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SMART ENVIRONMENT FOR SUSTAINABLE RESOURCE MANAGEMENT

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Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.tema.unina.it
e-mail: redazione.tema@unina.it

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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.

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.

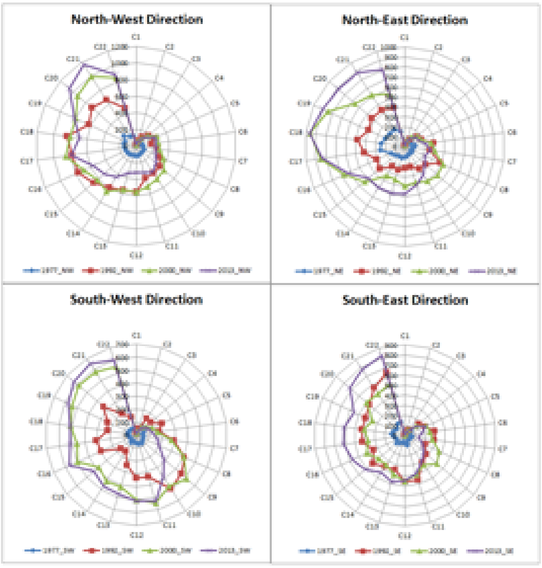

Figure 8(a) Number of urban patches

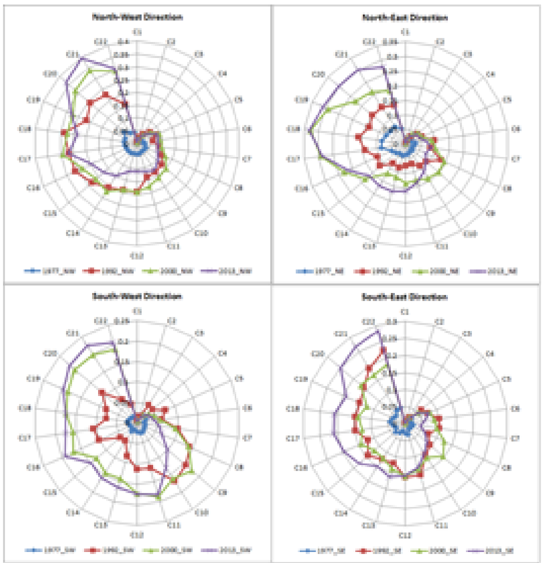

Figure 8(b) Patch density

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.

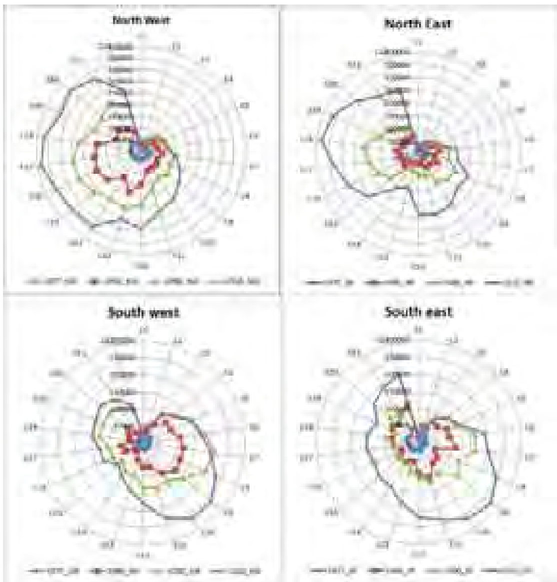

Figure 8(c) Total edge

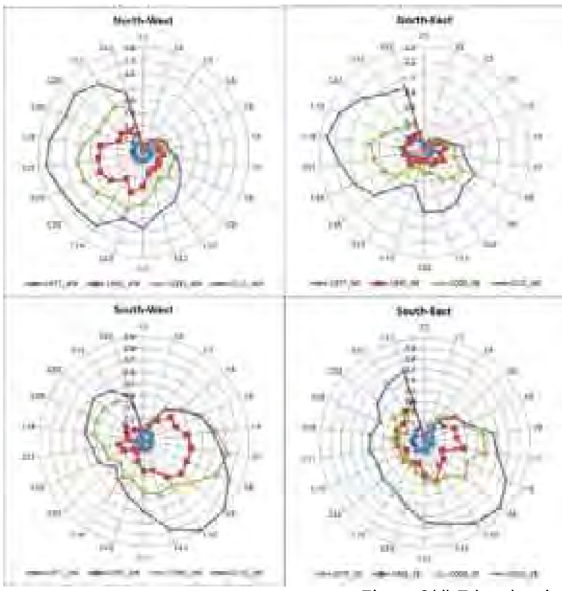

Figure 8(d) Edge density

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.

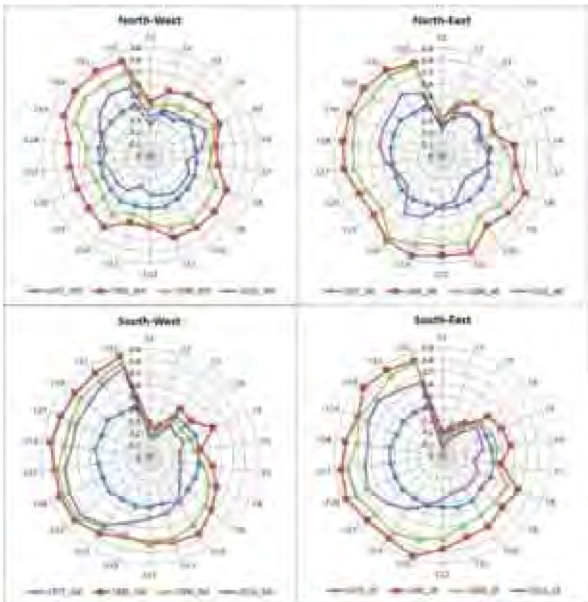

Fig. 8(e) Normalized landscape shape index

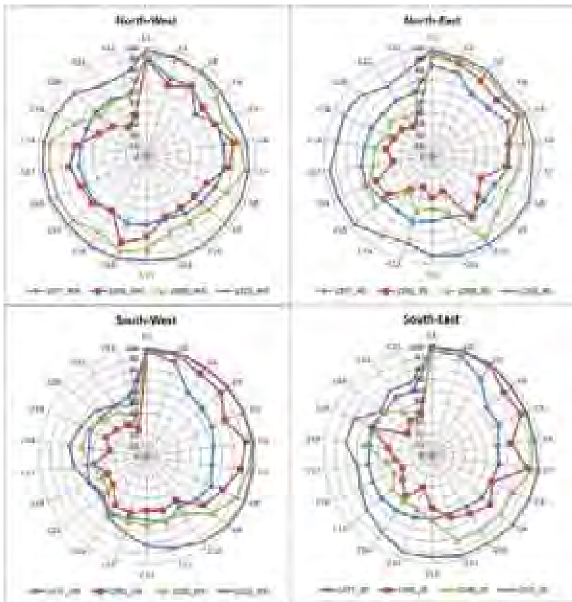

Figure 8(f) Cohesion index

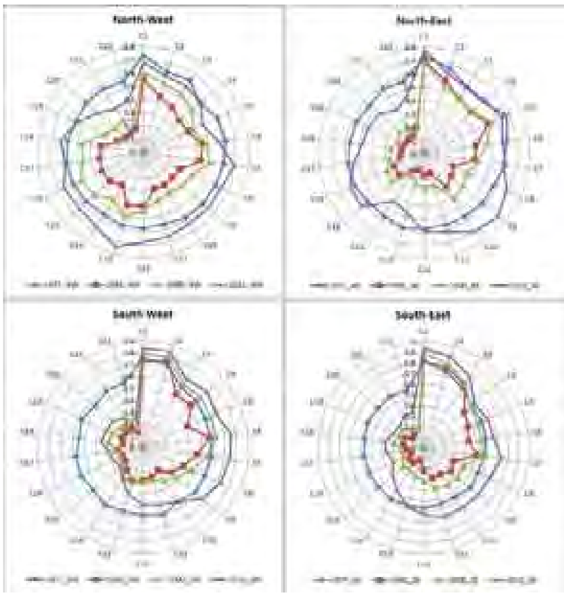

Fig. 8(g) Clumpiness index

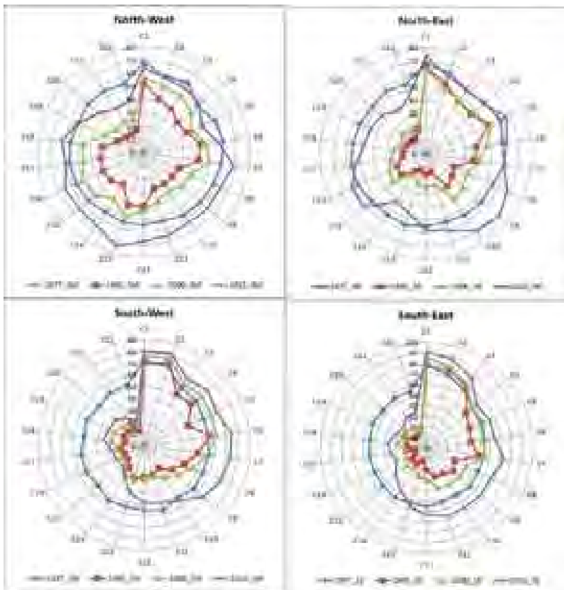

Fig. 8(h) Percentage of like adjacencies

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

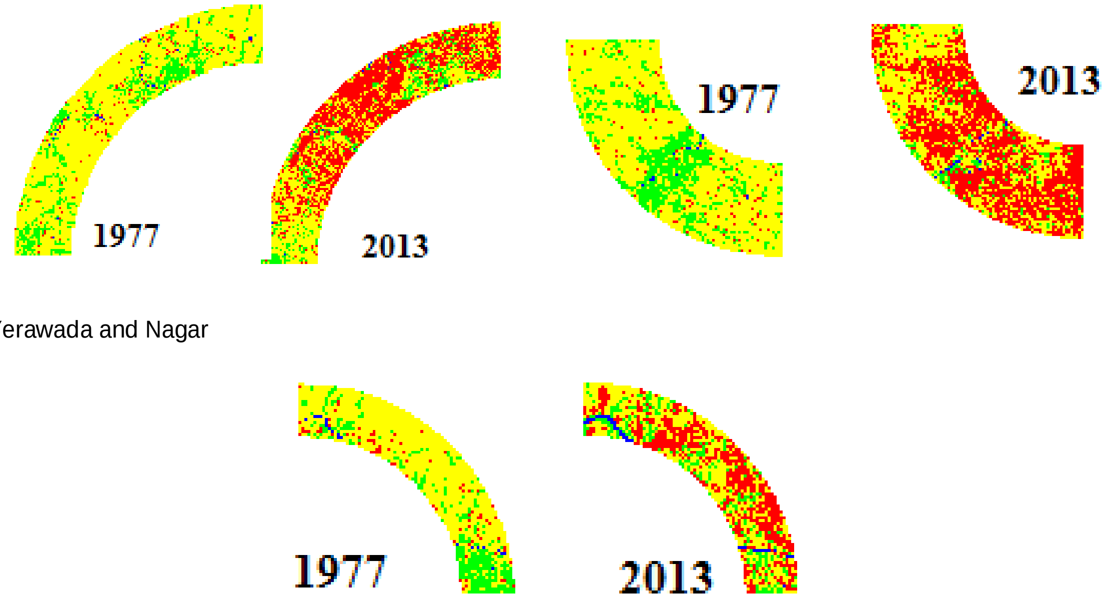

Fig.9 Spatial patterns of urbanization with industrialization in 1990's

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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AUTHOR'S PROFILE

Ramachandra T V

Dr. Ramachandra T V has Ph.D. in energy and environment from Indian Institute of Science. At present, Coordinator of Energy and Wetlands Research Group (EWRG), Convener of Environmental Information System (ENVIS) at Centre for Ecological Sciences (CES), Indian Institute of Science (IISc). He has made significant contributions in the area of energy and environment. His research area includes wetlands, conservation, restoration and management of ecosystems, environmental management, GIS, remote sensing, regional planning and decision support systems. During the past ten years he has established an active school of research in the area of energy and environment. He teaches principles of remote sensing, digital image processing and Natural resources management. He has published over 206 research papers in reputed peer reviewed international and national journals, 178 papers in the international and national symposiums as well as 14 books. In addition, he has delivered a number of plenary lectures at national and international conferences. He is a fellow of Institution of Engineers (India), IEE (UK), Senior member, IEEE (USA) and many similar institutions. Details of his research and copies of publications are available at http://ces.iisc.ernet.in/energy/, http://ces.iisc.ernet.in/grass

Bharath H Aithal

Bharath H Aithal, Electrical and Electronics Engineering graduate from Bangalore University. Currently, he is pursuing Ph.D at Indian Institute of Science. His area of interest are spatial pattern analysis, Urban growth modelling, natural disasters, geoinformatics, landscape modelling urban planning, open source GIS, digital image processing. He is a Graduate student member of the IEEE

Beas Barik M

Beas Barik M Tech at Symbiosis Institute of Geoinformatics, Pune. Her area of interest are spatial pattern analysis, geoinformatics, open source GIS, digital image processing.