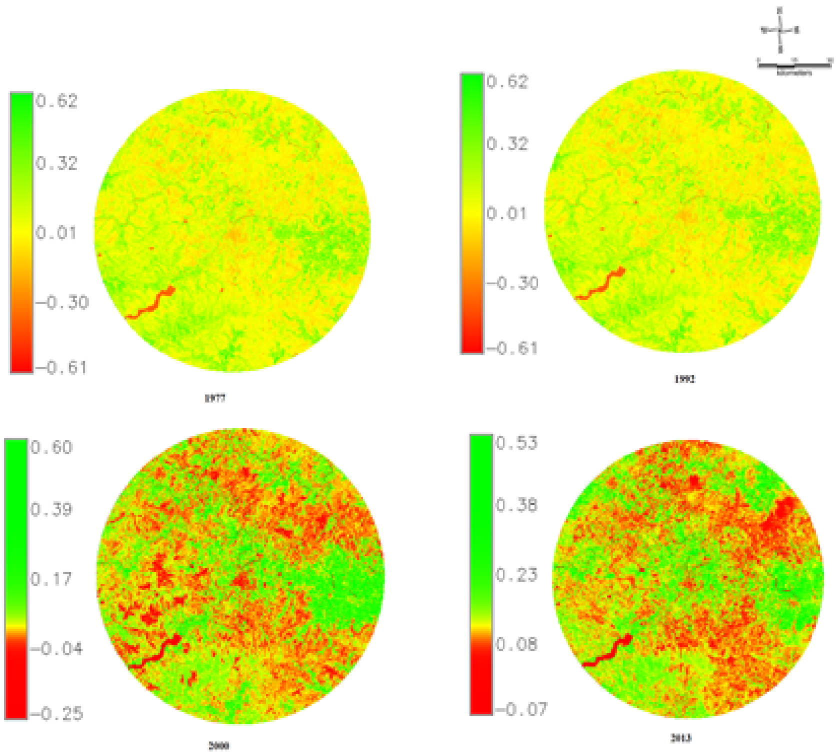


Fig. 4 land cover of Pune with 10 km buffer

Land cover in %	Vegetation	Non-Vegetation
1977	26.62	73.38
1992	16.74	83.26
2000	16.42	83.58
2013	21.32	78.68

Table 3: Land covers statistics for the study region

Accuracy assessment: Accuracy assessment of the classified images was done through the computation of overall accuracy and kappa statistics as shown in table 5. Overall accuracy ranges from 81% to 94%.

Urban growth in each decade is as represented in Fig. 6.

Shannon entropy: Shannon entropy was computed zone wise (by dividing the region into 4 parts based on cardinal directions and with one km incremental radius from the center). The Values close to log of the gradients in each direction explains that the region is completely fragmented and has experienced sprawl. The values close to zero indicated clumped central core growth.

The results of the analysis are as shown in Fig. 6. The values show that there is influence sprawl in the region especially in NW and NE directions.

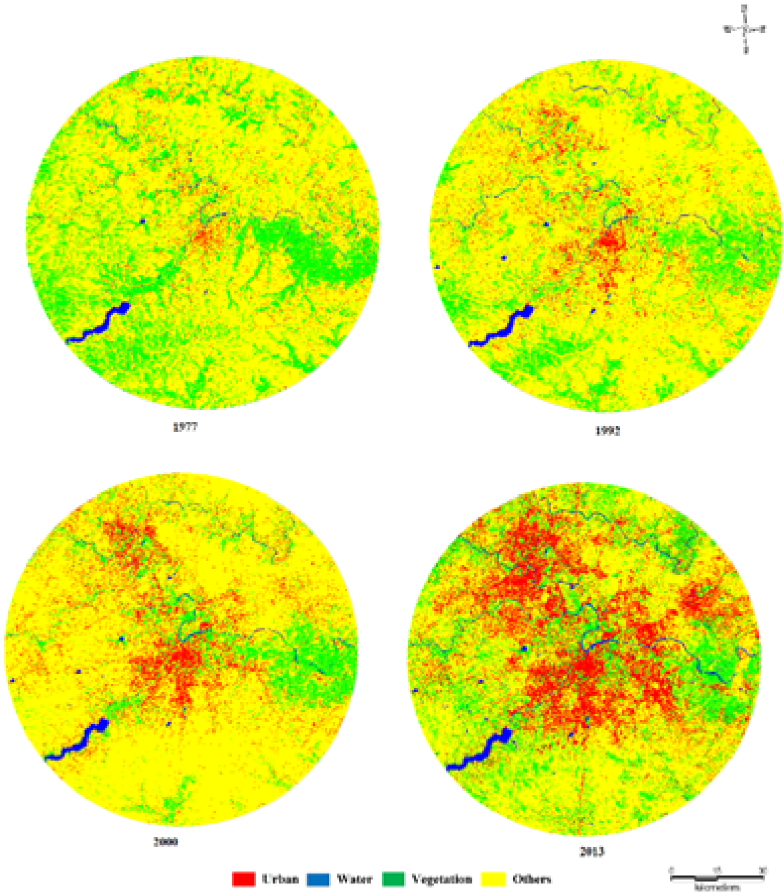


Fig. 5 Land use of Pune with 10 km buffer

Land use in %	Urban	Water	Vegetation	Others
1977	2.96	0.92	22.49	73.63
1992	5.09	1.33	14.09	79.49
2000	9.46	1.21	12.13	80.10
2013	20.40	1.75	17.96	59.89

Table 4: Land use statistics for the study region

1977		1992		2000		2013	
OA	κ	OA	κ	OA	κ	OA	κ
81	0.82	91.2	0.9	93.1	0.9	94.6	0.91

Table 5: Overall Accuracy and kappa statistics of classified images

The values are as high as 0.52 in NW and 0.41 in NE are just midway of log (22) (22 gradients) = 1.3. Shannon Entropy highlights that the region is experiencing land transformation from centric growth to multi-dimensional fragmented growth.

This growth might create more concentrated unconnected patch growths, leading to haphazard development without basic facilities, thereby impacting the local environment.

This indicates that the region has to be monitored gradient wise to understand the specific pockets of growth that will help city managers to plan further developments (Fig. 7). Thus an analysis of landscape metrics gradient wise and zone wise was carried out.

Spatial patterns of urbanisation: Spatial pattern of urbanization were assessed zone-wise for each gradient through select spatial metrics.

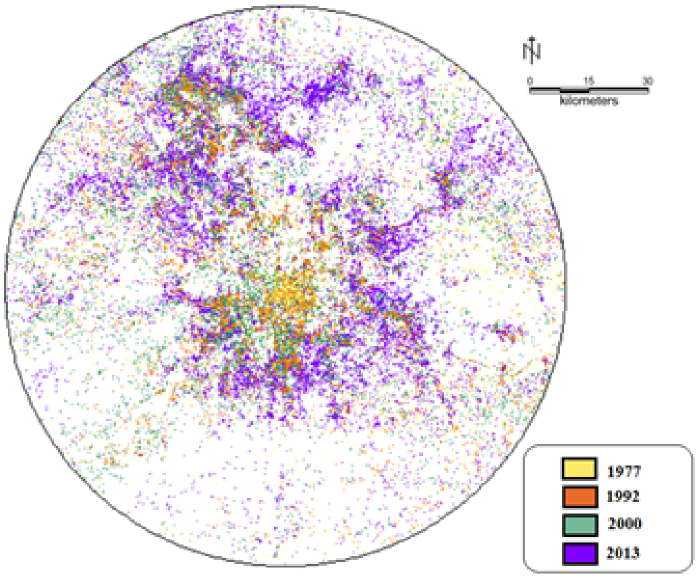


Fig.6 Urban growth pattern

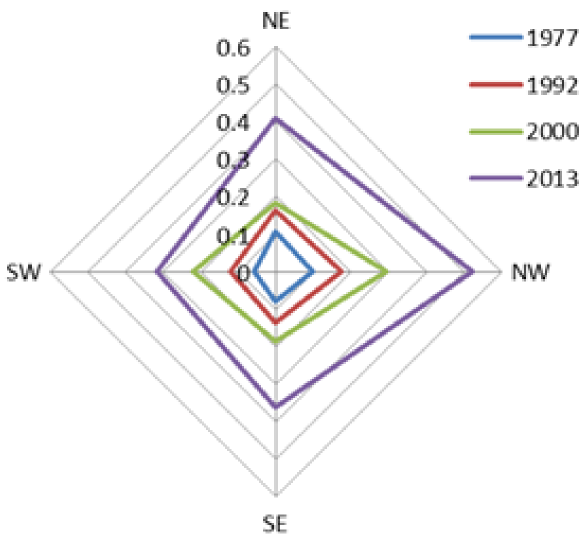


Fig. 7 Shannon entropy index calculated

Number of Urban patches (NP) and Patch density (PD): These metric quantifies patches that helps to identify the level of fragmentation (Fig. 8a). Higher the number of patches, then the region is under fragmentation. Patch density analogous to NP reflects number of patches per unit area is given in Fig. 8(a) and Fig. 8(b). Highlights that Pune had clumped growth during 70's and 90's in all zones and confined to the core areas of the city. Post 2000 the city showed the signs of fragmentation especially in north-west and north-east directions with values reaching 500 patches in near periphery. Buffer zones also show similar trends with approximately 200 patches on an average, and 800 patches (2013) in all directions resulting in higher patch densities which indicates of sprawl in the region.

Total edges and edge density: Edges and edge density basically are indicator of fragmentation in the landscape. Edge density represents denseness of the patches/edges in the landscape. Edges in 1977 across all zones and circles indicates that the core of the city are clumped. Further, post 1992 edges have increased highlighting fragmented out growth. In 2013, Gradients covering the inner core are clumped in the north-east and north-west directions, and the outskirts are with large number of edges (~300000 edges) in NW and NE directions. Density of 1.5 signify higher edges. Fig. 8c and 8(d) represents outputs of Total edge and Edge density.

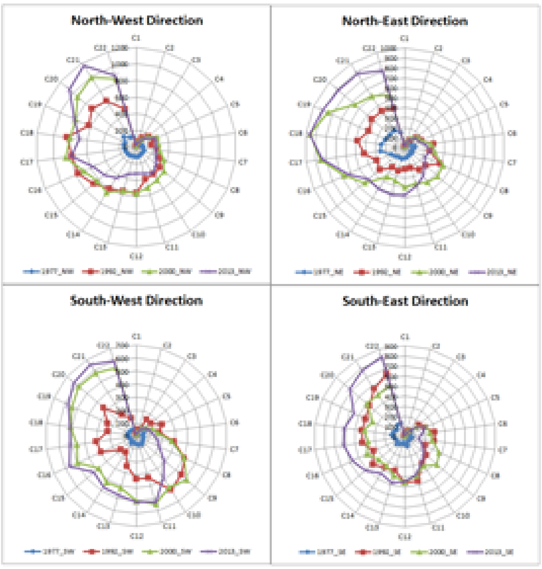


Figure 8(a) Number of urban patches

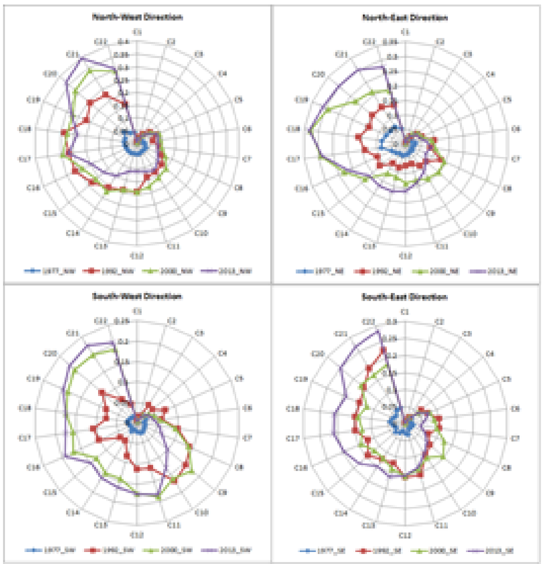


Figure 8(b) Patch density

Normalized shape index (NLSI): NLSI describes the shape of the particular class in the landscape. It is 0 when the landscape consists of a maximally compact patch and increases as the patch type becomes increasingly disaggregated and is 1 when the patch type is maximally disaggregated (Fig. 8(e)). The results of the analysis show that the gradients near the core with aggregations are forming a compact patch, whereas outer gradient in all direction with the spurt in urban activities show a value closer to 0.9 in almost all zones in the buffer zones indicating of sprawl as the shape of landscape is irregularly disaggregated and fragmented.

Cohesion index: Cohesion index implies the physical connectedness of the focal class and the value is 0 with the decline of the proportion of urban class in the landscape, which is indicative of fragmented outgrowth else increases monotonically, evident in Fig. 8f, indicating the emergence of urban sprawl in buffer zones and the decrease of the physical connectedness near the core similar to earlier metrics.

Clumpiness index (Clumpy) and Percentage of like adjacencies (Pladj): CLUMPY metric directly measure aggregation and disaggregation of the class in the landscape, equals -1 when the class is maximally disaggregated; and equals 0 when the class is distributed randomly, and approaches 1 when the patch type is maximally aggregated. PLADJ equals 0 when the focal class is maximally disaggregated and no like adjacencies and is equal to 100 when the focal class is a single patch is adjacent between same classes. These metrics are dependent on adjacent characteristics of the focal class in the landscape.

Fig. 8g and 8h shows that gradients reaching aggregation or single patch class from 1977 to 1992 in all zones. However, post 2000 the initiation of fragmentation value reaches 0 for Clumpy and Pladj signifying the fragmentation due to urban outgrowth. This phenomena can be mostly seen in the buffer zones and in regions under extreme pressures of sprawl.

Spatial metrics indicates of sprawl especially in the periphery and the buffer zones. These regions requires an immediate attention by the decision makers to provide appropriate infrastructure and basic amenities.

Metrics computed in each temporal gradients equip the decision-makers with fundamental information about the growth, the role of agents (for example policy decisions to setup industrial layouts, etc.), rate of growth, spatial patterns of growth and information about site specific details such as patches or clumpiness or shapes in the landscape.

This knowledge helps in visualizing the extent and patterns of future growth, which helps in adopting strategies to control or mitigate potential impacts on the sustenance of natural resources due to large scale land cover changes.

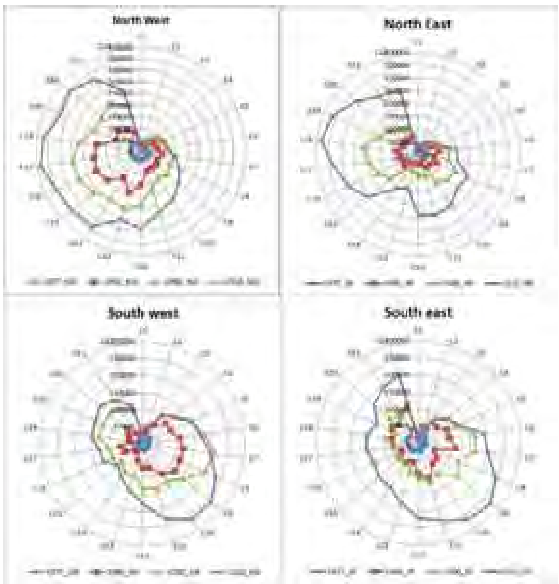


Figure 8(c) Total edge

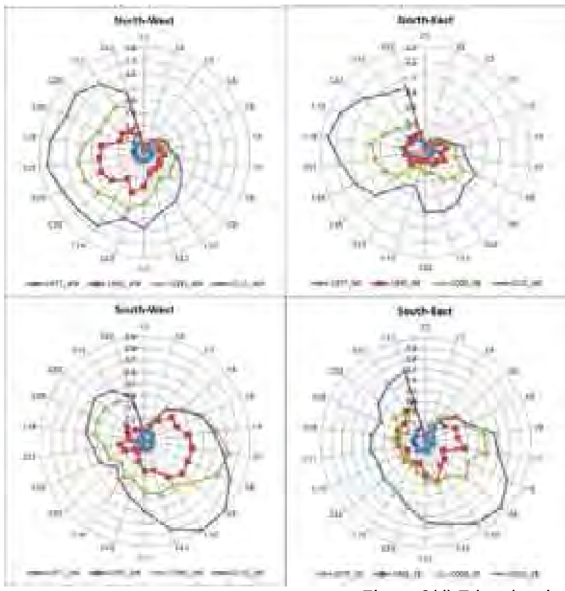


Figure 8(d) Edge density

Spatial pattern dynamics elucidation throws light on the role of earlier government policies (Fig. 9) in urban sprawl or urbanisation process in the region. This also helps in assessing the effectiveness of earlier urban policy measures to address sprawl and development of a city. Integrated management of natural resources involves understanding the rationale of development and making decisions of placing the regions specific development trajectory while maintaining the urban open spaces (parks, lakes, vegetation, etc.), natural water drains and resources.

Localities such as Pimpri, Chinchwad, Kahdakwasla, Dhayari phata, Katruj, Yerwada, Pashan, Lavale, Warje, Baner, Khadki, Tharwade, Pirangut etc., in and around Pune are experiencing large scale land cover changes due to the government push for industrialization in 1990's are now facing the problem due to sprawl and associated problems such as lack of basic amenities, etc.

The spatial analyses establishes that gradient based metrics computation helps in understanding thespatial patterns of a dynamically evolving urban landscape (Keiner and Arley, 2007, Aguilera, 2008) like Pune given the momentum of growth and pressing need to characterize and plan in efficient manner. Fig. 9 illustrates the potential of gradient based spatial pattern analysis in understanding the land use dynamics due to policy interventions.

Pimpri Chinchwad was established in 1988 and developed to cater the requirement of industrial needs. This region is located in gradients 11, 12 and 13 in the north-west zone.

These gradients had higher vegetative cover in the pre-1990. But post 2000 it can be seen extensive conversion of vegetative area urban land use. Landscape metrics for this gradients show that the urban impervious surface were located as a continuous simple shape concentrated surface pre-2000 (Fig. 9a). Post 2000 these regions have experience significant land use change and conversion in to highly fragmented area. In 2013 these regions have changed into most fragmented gradients in North West zone.

Warje (Fig. 9b) is located close to periphery of the Pune municipal boundary. Gradient 6-9 represents this industrial region in the south west zone. The land use before 1990 was dominated by other land use class and post 2000 is dominated by the urban land use. Post 2000, the region formed a clumped simple patch, which indicates of prevalence of urban patch dominance.

Yerawada and Nagar road (Fig. 9c) is located in north east region of Pune and 7-8 gradient of North east zone and contribute about 10% to the industrial output of Pune. Landscape metrics of urban land use highlights that these gradients (post 2000) are in the verge of forming a single dominant urban class with simple shapes.

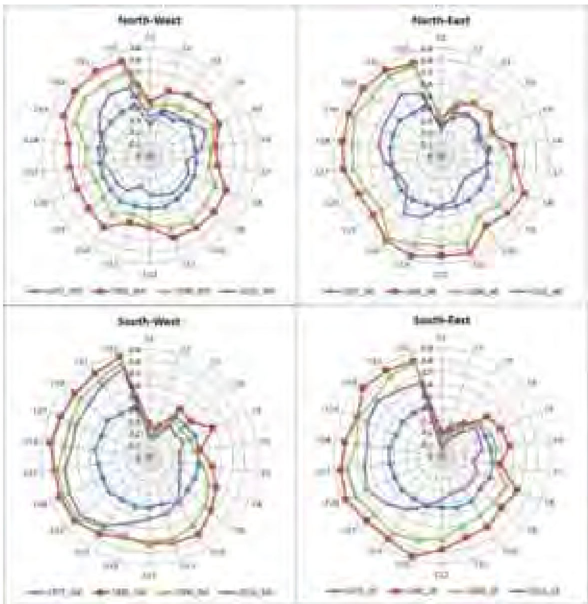


Fig. 8(e) Normalized landscape shape index

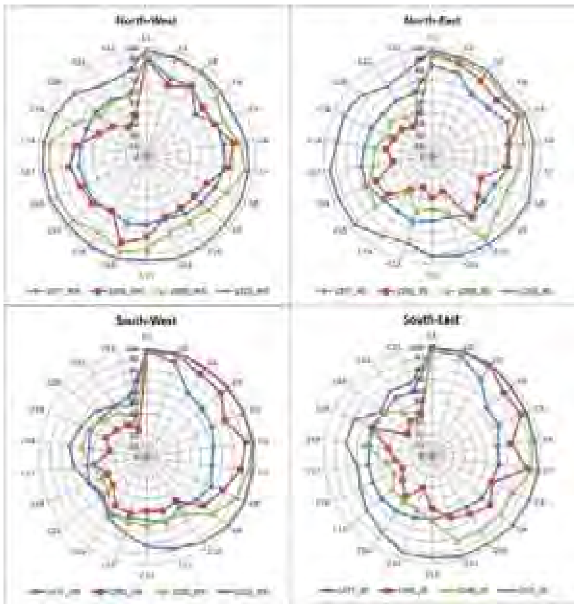


Figure 8(f) Cohesion index

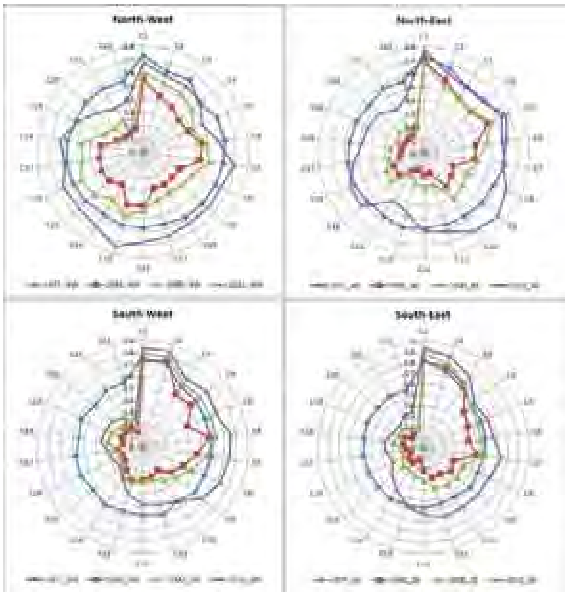


Fig. 8(g) Clumpiness index

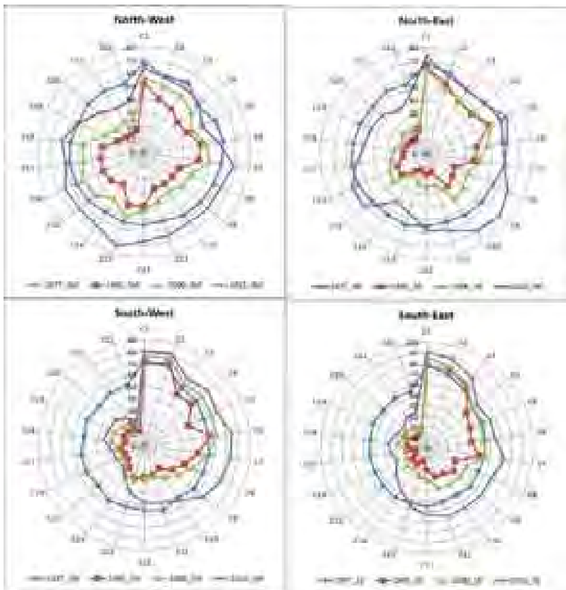


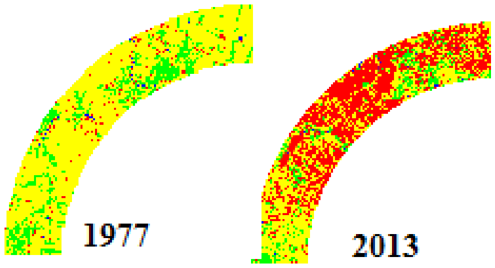
Fig. 8(h) Percentage of like adjacencies

These spatial analyses confirm that policy and socio-economic factors fuel URBANIZATION. Urban planning require essential up-to-date knowledge of spatial patterns of land use changes to regulate and plan the city's expansion as well as infrastructure development. Access to consistent and integrated spatial information about land use dynamics aids in the strategic understanding of the region specific growth for formulating effective cognitive decision on natural resources management by city planners with all stakeholders. Location specific information enhances the planning process through multitude of factors having decisive role in the land use sustainability.

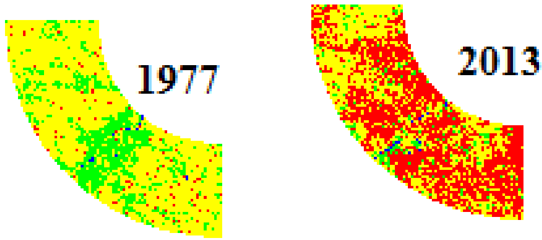
5 CONCLUSION

Spatial patterns of urbanisation and sprawl in Pune city with 10 km buffer has been analysed zone wise gradients using temporal remote sensing data through Geoinformatics and spatial metrics during 1977 to 1992 there was infilling in the core city area. During 2000 and 2013 the fragmentation was quite evident at city outskirts. Spatial pattern dynamics analysed through patch, contagion, edge and shape metrics.

a). Pimpri chinchwad



b). Warje



c). Yerawada and Nagar

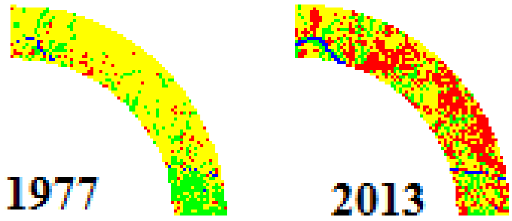


Fig.9 Spatial patterns of urbanization with industrialization in 1990's

The temporal pattern of the urbanization process of this region highlights the process of coalescence during the rapid urbanization decade (2000 to 2010). Results indicate the process of aggregation in the core compared to the periphery and the buffer zones. Globalisation and the reforms in the industrial sector during 1990's witnessed a spurt in urban growth, which is evident from the occurrence of large number of urban patches surrounded by other land uses, especially in industrial pockets such as Pimpri chinchwad, Warje, Yerawada, etc. Subsequent urban growth witnessed consolidation of fragmented patches with lower patch density and larger urban patch to form clumped urban pockets in NW and SE directions by 2010. Specifically, aggregation of patches is noticed in northwest at the outskirts and even at the buffer zone. Gradients with metrics provide vital information to the decision makers about level of urbanisation and the role of agents (policy issues, etc.). Information about the patterns of growth, rate of growth, patches, clumpiness etc. would help in evolving appropriate location specific strategies to mitigate environmental consequences. Visualisation of urban growth based on the behavior of agents with the temporal data help the city managers in help city planners and administrators to design towards achieving the goals of sustainable cities.

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