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Modelling the Spatial Patterns of Landscape dynamics: Review

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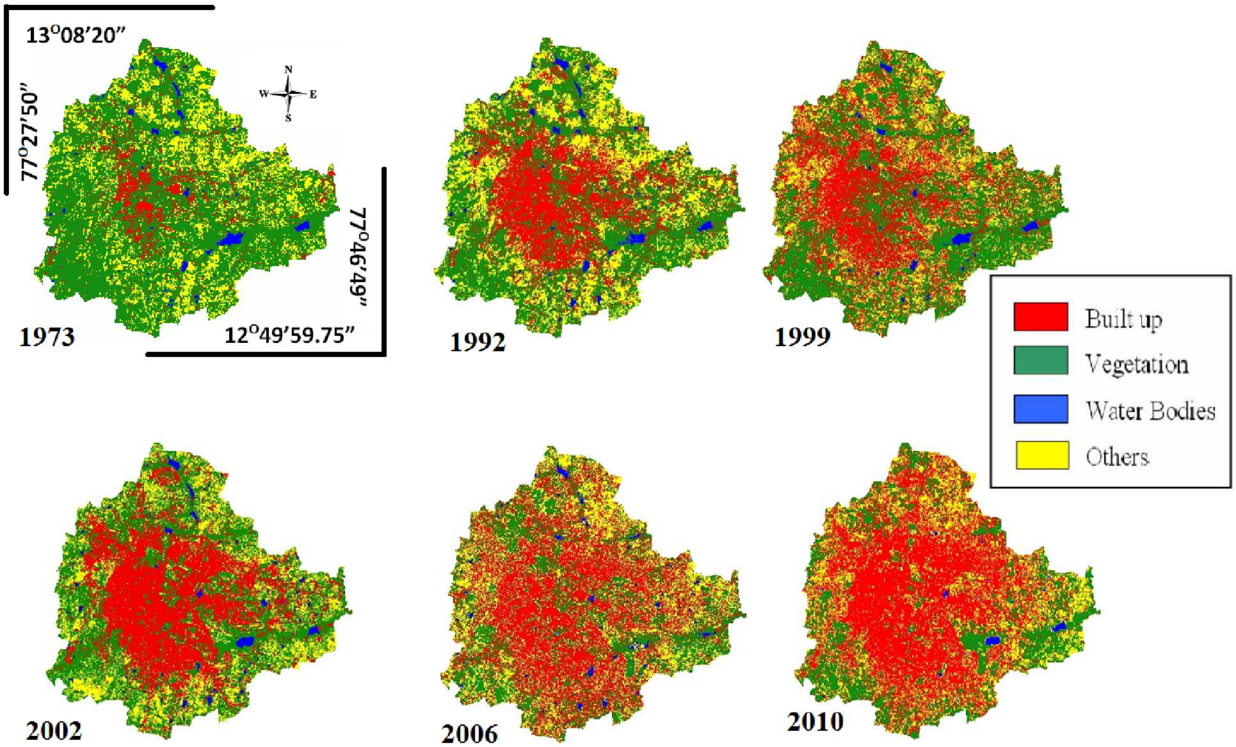

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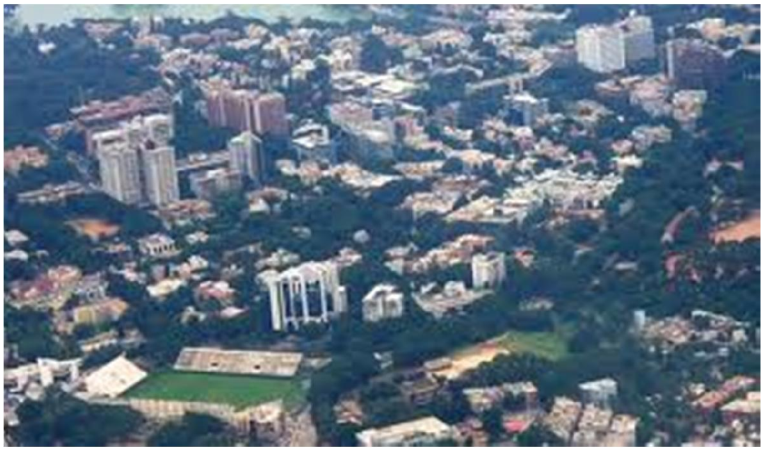

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Modelling the Spatial Patterns of Landscape dynamics: Review

Summary

This review focuses on the issues and concerns associated with the landscape dynamics and outline the essential steps to strengthen policy, planning and decision making while identifying the gaps. Review of the different geospatial modelling techniques (operations research, system dynamics, geospatial, agent-based, etc.) being used in the rapidly urbanizing landscape and peri-urban landscapes highlights the need for geo-based models and also the need for a landscape planning support system.

Introduction: Landscape is heterogeneous land area composed of a cluster of interacting systems which forms an interconnected system called ecosystem (Forman & Godron, 1986). Landscape can be further defined as a distinct, measurable unit defined by its spatially repetitive cluster of various interacting systems (Forman & Godron, 1986). As the functional ability of the landscape is dependent on its structure, landscape studies basically focus on mainly three aspects

i. Structure of the landscape deals with its constituent ecosystem elements along with its size, shape and configuration. It can be further divided as patches, matrix, corridors and networks.
ii. Landscape functions deal with the interaction of the spatial elements and results in nutrient cycles, bio-geo-chemical cycles and water cycling in a landscape.Landscape changes deal with the alteration in structure and consequent functions of the ecological mosaic over time.
iii. Landscape configuration are virtually non-randomly distributed, using various pattern that may occur and are divided (Forman and Gordon, 1986) into: Regular or even landscapes (where the distance between the landscape elements are relatively uniform), Aggregated distributions (landscape in the form of various clusters), Linear patterns (landscape elements clustered linearly), and Distinctive patterns. These configurations can be linked through two major approaches namely, Line (compared to a line, aggregation or compactness of a landscape element type and spatial linkages between different types) and Grid (analyse the horizontal distribution of a landscape) approaches.

Landscape influenced by humans may create a high contrast structures within large homogeneous patches. As a result, micro-heterogeneity is induced in the original landscape having macro-heterogeneous patches and are extremely common in all parts of the earth. Thus the reflectivity from the landforms decides the contrast which can be subdivided into low and high contrast (Forman and Gordon, 1986). Landscape can be divided as coarse or fine grained depending on the size of the landscape elements present. These helps in better understanding of landscape structure with its dynamics and are useful in modelling the landscape dynamics with its functions.

Landscape Dynamics

Landscape systems are major challenges as their complex interactions of environmental factors and driving forces continuously alter the composition of species, and these dynamics are reflected on different landscape patterns (Fry, 1998; Lambin et al., 2001). Landscape patterns depend on scale and time and hence are dependent on the observations (Delcourt et al., 1983; Turner et al., 1989), which tend to respond with varied time lags to changing environmental conditions (Lofvenhaft et al., 2002). Landscape pattern subjected to development and disturbances undergo rapid alterations in its grain sizes. Pattern and scale are therefore central issues in urban dynamics and require appropriate analyses. It also acts as a valuable surface upon to implement planning and management actions due to ecological, economic, and cultural values attached to the landscape.

Seasonality/temporal complexity of constant changes and human induced changes in the landscape were addressed since copper and iron ages (Forman & Godron, 1986). These modification and associated landscape dynamics are understood using patterns of human role in the landscape as a gradient. Highly diversified landscapes based on its dynamics are divided into five types as natural, managed, cultivable, suburban and urban. These changes on time (temporal) and spatial scales are characterized by size, shape, number and origin of patches in addition to factors such as matrix, habitations and different kinds of corridors (Forman & Godron, 1986). Urban landscape and peri-urban landscape are characterized on their coexistence in a particular ecosystem.

Landscape level analysis: Need and Opportunities

Landscape changes have been rapid and occurring at a large scale in the last century (Antrop, 2005; Calvo-Iglesias et al., 2008). Principal agents of these changes that act simultaneously are accessibility, urbanization, globalization and natural calamities (Sua et al., 2010; Ramachandra et al., 2012). The dynamics of these changes have been attributed to socioeconomic and regional factors or agricultural and industrial policies (Lasanta-Martínez et al., 2005; MacDonald et al., 2000; Olsson et al., 2000).

This dynamic phenomenon necessitates landscape monitoring and assessment of changes in spatial patterns over time. Identifying driving forces for landscape changes ensures sustainability of natural resources. Interactions between landscape spatial pattern and ecological processes explain the impacts of landscape changes on habitats, biodiversity, complexity and fragmentation of the landscape, and on cultural values (Dramstad et al., 2001; Zeng & Wu 2005). Hence, there is a need to quantify landscape changes considering both spatial arrangement modifications and their consequences.

Temporal Analysis of Landscape

Landscape structure, size and behavior have been considered in many studies related to landscape habitat analysis, human impact assessment (Harris, 1984; Theobald et al., 2000; Tinker et al.,1998), and modeling and simulation of temporal changes. Most landscape studies are specific time bound, although landscapes are affected by continuously ongoing processes. Due to the dynamic nature of the landscape, temporal changes must be considered (Dunn et al., 1991), including variation of the number and size of patches, corridors, dispersion barriers, and probability of disturbance propagation (Turner, 1989).

The temporal understanding of the landscape is necessary for a deeper understanding of sustainability of natural resources. Temporal changes in a landscape structure caused by human activities have been evaluated through mapping and through calculation of landscape metrics and associated landscape structural changes (e.g., Batisani & Yarnal, 2009;Chen et al., 2001; Coppedge et al., 2001; Cushman and Wallin, 2000; Kammerbauer and Ardon, 1999; Long et al., 2009;Rao and Pant, 2001; Reed et al., 1996; Skanes and Bunce, 1997; Tavares-Correa et al., 2009;Turner et al., 1996; Wu et al., 2009;Zheng et al., 1997).

Rapidly Urbanising Landscape Dynamics

An urban landscape is charecterised by the parameters such as the number of residents, population density, percent of people dependent upon non-agricultural income and provision of public utilities and services. In India, an area is designated as urban if the population is more than 5000 with a population density of more than 400 persons per sq. km and at least 75 percent of the population is involved in non-agricultural occupations. India's urban population is currently growing at about 2.3 percent per annum. An increased urban population and growth in urban areas is inadvertent with an unpremeditated population growth and migration. Urban growth, as such is a continuously evolving natural process due to population growth rates (birth and death). The number of urban agglomerations and towns in India has increased from 4369 in 2001 to 7938 in 2010. It is projected that the country's urban population would increase to about 41.4 percent by 2030 (United Nations, 2004; Ramachandra et al., 2012). In 2010, there are 48 urban agglomerations / cities having a population of more than one million from 35 urban agglomerations in 2001, which was 25 in 1991. Of the 4000 plus urban agglomerations, about 38 percent reside in just 35 urban areas, thus indicating the magnitude of urbanisation prevailing in the country. This clearly indicates the magnitude of concentrated growth and urban primacy, which also has led to urban sprawl.

The exponential growth of cities has been noticed since the industrial revolution and as transport sector changed the mobility of the masses drastically. This phenomenon has been referred as urban sprawl, urbanization, suburbanization, urban fringe, edge cities, exurbs, etc. and all reflect the complexity of the diverse levels of dynamic process (Champion, 2001; Pacione,2001; Antrop, 2000c; Geyer and Kontuly,1993; Bryant et al., 1982; Feranec et al., 2010; Foley et al., 2005; Lo´ pez & Sierra, 2010). Rapid urbanization in the developing world is one of the crucial issues of global change in the 21st century affecting the human dimensions (Sui and Zeng, 2001).

Urbanisation is a form of metropolitan growth in response to technological, economic, social, and political forces and to the physical geography of an area. The process of urbanisation is fairly contributed by rural-urban migration leading to higher proportional population growth of urban-rural and subsequent infrastructure initiatives, resulting in the transition of villages into towns, towns into cities and cities into metros. With the extensive urbanisation followed by industrialisation, the compact and densely populated cities emerged during the last century. Over the last century, these countries saw the emergence of large metropolitan cities. Cities are continuing to spread in spite of the saturated and stagnated urbanisation, in Europe and other developed countries (Batty et al., 2003). As the cities grew in population, infrastructure facilities such as transportation were affected. The affluent also aided by individual transportation moved towards the outskirts thereby minimising costs in the central business districts, while inducing the spread of cities (Marathe, 2001). Also, at times, the civic authorities provided better public transportation facilities from the core to the outskirts and along the periphery, which encouraged people to move outskirts also inducing sprawl. In other words, be it either better transportation or the population growth, the cities expanded transforming neighbouring agricultural lands and affecting ecologically sensitive habitats. This phenomenon of urban sprawl is being witnessed, studied and documented in most cities of north-western Europe and North America even after reaching the stagnation and saturation levels of urbanisation. The problem of sprawl has been addressed through extensive studies and policy recommendations in the European Union (Gayda et al., 2005) and United States of America (TRB, 2002). Urbanisation, as such, is not seen as a threat to environment and development, but it is the unplanned urbanisation and subsequent urban growth, or the sprawl affecting land-use with loss of prime agricultural lands and also ecologically sensitive regions. Indian economy is mainly agrarian (contribution to GDP is about 28 percent) with about 70 percent of the population residing in rural areas. It is thus imperative to carry out better regional planning through proper understanding of the implications associated with the problem of unplanned urban growth or sprawl.

Urban sprawl is an unplanned outgrowth of urban areas along the periphery of cities, along highways, and along the road connecting a city. Towns and cities are expanding in certain pockets with changes in land use along highways and in immediate vicinity of the cities due to ad hoc approaches in planning and decision-making. This uncontrolled and un-coordinated, dispersed development outside the compact urban and rural centres (along highways and in rural countryside) has the environmental impacts such as loss of agricultural land, open space, and ecologically sensitive habitats in and around the urban areas. These regions lack basic amenities due to lack of prior information and predictions of such growth during planning, policy and decision-making. Sprawl results in engulfing of surrounding / neighbouring villages into peri-urban areas, peri-urban areas to towns and towns into cities. However, in such a phenomenon of development, to have basic infrastructure, regional planning requires an understanding of the process and dynamics. Nevertheless, in a majority of the cases there are inadequacies to ascertain the nature of uncontrolled growth. This necessitates prior planning, coordinated decision-making and visualisation of the consequences of urbanization to ensure the sustainability of the resources.

Urban growth patterns resulting in sprawl are 'unsustainable', with the current consumption surging ahead of regions' carrying capacity and leading to depletion of natural resources for future generations. The need for managing urban sprawl also arises out of the global concerns of achieving sustainable urbanisation. Sustainable urbanisation is a dynamic, multi-dimensional process covering environmental as well as social, economic and political-institutional sustainability (UN-Habitat, 2002). Understanding the sprawl processes, its dynamics and modelling provide an insight of future growth trends, which is useful for effective resource utilisation and infrastructure planning. The efficiency of urban settlements largely depends on how well they are planned; how well they are developed economically and how efficiently they are managed.

In industrialised developed countries the growth of urban population is comparatively modest as population growth rates are low and over 80 percent of their population already live in urban areas. Conversely, developing countries with higher growth rates are in the middle of a transition. The exceptional growth of many urban agglomerations in many developing countries is the result of a threefold structural change process: the transition away from agricultural employment, high overall population growth, and increasing urbanisation rates (Grubler, 1994). Developing countries are faced with the problem of increasing urban poverty levels, higher population growth rates and rising numbers of slums or squatters resulting out of sprawl. This is in contrast to developed countries, where the problem of sprawl has to be addressed in terms of transport, energy, land use, and environment. It is in this context that the study on urban sprawl gains importance.

Rapid urbanization from landscape perspective has given rise to significant changes in the ecosystem structure, impacting its functions. Dramatic urban expansion and resultant land use changes have induced serious environmental issues threatening sustainable development (Yeh and Li, 1999; Ji et al., 2001; Weng, 2001; Li and Yeh, 2004; Chen et al., 2005; Xiao et al., 2006; Liu et al., 2007). Cities form extended circular networks affecting large areas with a multitude of different functions (Cheshire, 1995) describes this complexity. Management of the countryside along with functional urban areas is complex and interdisciplinary (Brandt et al., 2001).

Urban landscapes are charecterised by building, city blocks with the scattering of parks and uncommon landscape (Stearns and Montag, 1974, Dorney and McLellan, 1984). These are relatively unorganized homogeneous ensemble transforming the landscape into organized structure which cycles energy and information within itself (Wilson et al., 1973; Dorney and McLellan, 1984). Urban areas interact with the neighbouring landscape structures in the form flows of commuters, pollution, obtaining food grain, vegetables, etc. This creates stretch of dwelling localities between the metropolis and the rural landscapes and often these areas are devoid of basic amenities like treated water supply, electricity, sanitation, health, etc., these localities are often referred as urban sprawl.

The adverse effects of the process of unplanned urbanisation are amplification of the mosaic character of landscape, simplification of composition of the spatial landscape complexes with severe fragmentation of habitats (Solon, 1990). Landscape transformations under the influence of urbanization are multi-directional and differentiated in time and space. Li et al. (2003) pointed out that the dynamic process of urban expansion depends very much on topography, land use of the influenced area, as well as on demography and economy in a city.

Humans influence landscape heterogeneity in three ways: (i) landscape is modified to feed human stock, (ii) modification of landscape structure (example.: extraction of mineral deposits), and (iii) the aggregation process from rural to semi urban to urban. Therefore for the better utilization of landscape and its features, regional planning need to account all classes of the landscape ranging from urban area to rural area, which is possible only when the data is available for all classes and on a temporal scale.

Urban land expansion is one of the most direct representation forms of land use/land cover change, and refers specifically to change in land use pattern and urban space distribution resulting from land, social and economic pressure (Alphan et al., 2009; Gilliesa et al., 2003).

The best approach to understand the process of urbanization and its consequences can be easily understood by quantifying landscape pattern, either based on the analysis of indices (e.g., polygon shape index, Comberet et al., 2003) or a set of landscape metrics. The most classical is the urban–rural gradient analysis (Luck and Wu, 2002), extended by incorporation of temporal trends analysis (Weng,2 007), and multiplication of transects (Kong and Nakagoshi, 2006; Yu and Ng, 2007). The other approach based on grid analysis for the entire landscape, fills in the information gaps that arise by only presenting a cross-section of the study area (Hahs and McDonnell, 2006). An assumption is made that the landscape structure is shaped by different processes, occurring simultaneously at the same area, or separately in different parts of the region.

Urbanisation and sprawl were initially investigated in relation to population growth and the spatial extent of urban areas. Subsequently, studies dealt the problem of sprawl in relation to transportation, demography, economics, energy, land use, vehicular emissions, climate and safety. The problem of sprawl needs to be addressed considering all disciplines with an integrative approach (TRB, 1998 and 2002; Gayda et al., 2003 and 2005). The problem has been acknowledged for nearly six decades and ascribe sprawl as low-density development beyond the edge of service and employment (Sierra Club, 1998; Batty et al., 1999; Batty et al., 2002; Torrens and Alberti, 2000; and TRB, 2002). Urban sprawl has been accompanied with three interrelated problems of spatial dynamics: densification of central or core cities which usually mark the historical origins of growth; the emergence of edge cities which compete with and complement the functions of the core; and the rapid suburbanisation of the periphery of cities - core and edge - which represent the spatially most extensive indicator of such growth. This uncoordinated and unplanned incremental urban growth along the fringes of the metropolitan areas invading prime agricultural and resource land is unsustainable as such areas are over reliant on the automobile for access to resource and community facilities.

The study of urban sprawl and its implications have been addressed (TRB 1998, 2002; Sierra Club, 1998), considering the sprawl as the spread-out development that consumes significant amount of natural and man-made resources, including land and public works infrastructure of various types. Ascribing the resource impacts of sprawl in terms of costs, these impacts have been classified as land conversion, water and sewer infrastructure, local road infrastructure, local public-service cost and real estate development costs. The personal costs of sprawl have been mainly attributed to travel distance and costs. Sprawl also adds to overall travel costs due to the increasing use of automobile to access work and residence locations which are widely spaced. Sprawl raises the costs of operating urban infrastructure and hence leads to economic inefficiency (Ciscel, 2001) evident from the quantification of three components: the jobs, business and housing, commuting, and government infrastructure capital costs. Increase in population, rise in incomes and falling commuting costs have also fuelled the spatial growth (Brueckner, 2001). Studies have addressed issues of urbanization, urban growth, urban sprawl in relation to transportation, energy, land use, climate, etc. (Jothimani, 1997; Lata et al., 2001; Subidhi and Maithani, 2001; Sudhira et al., 2003 & 2004a, Ramachandra and Sudhira, 2011, Ramachandra et al., 2012), and modeling urban sprawl in India (Subudhi and Maithani, 2001; Sudhira et al., 2004b, Ramachandra et al., 2012). In India, as per constitutional provisions, urban local bodies are mandated for administering, managing and preparing master / development plans. Mostly these plans are static maps with limited forecasting capabilities. Nevertheless there is a need for modeling the dynamics planning process to prevent ad-hoc decisions. Further, with planning authorities restricting to mostly land uses, there is hardly any coordinated effort to involve or integrate transport, electricity, water and sanitation, etc. in the planning process. This results in organisations involved or catering to different services (transport, health, water, energy, etc.) work in isolation to address basic amenities. Lack of coordination among many agencies has led to unsustainable use of land and other resources and also uncoordinated urban growth. Much of this growth is normally attributed to migration of people from other places.

Rural-urban migration takes place mainly due to uncertain employment in agrarian based rural areas. It is found that lack of good governance and administration in the local bodies has resulted in unplanned and uncoordinated urban outgrowth. Urban governance and administration needs to keep track of various processes, activities, services and functions of the urban local body. In this context, regional models based on the information systems involving simulation for evolving location specific strategy and policy options are desirable.

• Landscape Dynamics in a Rural landscapes which are influenced by urbanization

Rural landscapes are the result of a dynamic process driven by environmental and anthropogenic factors (Firmino, 1999; Wood and Handley, 2001) and the spatial patterns of their transformation through time are undoubtedly related to changes in land use (Potter and Lobley, 1996). In fact, the polarization between more intensive and more extensive use of land is the main trend of actual landscape changes (Antrop, 2005; Bender et al., 2005). It is accepted that socio-economic impacts are often determinant of the types of land use within a given region; they in turn affect environmental issues (Mander and Palang, 1994; Melluma, 1994).

From the middle of the last century, changes in the rural landscapes have been more sudden and have occurred at a broader scale as a result of the impacts of industrialisation, urbanization and, globalization in post nineties, which needs to be addressed at a local/micro scale (Antrop, 2005; Calvo-Iglesias et al., 2008). Landscape changes are diverse but very often influenced by regional and agricultural policies.

Agriculture has played an important role in the formation of the rural landscapes (Beaufoy et al., 1994; McCracken et al., 1995). However, during the past two decades, mechanization and concentration of exploitation have resulted in a general decrease in importance of the primary sector within rural communities, with their socio-professional structure increasingly resembling that of more urban environments. For a long time the majority group in rural environment were agrarian but today the changing scenario is mainly due to rural-urban migration and creation of special economic zones in fertile agriculture land in many countries (Hervieux, 2008). Patterns and processes of globalization have influenced contemporary rural land use trends with the emergence of unknown challenges for sustaining land use systems (Currit and Easterling, 2009). In order to address these challenges without compromising the environment and their local communities, land use planning considering landscape dynamics is necessary and crucial, especially to developing countries under severe environmental and demographic transitions (Food and Agriculture Organization, 1995).

• Remote sensing and landscapes features

Remote sensing data acquired through space borne sensors from overhead perspective have evolved with time. Various parameters such as spatial, spectral and temporal resolutions (obtained from multi-satellite sensors) are essential parameters in analyzing landscape dynamics.

i. **Spatial resolution** –It is a measure of the smallest linear separation between two objects.

ii. **Spectral resolution** – This refers to the number and dimension of the specific wavelength interval (bands) in the electromagnetic spectrum to which a remote sensing instrument is sensitive. Higher the number and finer the width of bands better is the spectral resolution of the system.

iii. **Temporal resolution –** This refers to how often the remote sensing system records the images of a particular area. Analysis of multiple date data provides the information on how the variables are changing with respect to time.

iv. **Radiometric resolution –** This is defined as the sensitivity of a remote sensing detector to differences in the signal strength as it records the radiant flux reflected or emitted from the object. It defines the number of just differentiable signal levels.

During the last few years, efforts have been made to improve the integration and interpretation of different types of data to analyse land use and land cover (LULC) changes. These data include historical maps, statistical census, field surveys, aerial photographs and satellite images (e.g. Calvo Iglesias et al., 2008; Lucas et al., 2007; Mottet et al., 2006; Pelorosso et al., 2009; Petit and Lambin, 2001; Rogan et al., 2008).

Remote sensing represents a major source of urban information by providing spatially consistent coverage of large areas with both high spatial detail and temporal frequency, including historical time series (Jensen and Cowen, 1999; Donnay et al., 2001). Numerous Earth Observation Satellites (EOS) provide a synoptic and repetitive coverage of large areas with improvements in spatial and spectral resolutions through time.

It is now possible to monitor and analyze urban expansion and land use change in a timely and cost-effective way (Yang et al., 2003) with the availability of multi- resolution (spatial, spectral and temporal) remote sensing data as well as analytical techniques. However, there are some technical challenges caused by the high heterogeneity and complexity of the urban environment in terms of its spatial and spectral characteristics. A successful utilization of remote sensing data requires understanding of urban landscape characteristics along with the capabilities and limitation (Herold et al., 2005; Cowen and Jensen, 1998). Urban/suburban attributes dependent on its spatial extent and the level of heterogeneity decides the remote sensing resolutions to provide adequate information. Most important technical concern has been the pursuit of spatial resolutions (Lo, 1986; Curranand Williamson, 1986; Atkinson and Curran, 1997; Yang and Lo, 2002; Lu et al., 2004) required to determine adequately the high frequency detail which characterizes the urban scene. Despite many factors affecting the selection of suitable change detection methods, image differencing, principal component analysis (PCA) and post-classification comparison techniques demonstrate better performance (Collins and Woodcock, 1996; Yuan and Elvidge, 1998; Luet al., 2004; Jensen, 2005).

Urban land expansion and urban land use/land cover change has been one of the key subjects for study on dynamic changes of urban land use (Dewan & Yamaguchi, 2009; Wu et al.,

2006) and the multi-resolution remote sensing data has been useful for study on dynamic changes of urban expansion, and for management of natural resources (Kennedy et al., 2009). General consensus is that urban sprawl is characterized by unplanned and uneven pattern of growth, driven by multitude of processes and leading to inefficient resource utilization (Bhatta, 2010). The direct implication of sprawl is change in land-use and land-cover of the region as sprawl induces the increase in built-up and paved area (Sudhira & Ramachandra, 2007; Ramachandra et al., 2012).

Landscape dynamics through spatial metrics

Evolving appropriate measures to quantify urban sprawl is a prerequisite to understand sprawl dynamics. Essentially, the urban sprawl metrics aids in quantifying the process, monitor the extent and is an indicator for measuring the implications of policy decisions. The indicators for achieving sustainable development have been evolved by Meadows (1998), and there isn’t yet any broad consensus on the appropriate indices representing all of the factors and disciplines. A significant challenge is to understand the processes and identify the appropriate indicators towards achieving sustainable urbanization. However, there are some attempts in the recent past to characterise urban sprawl (Barnes et al., 2001; Hurd et al., 2001; Epstein et al., 2002; Sudhira et al., 2004b; Anindita et al., 2010; Priyadarshini et al., 2010) using spatial metrics. Essentially, the spatial metrics aids in quantifying the process, monitoring the extent of urban sprawl and also aid as useful indicators for measuring the implications of policy decisions. Gayda et al. (2003) have evolved metrics, adopted as indicators to achieve sustainable development. Furthermore, on the lines of sustainable development framework, there also exists quantification of metrics based on the carrying capacity approach. In this case, the carrying capacity of an urban system is evaluated based on the different functions and activities of the urban systems and accordingly a certain threshold for development is set, beyond which it is detrimental to the entire system itself. The concept of carrying capacity has been in news since the seminal work by Meadows et al. (1972) on the notion of ‘Limits to growth’. In India, the NIUA (National Institute of Urban Affairs) (1996) has evolved a framework for the carrying capacity based regional planning. The essence of carrying capacity based approach on the lines of achieving sustainable development lies in the fact that a host of factors are under consideration in planning process. Essentially, the urban sprawl metrics aid in quantifying the process, monitoring the extent of urban sprawl and also become useful as indicators for measuring the implications of policy decisions. The indicators for achieving sustainable development have been evolved by Meadows (1998), and there isn’t yet any broad consensus on the appropriate indices representing all of the factors and disciplines.

Some of the existing works on sprawl ascribe spatial extent of built-up areas derived from remote sensing data or other geospatial data as the measure of sprawl. Landscape metrics are mainly applied to land use, land cover or vegetation data. The digital nature of the information of land cover obtained from remote sensing data enables the derivation of potentially large number of metrics, which is advantageous (Haines-Young & Chopping, 1996; Lausch & Herzog, 2002). These metrics have been useful to quantify the individual patterns through the understanding of spatiotemporal patterns of landscape dynamics (Fuller, 2001; Tang et al.,2005). This aids in objectively quantifying the structure and pattern of an urban environment directly from the classified remote sensing data (Herold et al., 2005). Changes of landscape pattern detected and described by landscape metrics helps in quantifying and categorizing complex landscape into recognizable patterns revealing ecosystem properties that are otherwise not directly observable (Antrop andVan Eetvelde, 2000; Turner et al., 2001; Weng, 2007).

During the last four decades a variety of landscape metrics have been proposed to characterize the spatial configuration for the individual landscape class or the whole landscape base (Patton, 1975; Forman and Gordron, 1986; Gardner et al., 1987; Schumaker, 1996; Chuvieco, 1999; Imbernon and Branthomme, 2001), which aided in the detailed analyses of spatio-temporal patterns of landscape changes, and interpretation of dynamics process. Attempts of application of spatial metrics in urban analysis has been in the spatial analysis of the urban structure and associated dynamics of ecology and growth (Zhou, 2000; Sui and Zeng, 2001; Apan et al., 2002; Luck and Wu, 2002; Li and Yeh, 2004; Dietzel et al., 2005; PorterBolland et al., 2007; Macleod and Congalton, 1998; Miller et al., 1998; Mas,1999; Roy and Tomar, 2001; Yang and Lo, 2002).

To understand the phenomena of urban sprawl spatial metrics have been used widely such as entropy, patchiness and built-up density have been suggested (Yeh and Li, 2001; Sudhira et al. 2004b; Torrens and Alberti 2000; Gayda et al., 2005; Sudhira et al., 2003, Ramachandra et al., 2012). However, some attempts are made to capture sprawl in its spatial dimensions, which fail to capture sprawl process in other dimensions (like, travel times, pollution, resource usage, etc.) and also do not indicate their intensity (density metrics). It is imperative for research to address intensity of sprawl through appropriate metrics or indicators for effective regional planning.

Landscape metrics have been advantageous in capturing inherent spatial structure of landscape pattern and biophysical characteristics of spatial change dynamics. Landscape metrics - patch size and patch shape have been used to convey meaningful information on biophysically changed phenomena associated with patch fragmentation at a large scale (Viedma and Melia, 1999; Fuller, 2001; Imbernon and Branthomme, 2001). Heterogeneity-based indices were proposed to quantify the spatial structures and organization within the landscape. The dominance and contagion indices were first developed by O'Neill et al.(1988) on the basis of the information theory to capture major features of spatial patterns.

The landscape metrics, based on the geometric properties of the landscape elements, have been used to measure the landscape structure, spatial pattern, and their variation in space and time (Li et al., 2005), and monitoring landscape changes (Haines-Young & Chopping, 1996; Lausch& Herzog, 2002; Peng et al., 2010; Petrov & Sugumaran, 2009;Rocchini, Perry, Salerno, Maccherini, & Chiarucci, 2006), assessing impacts of management decisions and human activities (Geri et al.,2010; Lin, Han, Zhao, & Chang, 2010; Narumalani, Mishra, & Rothwell, 2004; Proulx & Fahrig, 2010), supporting decisions on landscape and conservation planning (Leitão & Ahern, 2002; Sundell-Turner & Rodewald, 2008), and to analyze landscape and habitats fragmentation (Hargis, Bissonette, & David, 1998; Zeng &Wu, 2005).

Thus, spatial metrics with remote sensing data provide spatially consistent and detailed information about urban structure and change, and consequently allowing improved representations and understanding of both the heterogeneous characteristics of landscapes and the impacts of landscape dynamics on the surrounding environment. Parker et al. (2001) summarize the usefulness of spatial metrics with respect to a variety of urban models and argue for the contribution of spatial metrics in helping link economic processes and patterns of land use. Some of the existing works on sprawl ascribe spatial extent of built-up areas derived from remote sensing data or other geospatial data as measure of sprawl. On the spatial metrics for sprawl, entropy, patchiness and built-up density have been suggested (Yeh and Li, 2001, Sudhira et al. 2004, Torrens and Alberti 2001, Ramachandra et al., 2012). In addition to this, the percentage of population residing over the built-up area to arrive at population-built-up density was considered as metric for sprawl (Bhatta, 2009a; Sudhira et al., 2003, Jiang et al. 2007, Ramachandra et al., 2012). Angel et al., (2007) have demonstrated five metrics for measuring manifestations of sprawl and five attributes for characterizing the sprawl. Under each attribute they have used several metrics to measure the sprawl phenomenon. Alberti and Waddell (2000) proposed spatial metrics to model the effects of the complex spatial pattern of urban land use and cover on social and ecological processes. These metrics allow for an improved representation of the heterogeneous characteristics of urban areas and of the impacts of urban development on the surrounding environment. Herold et al. (2005) provide a framework for combining remote sensing and spatial metrics to analyse and model land use changes, which helped in improved understanding and representation of dynamics and develop alternative conceptions of spatial structure and change.

Innovative land use planning and management approaches such as sustainable development and smart growth proposed (Walmsley, 2006; Gabriel et al., 2006) based on information and knowledge about the causes, chronology, effects of urbanization, especially interactions between urbanization and natural landscape systems. However, there is still a need for an improved understanding of urban change and its natural environmental and landscape consequences (Stephan and Friedrich, 2001; Stephan et al., 2005; Su et al., 2007a). The percentage of increase in growth rate of the city-extent exceeding the percentage increase in built-up growth rate, leading to an occurrence of sprawl has been reported (Bhatta 2009b). Landscape pattern has been investigated by examining the variations of a set of landscape metrics in different zones (Liu &Weng, 2009; Weng, Liu, & Lu, 2007), or in different types of land use patches (Weng, Liu, Liang, & Lu, 2008) suggesting that variables of landscape metrics may play an important role in the spatial patterns of temperature.

Quantification of spatial patterns of urbanization is done by combining landscape metrics with linear gradient analysis (Luck and Wu, 2002). Linear gradient analysis is, however, limited in capturing the spatial variation of land use patterns as it only examines patterns along a predefined direction (Yeh and Huang, 2009). The cities often results in non-linear morphologies, such as the concentric form (Jim and Chen, 2003; Tian et al., 2010), necessitating the analysis of spatial variation of land use patterns in concentric forms.

Many spatial landscape properties have been quantified by using a set of metrics (McGarigal et al., 2002; Li and Wu, 2004; Uuemaa et al., 2009; Herold et al., 2003, 2005). In this context, spatial metrics are very valuable in planning with better understanding of urban processes and their consequences (Herold et al., 2005; DiBari, 2007; Kim and Ellis, 2009). Although there are some attempts to understand landscape pattern and dynamics in its spatial dimensions, for rural, peri-urban and urban landscapes, it is imperative to address the change in landscape dynamics in various levels and through appropriate metrics or indicators for effective regional planning and sustainable utilization of natural resources.

- **Modelling of landscape dynamics**

Modelling landscape dynamics has the history of traditional urban growth modelling approaches. Subsequently, in 1960's to manage urban sprawl, modelling of urban sprawl was undertaken (Batty et al., 1999; Torrens &Alberti, 2000; Lowry 2001; Walter, 1975; Allen, 1979; Pumain, 1986). The approach involved linking independent to dependent variables, which were statistically significant, additive as in a linear model or a non-linear model but tractable in a mathematical way. However, these models although used mostly for policy purposes, could not be useful when processes involved rule-based systems, which in practice cannot be tractable mathematical operations (Batty & Torrens, 2001). Initial attempt to model urban dynamics was based on complexity (Forrester, 1969) involving dynamic relations represented by stocks and flows which determined the various activity volumes in the city, and were synthesized from knowledge and observation of causal factors. A key distinction of this model was its ability to represent emergent behaviour of the system originating out of complexity. However, this model could not be represented spatially. Batty et al. (1999) and Sudhira et al. (2004) provided spatially aggregate model for the urban sprawl phenomenon. Cheng and Masser (2003) report spatial logistic regression techniques for analysing urban growth pattern, considering the causal factors which was applied for a city in China. Geographically weighted regression was employed to identify spatial interaction between level of regional industrialisation and for analysing spatial non-stationarity of different factors affecting regional industrialization (Huang and Leung, 2002) as conventional regression analysis would only produce the 'average' and 'global' parameter estimates which vary over space depending on the respective spatial systems. .Allen (1986), Couclelis (1987) and Engelen (1988) model urban systems as complex systems, acknowledging the self-organisation in urban systems. Capturing urban systems as discrete models gained further momentum with the cellular automata (CA) based techniques (Li & Yeh, 2000; White et al, 1993; Wolfram, 1984, 2002). Subsequently CA based simulation of urban growth was done (Couclelis, 1987; Diana et al., 2010; Batty & Xie, 1994). Current approaches of modeling spatial dynamics are based on land cover and land use dynamics (Yang, 2003), urban growth models (Batty & Xie, 1997; Batty, 1998; Clarke & Gaydos, 1998; Clarke et al., 1996; Couclelis, 1987; Jianguan, 2002; White et al., 1993, 1997), simulation of urban growth process (Li & Yeh, 2000; Torrens, 2000; Vyasalu & Reddy , 1985; Vyasalu, 1985). There are several models considering the spatial and temporal dynamics such as LUCAS (Land Use Change Analysis System) model (Berry et al., 1996), GIGALOPOLIS (Clarke et al., 1996), and California Urban Futures (CUF-II) model (Landis & Zhang, 1996). Li and Yeh (2000) developed and demonstrate the constrained CA model for sustainable urban development modelling. Some of these models interact with causal factors driving the sprawl such as the availability of land and proximity to city centres and highway. The calibration and prediction of the CA model was done coupling with GIS for generating long-term prediction for urban growth (Clarke &Gaydos, 1998).

CA has been used for simulating urban growth quite successfully mostly considering various driving forces that are responsible for sprawl. However some issues like the impact on ecology, energy, environment and economy for taking policy decisions have not been addressed effectively. In this context, the integration of agent-based models and CA models, where agent-based models would help in capturing the externalities driving the processes. CA with agent-based models would help in identifying the location of the sprawl that help in effective visualization and understanding of the impacts of urban sprawl. However, to achieve an efficient simulation of urban sprawl, modelling has to be attempted in both spatial and non-spatial domain. Modelling urban sprawl in non-spatial domain is mainly by the application of statistical techniques while CA models and agent-based modelling are known to complement modelling in spatial domain. Integration of CA and agent-based models to simulate urban sprawl phenomenon has been done through Geographic Automata Systems (GAS) framework (Benenson and Torrens, 2004), Dynamic Geo-Spatial Simulation (DGSS) framework (Sudhira et al., 2005) the swarm optimization model (Fenga et al.,2011) .

The spatial visualization capacity of CA as well as the computational effectiveness are documented by Liu (2008). The swarming methods such as PSO and ant colony optimization have only emerged in the last decade, such as the geospatial reasoning (Parunak, et al., 2006), optimal path (Li, et al., 2009). The Swarming intelligence method was also used in urban geospatial scenario based on Multiple Perspectives and agent based interaction (Parunak et al.,2010). Other endevours include Agent-based ecological modelling based on swarm intelligence (Perez and Dragi civic, 2011) spatial clustering analysis (Kuo and Lin, 2010). Wang et al., (2008) attributes the aspects of human geography, urban geography and economic geography, on a series of subjects such as shape and direction of urban expansion, spatial evolution processes, dynamic mechanisms of urban expansion, transformation of farmland to urban land and internal differentiation of urban land. It is imperative to address the landscape dynamics at various levels and through appropriate metrics or indicators for effective regional planning and sustainable utilization of natural resources. The following research issues need to be addressed

- Land cover dynamics with the optimal combination of multi-resolution data for cost effective landscape dynamics analysis and mapping (Urban, peri-urban, rural).
- Land use dynamics with the multi-resolution data over various landscape (Urban, peri-urban, rural).
- Visualizing of growth patterns of Cities.

Research Gaps

In India, as per constitutional provisions, urban local bodies are mandated for administering, managing and preparing master / development plans. Mostly these plans are static maps with limited forecasting capabilities. Nevertheless there is a need for modeling the dynamics planning process to prevent ad-hoc decisions. In this context, regional models based on the information systems involving simulation for evolving location specific strategy and policy options are desirable.

From the middle of the last century, changes in the rural landscapes have been more sudden and have occurred at a broader scale as a result of the impacts of industrialisation, urbanization and, globalization in post nineties, which needs to be addressed at a local/micro scale (Antrop, 2005; Calvo-Iglesias et al., 2008).

The problem of sprawl needs to be addressed considering all disciplines with an integrative approach (TRB, 1998 and 2002; Gayda et al., 2003 and 2005). However, some attempts are made to capture sprawl in its spatial dimensions, which fail to capture sprawl process in other dimensions (like, travel times, pollution, resource usage, etc.) and also do not indicate their intensity (density metrics). Therefore for the better utilization of landscape and its features, regional planning need to account all classes of the landscape ranging from urban area to rural area, which is possible only when the data is available for all classes and on a temporal scale. Linear gradient analysis is, however, limited in capturing the spatial variation of land use patterns as it only examines patterns along a predefined direction (Yeh and Huang, 2009). The cities often results in non-linear morphologies, such as the concentric form (Jim and Chen, 2003; Tian et al., 2010), necessitating the analysis of spatial variation of land use patterns in concentric forms.

The indicators for achieving sustainable development have been evolved by Meadows (1998), and there isn’t yet any broad consensus on the appropriate indices representing all of the factors and disciplines. However, there is still a need for an improved understanding of urban change and its natural environmental and landscape consequences (Stephan and Friedrich, 2001; Stephan et al., 2005; Su et al., 2007a). It is imperative to address the change in landscape dynamics in various levels and through appropriate metrics or indicators for effective regional planning and sustainable utilization of natural resources.

CA has been used for simulating urban growth quite successfully mostly considering various driving forces that are responsible for sprawl. However some issues like the impact on ecology, energy, environment and economy for taking policy decisions have not been addressed effectively. In this context, the integration of agent-based models and CA models, where agent-based models would help in capturing the externalities driving the processes.

Development of new methods for retrieving information from mixed pixels based on Constrained Energy Minimisation, Mixture Tuned Matched Filtering, Adaptive Coherence Estimator, Spectral Feature Fitting, etc (Settle, 2002).

Development of new hard classification techniques based on (i) The object-oriented classification of remote sensing image takes the characteristics of the imaging spectrum and differences in geometric characteristics into account, which can extract more accurate image information. (ii) Genetic algorithms (GA) - GAs searches combination of multiple parameters in order to achieve the greatest level of satisfaction, either minimum or maximum, depending on the nature of the problem. It determines the knowledge rules for land-cover classification from remote sensing image datasets (Tseng et al., 2008).

Incorporation of endmember variability in the absence of endmembers in hyper-spectral data.

Development of Kernel-based methods for hyper-spectral image classification (Camps-valls and Bruzzone, 2005).

Feature extraction (such as roads, high rise buildings, etc.) using biologically inspired techniques - ant colonization, particle swarm optimisation, scale invariant feature transform (SIFT), etc. (Mikolajczyk and Schmid, 2005).

• Motivation: Need for research

Developing countries are faced with the problem of increasing urban poverty levels, higher population growth rates and rising numbers of slums or squatters resulting out of sprawl. This is in contrast to developed countries, where the problem of sprawl has to be addressed in terms of transport, energy, land use, and environment. It is in this context that the study on landscape dynamics focusing on urban sprawl gains importance.

Nevertheless, in a majority of the cases there are inadequacies to ascertain the nature of uncontrolled growth. This necessitates prior planning, coordinated decision-making and visualisation of the consequences of urbanization to ensure the sustainability of the resources.

In order to address urban growth challenges without compromising the environment and their local communities, land use planning considering landscape dynamics is necessary and crucial, especially to developing countries under severe environmental and demographic transitions (Food and Agriculture Organization, 1995). Urban land expansion and urban land use/land cover change has been one of the key subjects for study on dynamic changes of urban land use (Dewan & Yamaguchi, 2009; Wu et al., 2006)

It is thus imperative to carry out better regional planning through proper understanding of the implications associated with the problem of unplanned urban growth or sprawl. Given the benefits and constraints of image acquisition and data, there needs to be bank of data across various levels of administration that gives planners and administrators the way to define policies, plan and execute the programme efficiently and sustainably.

• Objectives

The objective of the proposed research is to understand and model the spatio temporal patterns of landscape dynamics. This involves

i. Analysis of Landscape dynamics using multi-resolution (spatial, temporal) data.
ii. Quantifying landscape dynamics using landscape metrics and associated landscape parameters.
iii. Modeling of landscape dynamics using these parameters.
iv. Model the landscape metrics using soft computing techniques.

• Methods

1) **Preprocessing:** The remote sensing data will be obtained and geo-referenced, rectified and cropped pertaining to the study area. Preprocessing techniques required will be applied
2) **Land Cover Analysis:** Normalised Difference Vegetation index (NDVI) will be computed temporally to understand the change of land cover during the study period. NDVI is the most common measurement used for measuring vegetation cover. It ranges from values -1 to +1. Very low values of NDVI (-0.1 and below) correspond to barren areas of rock, sand, or urban/builtup. Zero indicates the water cover. Moderate values represent low density of vegetation (0.1 to 0.3), while high values indicate vegetation (0.6 to 0.8).
3) **Land use analysis:** This will be carried out using available data using both supervised and unsupervised pattern classifiers (whichever is suitable). For the purpose of accuracy assessment, a confusion matrix is used. Land Use analysis will be done using the temporal data through open source GRASS GIS - Geographic Resource Analysis Support System (http://wgbis.ces.iisc.ernet.in/grass).
4) **Density Gradient Analysis:** The classified image will then divided into four zones based on four directions based on the city center (Central Business district). The zones

are named as– Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE) respectively (Figure 2). The growth of the urban areas will be monitored in each zone separately through the computation of urban density for different periods.

5) **Division of these zones to concentric circles and computation of metrics:** Each zone will be further divided into incrementing concentric circles of 1km radius from the center of the city. The built up density in each circle is monitored overtime using time series analysis.
6) **Analyzing and evaluating the efficiency of various landscape matrices.**
7) **Modeling the outcomes of the concentric circle study using suitable modeling techniques (including soft computing techniques)**

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Insights to Urban Dynamics through Landscape Spatial Pattern Analysis

Urbanisation is a dynamic complex phenomenon involving large scale changes in the land uses at local levels. Analyses of changes in land uses in urban environments provide a historical perspective of land use and give an opportunity to assess the spatial patterns, correlation, trends, rate and impacts of the change, which would help in better regional planning and good governance of the region. Main objective of this research is to quantify the urban dynamics using temporal remote sensing data with the help of well-established landscape metrics. Bangalore being one of the rapidly urbanizing landscapes in India has been chosen for this investigation. Complex process of urban sprawl was modelled using spatio temporal analysis. Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010. The Study area was divided into four zones and each zone is further divided into 17 concentric circles of 1 km incrementing radius to understand the patterns and extent of the urbansiation at local levels. The urban density gradient illustrates radial pattern of urbanization for the period 1973 to 2010. Bangalore grew radially from 1973 to 2010 indicating that the urbanization is intensifying from the central core and has reached the periphery of the Greater Bangalore. Shannon's entropy, alpha and beta population densities were computed to understand the level of urbanization at local levels. Shannon's entropy values of recent time confirms dispersed haphazard urban growth in the city, particularly in the outskirts of the city. This also illustrates the extent of influence of drivers of urbanization in various directions. Landscape metrics provided in depth knowledge about the sprawl. Principal component analysis helped in prioritizing the metrics for detailed analyses. The results clearly indicates that whole landscape is aggregating to a large patch in 2010 as compared to earlier years which was dominated by several small patches. The large scale conversion of small patches to large single patch can be seen from 2006 to 2010. In the year 2010 patches are maximally aggregated indicating that the city is becoming more compact and more urbanised in recent years. Bangalore was the most sought after destination for its climatic condition and the availability of various facilities (land availability, economy, political factors)compared to other cities. The growth into a single urban patch can be attributed to rapid urbanisation coupled with the industrialisation. Monitoring of growth through landscape metrics helps to maintain and manage the natural resources.

Keywords: Urbanisation, urban sprawl, landscape metrics, spatial metrics, remote sensing

I. Introduction

Urbanization and Urban Sprawl: Urbanisation is a dynamic process involving changes in vast expanse of land cover with the progressive concentration of human population. The process entails switch from spread out pattern of human settlements to compact growth in urban centres. Rapidly urbanising landscapes attains inordinately large population size leading to gradual collapse in the urban services evident from the basic problems in housing, slum, lack of treated water supply, inadequate infrastructure, higher pollution levels, poor quality of life, etc. Urbanisation is a product of demographic explosion and poverty induced rural-urban migration. Globalisation, liberalization, privatization are the agents fuelling urbanization in most parts of India. However, unplanned urbanization coupled with the lack of holistic approaches, is leading to lack of infrastructure and basic amenities. Hence proper urban planning with operational, developmental and restorative strategies is required to ensure the sustainable management of natural resources.

Urban dynamics involving large scale changes in the land use depend on (i) nature of land use and (ii) the level of spatial accumulation. Nature of land use depends on the activities that are taking place in the region while the level of spatial accumulation depends on the intensity and concentration. Central areas have a high level of spatial accumulation of urban land use (as in the CBD: Central Business District), while peripheral areas have lower levels of accumulation. Most economic, social or cultural activities imply a multitude of functions, such as production, consumption and distribution. These functions take place at specific locations depending on the nature of activities – industries, institutions, etc.

Unplanned growth would involve radical land use conversion of forests, surface water bodies, etc. with the irretrievable loss of ground prospects (Pathan et al., 1989, 1991, 1993, 2004). The process of urbanization could be either in the form of townships or unplanned or organic. Many organic towns in India are now influencing large scale infrastructure development, etc. due to the impetus from the National government through development schemes such as JNNURM (Jawaharlal Nehru National Urban Renewal Mission), etc. The focus is on the fast track development through an efficient infrastructure and delivery mechanisms, community participation, etc.

The urban population in India is growing at about 2.3% per annum with the global urban population increasing 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 (Ramachandra and Kumar, 2008; World Urbanization Prospects, 2005). The increase in urban population in response to the growth in urban areas is mainly due to migration. There are 48 urban agglomerations/cities having a population of more than one million in India (in 2011).

Urbanisation often leads to the dispersed haphazard development in the outskirts, which is often referred as sprawl. Thus urban sprawl is a consequence of social and economic development of a certain region under certain circumstances. This phenomenon is also defined as an uncontrolled, scattered suburban development that depletes local resources due to large scale land use changes involving the conversion of open spaces (water bodies, parks, etc.) while increasing carbon footprint through the spurt in anthropogenic activities and congestion in the city (Peiser, 2001, Ramachandra and Kumar, 2009). Urban sprawl increasingly has become a major issue facing many metropolitan areas. Due to lack of visualization of sprawl a priori, these regions are devoid of any infrastructure and basic amenities (like supply of treated water, electricity, sanitation facilities). Also these regions are normally left out in all government surveys (even in national population census), as this cannot be grouped under either urban or rural area. Understanding this kind of growth is very crucial in order to provide basic amenities and more importantly the sustainable management of local natural resources through decentralized regional planning.

Urban sprawl has been captured indirectly through socioeconomic indicators such as population growth, employment opportunity, number of commercial establishments, etc. (Brueckner, 2000; Lucy and Phillips, 2001). However, these techniques cannot effectively identify the impacts of urban sprawl in a spatial context. In this context, availability of spatial data at regular interval through space-borne remote sensors are helpful in effectively detecting and monitoring rapid land use changes (e.g., Chen, et al., 2000; Epstein, et al., 2002; Ji et al., 2001; Lo and Yang, 2002; Dietzel et al., 2005). Urban sprawl is characterised based on various indicators such as growth, social, aesthetic, decentralisation, accessibility, density, open space, dynamics, costs, benefits, etc. (Bhatta et al., 2009a, 2009b, 2010). Further, Galster et al. (2001), has identified parameters such as density, continuity, concentration, clustering, centrality, nuclearity, proximity and mixed uses for quantifying sprawl. Urbanisation and sprawl analysis would help the regional planners and decision makers to visualize growth patterns and plan to facilitate various infrastructure facilities. In the context of rapid urban growth, development should be planned and properly monitored to maintain internal equilibrium through sustainable management of natural resources. Internal equilibrium refers to the urban system and its dynamics evolving harmony and thus internally limiting impacts on the natural environment consequent to various economic activities with the enhanced growth of population, infra-structure, services, pollution, waste, etc. (Barredo and Demicheli, 2003). Due to globalisation process, the cities and towns in India are experiencing rapid urbanization consequently lacking appropriate infrastructure and basic amenities. Thus understanding the urban dynamics considering social and economic changes is a major challenge. The social and economic dynamics trigger the change processes in urban places of different sizes ranging from large metropolises, cities and small towns. In this context, the analysis of urban dynamics entails capturing and analyzing the process of changes spatially and temporally (Sudhira et al., 2004; Tian, et al., 2005; Yu and Ng, 2007).

Land use Analysis and Gradient approach: The basic information about the current and historical land cover and land use plays a major role in urban planning and management (Zhang et al., 2002). Land-cover essentially indicates the feature present on the land surface (Janssen, 2000; Lillesand and Keifer, 2002; Sudhira et al., 2004). Land use relates to human activity/economic activity on piece of land under consideration (Janssen, 2000; Lillesand and Keifer, 2002; Sudhira et al., 2004). This analysis provides various uses of land as urban, agriculture, forest, plantation, etc., specified as per USGS classification system (http://landcover.usgs.gov/pdf/anderson.pdf) and National Remote Sensing Centre, India (http://www.nrsc.gov.in). Mapping landscapes on temporal scale provide an opportunity to monitor the changes, which is important for natural resource management and sustainable planning activities. In this regard, “Density Gradient metrics” with the time series spatial data analysis are potentially useful in measuring urbanisation and sprawl (Torrens and Alberti, 2000). Density gradient metrics include sprawl density gradient, Shannon’s entropy, alpha and beta population densities, etc. This paper presents temporal land use analysis for rapidly urbanizing Bangalore and density gradient metrics have been computed to evaluate and monitor urban dynamics. Landscape dynamics have been unraveled from temporally discrete data (remote sensing data) through spatial metrics (Crews-Meyer, 2002). Landscape metrics (longitudinal data) integrated with the conventional change detection techniques would help in monitoring land use changes (Rainis, 2003; Narumalani et al., 2004). This has been demonstrated through the application in many regions (Kienast, 1993; Luque et al., 1994; Simpson et al., 1994; Thibault and Zipperer, 1994; Hulshoff, 1995; Medley et al., 1995; Zheng et al., 1997; Palang et al., 1998; Sachs et al., 1998; Pan et al., 1999; Lausch and Herzog, 1999).

Further, landscape metrics were computed to quantify the patterns of urban dynamics, which helps in quantifying spatial patterns of various land cover features in the region (McGarigal and Marks, 1995) and has been used effectively to capture urban dynamics similar to the applications in landscape ecology (Gustafson, 1998; Turner et al., 2001) for describing ecological relationships such as connectivity and adjacency of habitat reservoirs (Geri et al., 2009; Jim and Chen, 2009). Herold et al. (2002, 2003) quantifies urban land use dynamics using remote sensing data and landscape metrics in conjunction with the spatial modelling of urban growth. Angel et al. (2007) have considered five metrics for measuring the sprawl and five attributes for characterizing the type sprawl. Spatial metrics were used for effective characterisation of the sprawl by quantifying landscape attributes (shape, complexity, etc.). Jiang et al. (2007) used 13 geospatial indices for measuring the sprawl in Beijing and proposed an urban sprawl index combining all indices. This approach reduces computation and interpretation time and effort. However, this approach requires extensive data such as population, GDP, land-use maps, floor-area ratio, maps of roadways/highways, urban city centre spatial maps, etc. This confirms that landscape metrics aid as important mathematical tool for characterising urban sprawl efficiently. Population data along with geospatial indices help to characterise the sprawl (Ji et al., 2006) as population is one of the causal factor driving land use changes. . These studies confirm that spatio-temporal data along with landscape metrics, population metrics and urban modelling would help in understanding and evaluating the spatio temporal patterns of urban dynamics.

II. Objective:

The objective of this study is to understand the urbanization and urban sprawl process in a rapidly urbanizing landscape, through spatial techniques involving temporal remote sensing data, geographic information system with spatial metrics. This involved (i) temporal analysis of land use pattern, (ii) exploring interconnection and effectiveness of population indices, Shannon's entropy for quantifying and understanding urbanisation and (iii) understanding the spatial patterns of urbanization at landscape level through metrics.

III. Study area:

The study has been carried out for a rapidly urbanizing region in India. Greater Bangalore is the administrative cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India with an area of 741 sq. km. and lies between the latitudes 12°39’00’’ to 13°13’00’’ N and longitude 77°22’00’’ to 77°52’00’’ E. Bangalore city administrative jurisdiction was redefined in the year 2006 by merging the existing area of Bangalore city spatial limits with 8 neighboring Urban Local Bodies (ULBs) and 111 Villages of Bangalore Urban District. Bangalore has grown spatially more than ten times since 1949 (~69 square kilometers to 716 square kilometers) and is the fifth largest metropolis in India currently with a population of about 7 million (Ramachandra and Kumar, 2008). Bangalore city population also has increased enormously from 65,37,124 in 2001 to 95,88,910 in 2011, Which accounts to 46.68 percentage growth in a decade and density of population which was 10732 persons per sq km in 2001 has grown to 13392 persons per sq km.It has a per capita GDP of $2066, which is considerably low with limited expansion to balance both environmental and economic needs.

IV. Materials & Methods

Urban dynamics was analysed using temporal remote sensing data of the period 1973 to 2010. The time series spatial data acquired from Landsat Series Multispectral sensor (57.5m) and Thematic mapper (28.5m) sensors for the period 1973 to 2010 were downloaded from public domain (http://glcf.umiacs.umd.edu/data). Survey of India (SOI) topo-sheets 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 BBMP (Bruhat Bangalore Mahanagara Palike) map. Population data was collected from the Directorate of Census Operations, Bangalore region (http://censuskarnataka.gov.in). Table1 lists the data used in the current analysis. Ground control points to register and geo-correct remote sensing data were collected using handheld pre-calibrated GPS (Global Positioning System), Survey of India Toposheet and Google earth (http://earth.google.com, http://bhuvan.nrsc.gov.in).

DATA	Year	Purpose
Landsat Series Multispectral sensor (57.5m)	1973	Land use analysis
Landsat Series Thematic mapper (28.5m) and Enhanced Thematic Mapper sensors	1992,1999, 2002, 2006,2010	Land use analysis
Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales		boundary and base layers.
Census Data	2001	Population density ward-wise

Table 1: Materials used in the analysis.

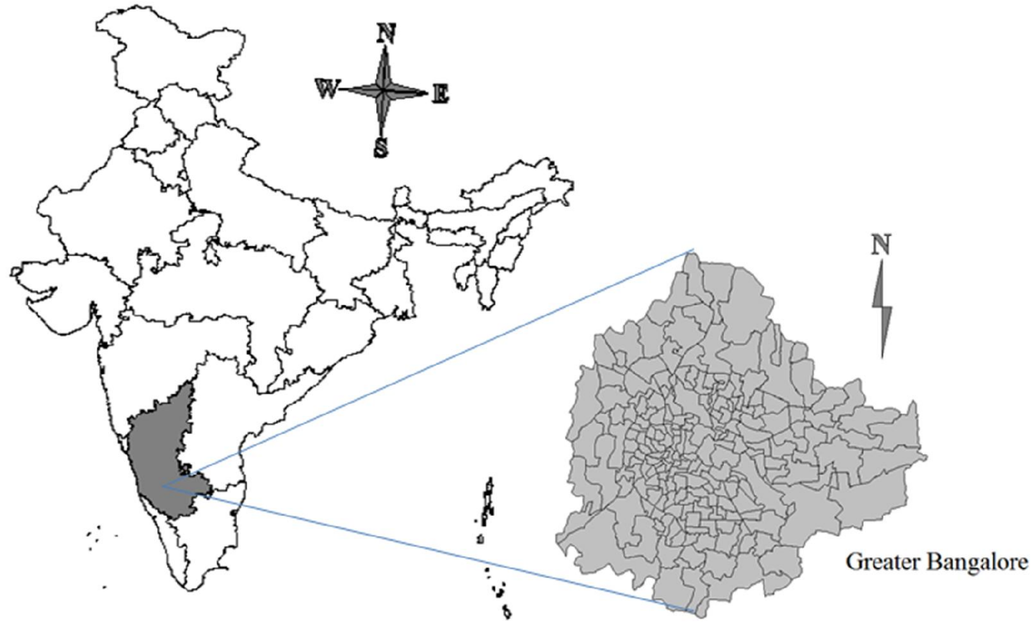


Figure 1. Study area : Greater Bangalore

Data analysis

Pre-processing: The remote sensing data obtained were geo-referenced, rectified 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 published by the Survey of India. The Landsat satellite 1973 images have a spatial resolution of 57.5 m x 57.5 m (nominal resolution) were resampled to 28.5m comparable to the 1989 - 2010 data which are 28.5 m x 28.5 m (nominal resolution). Landsat ETM+ bands of 2010 were corrected for the SLC-off by using image enhancement techniques, followed by nearest-neighbour interpolation.

Vegetation Cover Analysis: Normalised Difference Vegetation index (NDVI) was computed to understand the changes in the vegetation cover during the study period. NDVI is the most common measurement used for measuring vegetation cover. It ranges from values -1 to +1. Very low values of NDVI (-0.1 and below) correspond to soil or barren areas of rock, sand, or urban builtup. Zero indicates the water cover. Moderate values represent low density vegetation (0.1 to 0.3), while high values indicate thick canopy vegetation (0.6 to 0.8).

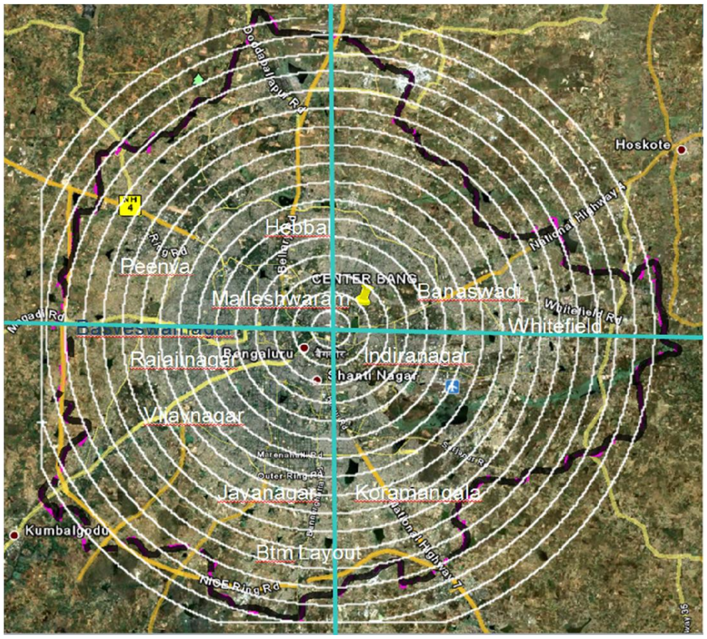
Land use analysis: The method involves i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, 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 v) 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 algorithm. This has been proved superior classifier as it uses various classification decisions using probability and cost functions (Duda et al., 2000). Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Accuracy assessment to evaluate the performance of classifiers (Mitrakis et al., 2008; Ngigi et al., 2008; Gao and Liu, 2008), was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients (Congalton et al., 1983; Sha et al., 2008) and proportion of correctly allocated cases (Gao & Liu, 2008). Recent remote sensing data (2010) was classified using the collected training samples. 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. For earlier time data, training polygon along with attribute details were compiled from the historical published topographic maps, vegetation maps, revenue maps, etc.

Application of maximum likelihood classification method resulted in accuracy of 76% in all the datasets. Land use was computed using the temporal data through open source program GRASS - Geographic Resource Analysis Support System (http://grass.fbk.eu/). Land use categories include i) area under vegetation (parks, botanical gardens, grass lands such as golf field.), ii) built up (buildings, roads or any paved surface, iii) water bodies (lakes/tanks, sewage treatment tanks), iv) others (open area such as play grounds, quarry regions, etc.).

Density Gradient Analysis: Urbanisation pattern has not been uniform in all directions. To understand the pattern of growth *vis a vis* agents, the region has been divided into 4 zones based on directions - Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE) respectively (Figure 2) based on the Central pixel (Central Business district). The growth of the urban areas in respective zones was monitored through the computation of urban density for different periods.

Division of these zones to concentric circles and computation of metrics: Further each zone was divided into concentric circle of incrementing radius of 1 km radius from the centre of the city (Figure 2), that would help in visualizing and understanding the agents responsible for changes at local level. These regions are comparable to the administrative wards ranging from 67 to 1935 hectares. 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 overtime using time series analysis.



Source: Google earth

Figure 2: Division of the study area into concentric circles of incrementing radius of 1km.

Computation of Shannon's Entropy: To determine whether the growth of urban areas was compact or divergent the Shannon's entropy (Yeh and Liu, 2001; Li and Yeh, 2004; Lata et al., 2001; Sudhira et al., 2004; Pathan et al., 2004*)* was computed for each zones. Shannon's entropy (H_n) given in equation 1, provides the degree of spatial concentration or dispersion of geographical variables among 'n' concentric circles across Zones.

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

Where Pi is the proportion of the built-up in the i^{th} concentric circle. As per Shannon's Entropy, if the distribution is maximally concentrated in one circle the lowest value zero will be obtained. Conversely, if it is an even distribution among the concentric circles will be given maximum of log n.

Computation of Alpha and Beta population density: Alpha and Beta population densities were calculated for each circle with respect to zones. Alpha population density is the ratio of total population in a region to the total builtup area, while Beta population density is the ratio of total population to the total geographical area. These metrics have been often used as the indicators of urbanization and urban sprawl and are given by:

$$\propto density = \left(Total\ Population \middle/ Total\ Built\ up \right) \tag{2}$$

$$\beta\ density = \left(Total\ Population \middle/ Total\ Geographic\ Area \right) \tag{3}$$

Gradient Analysis of NDVI images of 1973 and 2010: The NDVI gradient was generated to visualize the vegetation cover changes in the specific pockets of the study area.

Calculation of Landscape Metrics: Landscape metrics provide quantitative description of the composition and configuration of urban landscape. 21 spatial metrics chosen based on complexity, centrality and density criteria (Huang et al., 2007) to characterize urban dynamics, were computed zone-wise for each circle using classified land use data at the landscape level with the help of FRAGSTATS (McGarigal and Marks, 1995). The metrics include the patch area (Built up (Total Land Area), Percentage of Landscape (PLAND), Largest Patch Index (Percentage of landscape), Number of Urban Patches, Patch density, Perimeter-Area Fractal Dimension (PAFRAC), Landscape Division Index (DIVISION)), edge/border (Edge density, Area weighted mean patch fractal dimension (AWMPFD), Perimeter Area Weighted Mean Ratio (PARA_AM), Mean Patch Fractal Dimension (MPFD), Total Edge (TE), shape (NLSI(Normalized Landscape Shape Index), Landscape Shape Index (LSI),), epoch/contagion/ dispersion (Clumpiness, Percentage of Like Adjacencies (PLADJ), Total Core Area(TCA), ENND coefficient of variation, Aggregation index, Interspersion and Juxtaposition). These metrics were computed for each region and Principal Component Analysis was done to prioritise metrics for further detailed analysis. The metrics include the patch area, edge/border, shape, cpoact/contagion/ dispersion and are listed in Appendix I.

Principal Component Analysis: Principal component analysis (PCA) is a multivariate statistical analysis that aids in identifying the patterns of the data while reducing multiple dimensions. PCA through Eigen analysis transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible (Wang. 2009). PCA helped in prioritizing eight landscape metrics based on the relative contributions of each metrics in the principal components with maximum variability (Table 2). PCA were performed on the 21 landscape metrics, which helped in prioritizing Landscape metrics. This is done based on the relative contributions of each metrics in the principal components with maximum variability. The new components does represent the original datasets of 21 metrics Based on this, eight landscape metrics were selected for further detailed analysis.

	Indicators	Type of metrics and Formula	Range	Significance/ Description
1	Number of Urban Patches	Patch Metrics $NPU = n$ NP equals the number of patches in the landscape.	NPU>0, without limit.	Higher the value more the fragmentation
2	Perimeter Area Weighted Mean Ratio. PARA_AM	*Edge metrics* PARA _AM= Pij/Aij Pij = perimeter of patch ij Aij= area weighted mean of patch ij $AM = \sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$	≥ 0,without limit	PARA AM is a measure of the amount of 'edge' for a landscape or class. PARA AM value increases with increasing patch shape complexity.
3	Landscape Shape Index (LSI)	Shape Metrics $LSI = \frac{e_i}{\min e_i}$ e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i = minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces (see below).	LSI>1, Without Limit	LSI = 1 when the landscape is a single square or maximally compact patch; LSI increases without limit as the patch type becomes more disaggregated
4.	Clumpiness	*Compactness/ contagion /*	-1≤ CLUMPY	It equals 0

		dispersion metrics $CLUMPY = \begin{bmatrix} \frac{G_i - P_i}{P_i} for G_i < P_i \,\&\, P_i < 5, else \\ \frac{G_i - P_i}{1 - P_i} \end{bmatrix}$ $G_{i=} \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right) - \min e_i} \right)$ 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. min-e_i =minimum perimeter (in number of cell surfaces) of patch type (class)i for a maximally clumped class. P_i =proportion of the landscape occupied by patch type (class) i.	≤1 .	when the patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated
5.	Aggregation index	*Compactness/ contagion / dispersion metrics* $AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{\max \rightarrow g_{ii}} \right) P_i \right] (100)$ g_{ii} =number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type class i based on single count method. P_i= proportion of landscape comprised of patch type (class) i.	1≤AI≤100	AI equals 1 when the patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch.
6.	Interspersion and Juxtaposition	*Compactness/ contagion / dispersion metrics* $IJI = \frac{-\sum_{i=1}^{m} \sum_{k=i+1}^{m} \left[\left(\frac{e_{ik}}{E} \right) . \ln \left(\frac{e_{ik}}{E} \right) \right]}{\ln \left(0.5 \left[m(m-1) \right] \right)} (100)$ e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k.	0≤ IJI ≤100	IJI is used to measure patch adjacency. IJI approach 0 when distribution of adjacencies among unique patch types becomes

		E = total length (m) of edge in landscape, excluding background m = number of patch types (classes) present in the landscape, including the landscape border, if present.		increasingly uneven; is equal to 100 when all patch types are equally adjacent to all other patch types.

Table 2: Prioritised landscape metrics

V. Results and Discussion

Land cover analysis: Vegetation cover of the study area was analysed through NDVI. Figure 3 illustrates that area under vegetation has declined from 72% (488 sq.km in 1973) to 21% (145 sq.km in 2010).

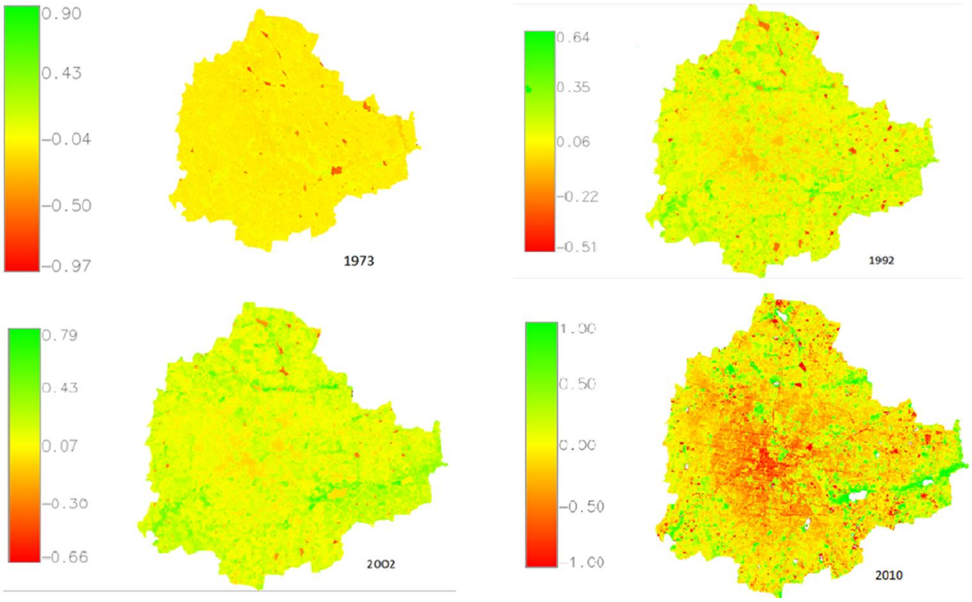


Figure 3: Land cover changes from 1973 – 2010

Land use analysis: Land use analysis for the period 1973 to 2010 has been done using Gaussian maximum likelihood classifier and the temporal land use details are given in table 3. Figure 4 provides the land use in the region during the study period. Overall accuracy of the classification was 72% (1973), 77% (1992), 76% (1999), 80% (2002), 75% (2006) and 78% (2010) respectively. There has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010. Figure 5 illustrates the zone-wise temporal land use changes at local levels. Table 4 lists kappa statistics and overall accuracy.

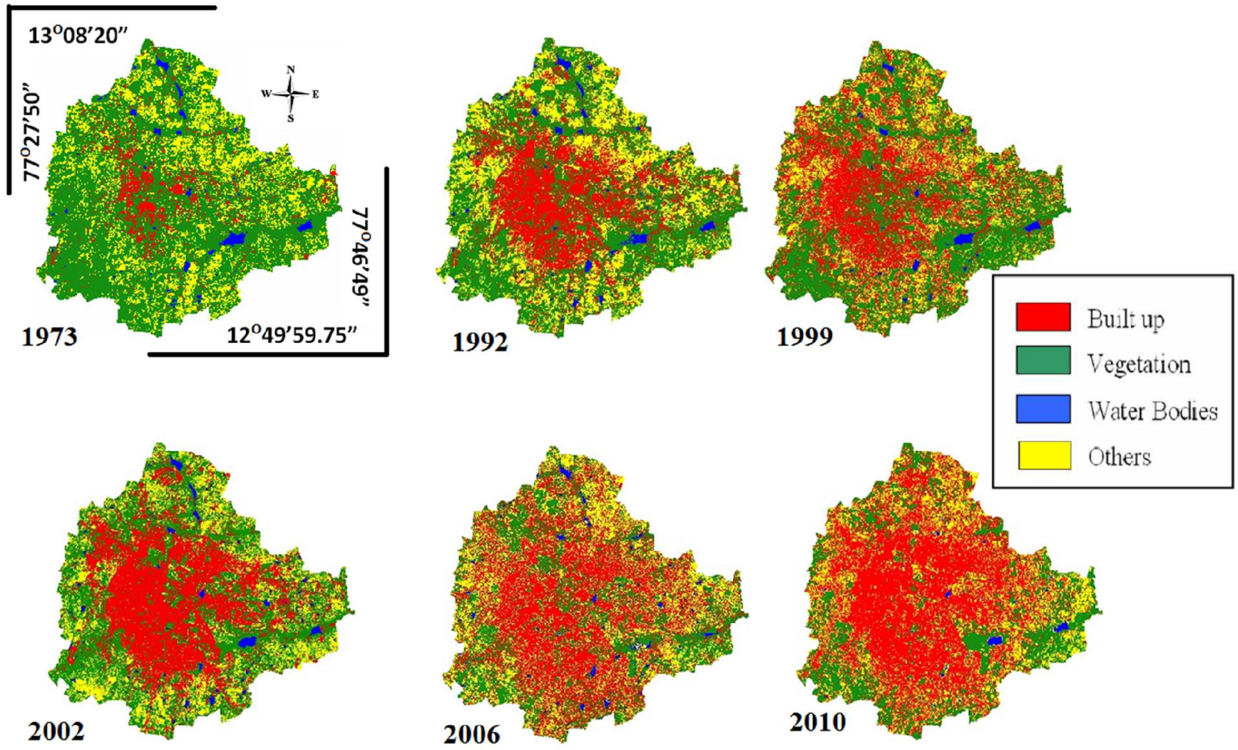


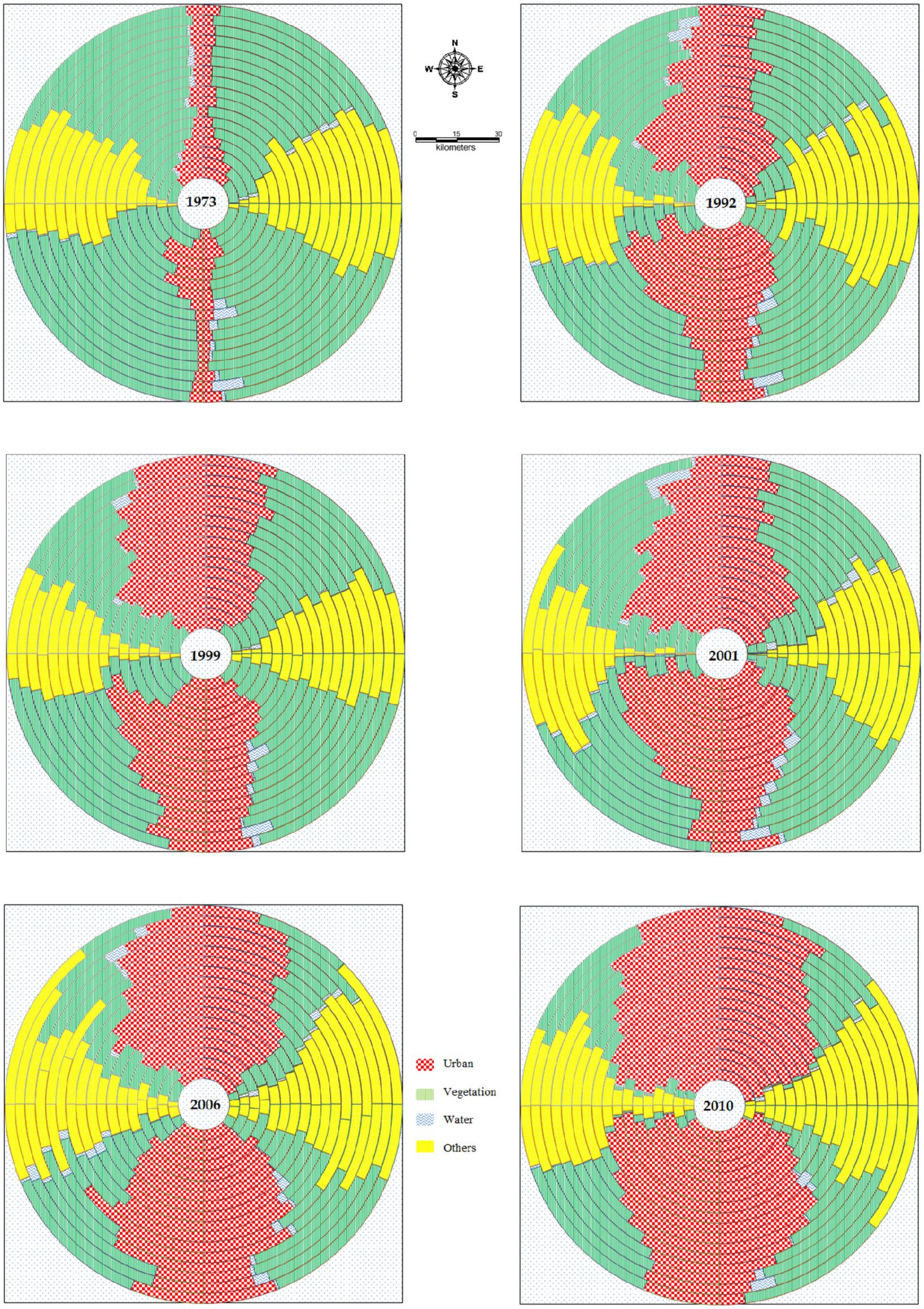
Figure 4: Land use changes in Greater Bangalore

Class →	Urban		Vegetation		Water		Others	
Year ↓	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
1973	5448	7.97	46639	68.27	2324	3.40	13903	20.35
1992	18650	27.30	31579	46.22	1790	2.60	16303	23.86
1999	24163	35.37	31272	45.77	1542	2.26	11346	16.61
2002	25782	37.75	26453	38.72	1263	1.84	14825	21.69
2006	29535	43.23	19696	28.83	1073	1.57	18017	26.37
2010	37266	54.42	16031	23.41	617	0.90	14565	21.27

Table 3: Temporal land use details for Bangalore

Year	Kappa coefficient	Overall accuracy (%)
1973	0.88	72
1992	0.63	77
1999	0.82	76
2002	0.77	80
2006	0.89	75
2010	0.74	78

Table 4: Kappa values and overall accuracy.



Greater Bangalore

Figure 5: Zone-wise and Gradient-wise temporal land use

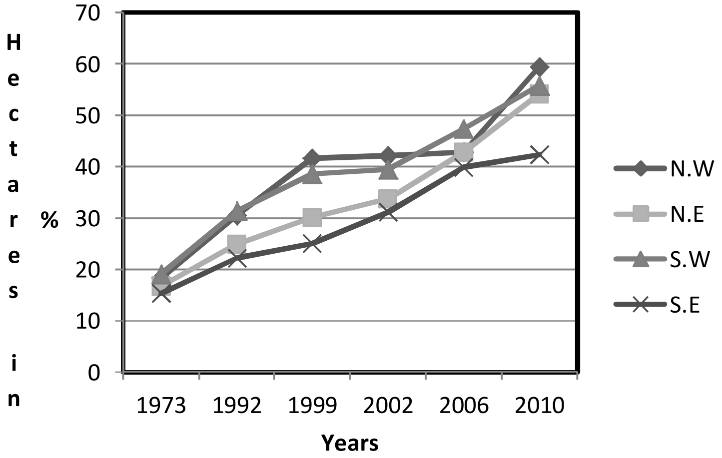


Figure 6: Built up density across years from 1973 to 2010

Density Gradient Analysis: Study area was divided into concentric incrementing circles of 1 km radius (with respect to centroid or central business district) in each zone. The urban density gradient given in Figure 7 for the period 1973 to 2010, illustrates radial pattern of urbanization and concentrated closer to the central business district and the growth was minimal in 1973. Bangalore grew intensely in the NW and SW zones in 1992 due to the policy of industrialization consequent to the globalization. The industrial layouts came up in NW and housing colonies in SW and urban sprawl was noticed in others parts of the Bangalore. This phenomenon intensified due to impetus to IT and BT sectors in SE and NE during post 2000. Subsequent to this, relaxation of FAR (Floor area ratio) in mid-2005, lead to the spurt in residential sectors, paved way for large scale conversion of land leading to intense urbanisation in many localities. This also led to the compact growth at central core areas of Bangalore and sprawl at outskirts which are deprived of basic amenities. The analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanisation has intensified from the city centre and reached the periphery of Greater Bangalore. Gradients of NDVI given in Figure 8 further corroborate this trend. Shannon entropy, alpha and beta population densities were computed to understand the level of urbanization at local levels.

Calculation of Shannon's Entropy, Alpha and Beta Densities: Shannon entropy was calculated for the years 1973, 1992, 1999, 2002, 2006, 2010 listed in Table 5. The value of entropy ranges from zero to log (n). Lower entropy values indicate aggregated or compact development. Higher the value or closer to log (n) indicates the sprawl or dispersed or sparse development. Grater Bangalore grew and has almost reached the threshold of growth (log (n) = log (17) = 1.23) in all directions. Lower entropy values of 0.126 (SE), 0.173 (NE), 0.170 (SW) and 0.217 (NW) during 70's show aggregated growth. However, the dispersed growth is noticed at outskirts in 90's and post 2000's (0.64 (SE), 0.771 (NE), 0.812 (NW) and 0.778 (SW)). Shannon's entropy values of recent time confirm dispersed haphazard urban growth in the city, particularly in city outskirts. This also illustrates the extent of influence of drivers of urbanization in various directions. In order to understand this phenomenon, Alpha and Beta population densities were computed.

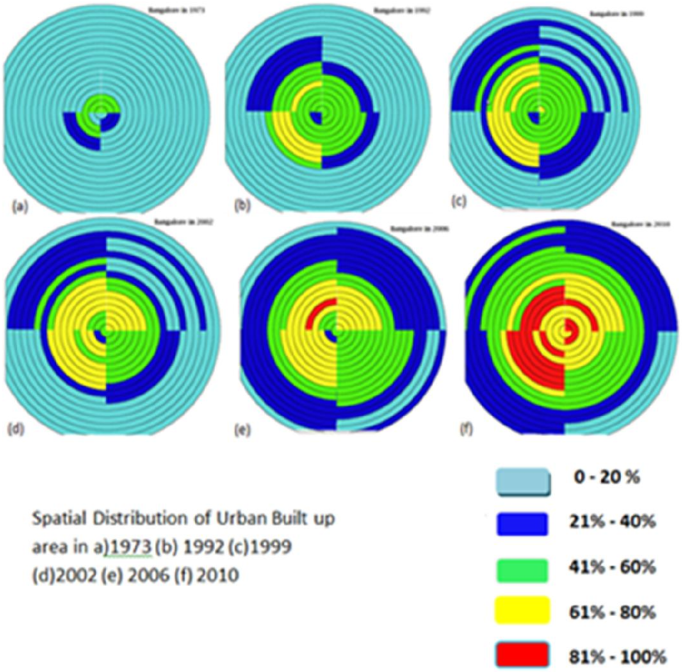


Figure 7: Gradient analysis of Greater Bangalore- Builtup density circlewise & zonewise.

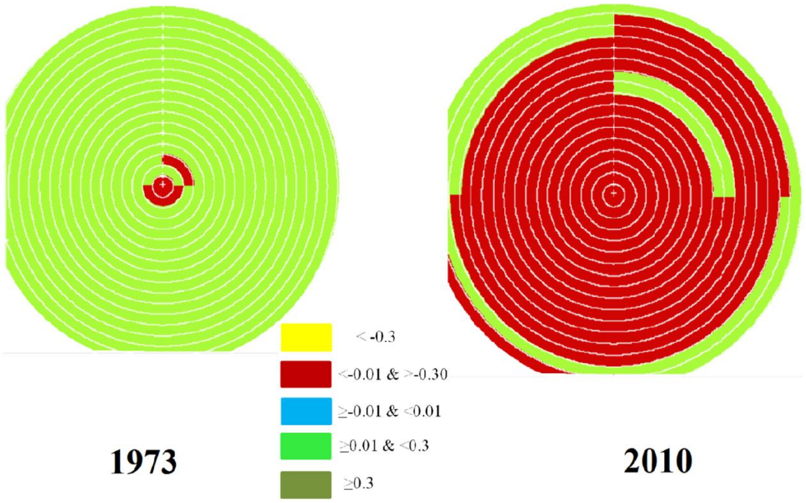


Figure 8: NDVI gradients - circlewise and zone wise

	NE	NW	SE	SW
1973	0.173	0.217	0.126	0.179
1992	0.433	0.509	0.399	0.498
1999	0.504	0.658	0.435	0.607
2002	0.546	0.637	0.447	0.636
2006	0.65	0.649	0.610	0.695
2010	0.771	0.812	0.640	0.778

Table 5. Shannon Entropy.

Table 6 lists alpha and beta densities zone-wise for each circle. These indices (both alpha and beta densities) indicate that there has been intense growth in the center of the city and SE, SW and NE core central area has reached the threshold of urbanisation.

Radius	North East		North West		South East		South West	
	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
1	1526.57	1385.38	704.71	496.05	3390.8	2437.3	3218.51	2196.83
2	333.99	288.58	371.00	280.41	983.51	857.04	851.23	555.33
3	527.99	399.83	612.02	353.50	904.02	701.47	469.19	369.67
4	446.99	343.51	360.72	286.39	602.14	441.66	308.47	262.52
5	152.43	122.74	255.11	226.72	323.07	243.02	236.56	188.26
6	123.16	94.91	370.22	324.12	306.48	203.54	58.57	51.12
7	73.65	57.96	254.49	207.29	54.77	32.64	77.07	73.09
8	38.16	27.80	71.54	62.38	57.22	30.52	61.85	57.29
9	44.99	29.54	92.73	69.97	51.74	26.00	37.60	31.90
10	48.43	25.22	93.51	55.75	33.31	17.44	25.99	16.61
11	50.32	23.77	100.55	56.56	22.69	11.63	35.90	18.75
12	42.34	17.92	67.36	34.36	27.12	11.29	25.52	10.86
13	59.87	22.20	40.87	17.71	30.66	9.44	35.59	11.92
14	54.10	18.38	24.51	9.91	24.16	5.35	19.77	5.49
15	60.81	20.73	21.48	8.98	19.52	3.50	26.41	6.56
16	62.17	23.79	46.81	12.83	16.92	2.96	66.19	17.35
17	16.54	24.76	53.30	14.58	16.45	2.02	41.40	10.36

Table 6. Alpha and Beta density in each region – Zone wise, Circle wise.

Gradients of alpha and beta densities is given in Figure 9, illustrates of urban intensification in the urban center and sprawl is also evident NW and SW regions.

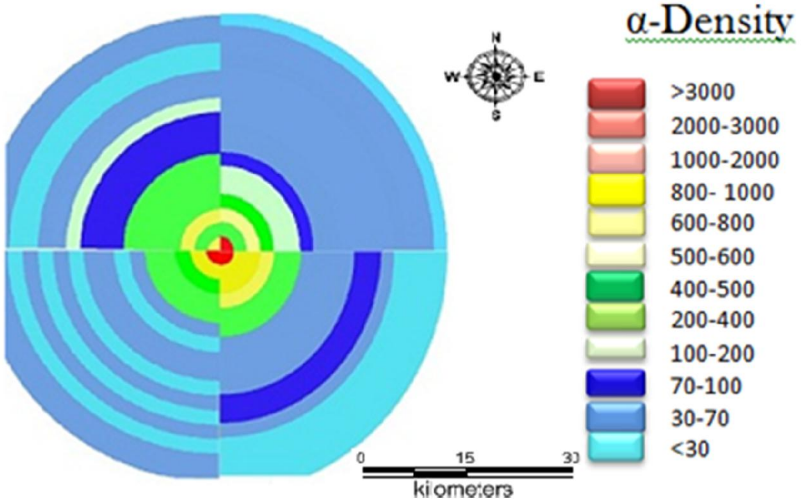


Figure 9: Alpha Density– zonewise for each local regions

Landscape Metrics: Landscape metrics were computed circle-wise for each zones. Percentage of Landscape (PLAND) indicates that the Greater Bangalore is increasingly urbanized as we move from the centre of the city towards the periphery. This parameter showed similar trends in all directions. It varied from 0.043 to 0.084 in NE during 1973. This has changed in 2010, and varies from 7.16 to 75.93. NW also shows a maximum value of 87.77 in 2010. Largest patch index indicate that the city landscape is fragmented in all direction during 1973 due to heterogeneous landscapes. However this has aggregated to a single patch in 2010, indicating homogenisation of landscape. The patch sizes were relatively small in all directions till 2002 with higher values in SW and NE. In 2006 and 2010, patches reached threshold in all directions except NW which showed a slower trend. Largest patches are in SW and NE direction (2010). The patch density was higher in 1973 in all directions due to heterogeneous land uses, which increased in 2002 and subsequently reduced in 2010, indicating the sprawl in early 2000's and aggregation in 2010. PAFRAC had lower values (1.383) in 1973 and maximum of 1.684 (2010) which demonstrates circular patterns in the growth evident from the gradient. Lower edge density was in 1973, increased drastically to relatively higher value 2.5 (in 2010). Clumpiness index, Aggregation index, Interspersion and Juxtaposition Index highlights that the centre of the city is more compact in 2010 with more clumpiness in NW and SW directions. Area weighted Euclidean mean nearest neighbour distance is measure of patch context to quantify patch isolation. Higher v values in 1973 gradually decrease by 2002 in all directions and circles. This is similar to patch density dynamics and can be attributed to industrialization and consequent increase in the housing sector. Analyses confirm that the development of industrial zones and housing blocks in NW and SW in post 1990's, in NE and SE during post 2000 are mainly due to policy decision of either setting up industries or boost to IT and BT sectors and consequent housing, infrastructure and transportation facilities. PCA was performed with 21 metrics computed zonewise for each circle. This helped in prioritising the metrics (Table 2) while removing redundant metrics for understanding the urbanization, which are discussed next.

i. Number of urban patches has steadily decreased in the inner core circles from 1973 to 2010, which indicates aggregation. A sharp increase in the urban patches in the periphery (outer rings) from 25 to 120 indicates of numerous smallurban patches pointing to the urban sprawl. Urban sprawl is thus effectively visualized by this index, evident with SW, SE and NE zones in Figure 10. The outer circle having on an average 120 urban patches compared to 5 in inner circles.

ii. Perimeter Area Weighted Mean Ratio (PAWMR) reflects the patch shape complexity and is given in Figure 11. The values closer to zero in the inner circles indicate the simple shape, whereas the outer circles show the increasing trends in all directions. This highlights an enhanced rate of anthropogenic interventions and hence the process of Sprawl.

iii. Landscape shape index indicates the complexity of shape, close to zero indicates maximally compact (at city centre) and higher values in outer circles indicate disaggregated growth in 2010 (Figure 12). The trend of sprawl at city outskirts as well as at the centre was noticed till 1980's. However, post 80's values indicate of compactness at city centre, while outer rings show disaggregated growth.

iv. Clumpiness index represents the similar trend of compact growth at the center of the city which gradually decreases towards outer rings indicating the urban agglomeration at centre and phenomena of sprawl at the outskirts in 2010 (Figure13). This phenomenon is very prominent in Northeast and Southwest direction.

v. Aggregation index indicated that the patches are maximally aggregated in 2010 while it was more dispersed in 1973, indicating that city is getting more and more compact (Figure 14).

vi. Interspersion and Juxtaposition Index was very high as high as 94 in all directions which indicate that the urban area is becoming a single patch and a compact growth towards 2010 (Figure 15). All these metrics point towards compact growth in the region, due to intense urbanization. Concentrated growth in a region has telling influences on natural resources (disappearance of open spaces – parks and water bodies), traffic congestion, enhanced pollution levels and also changes in local climate (Ramachandra and Kumar 2009; 2010)

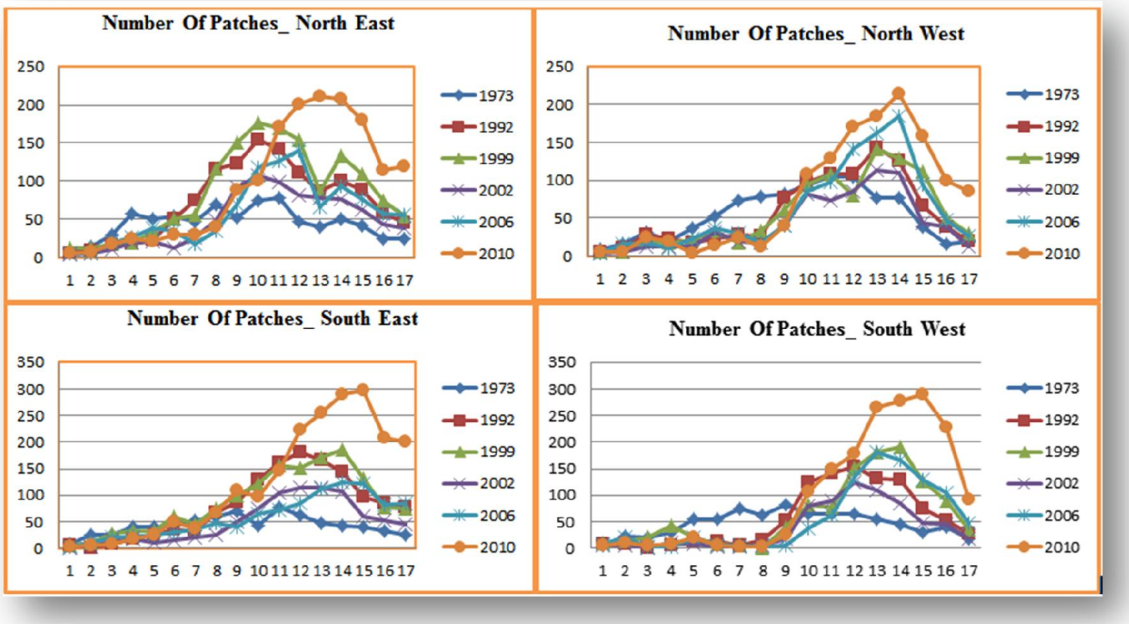
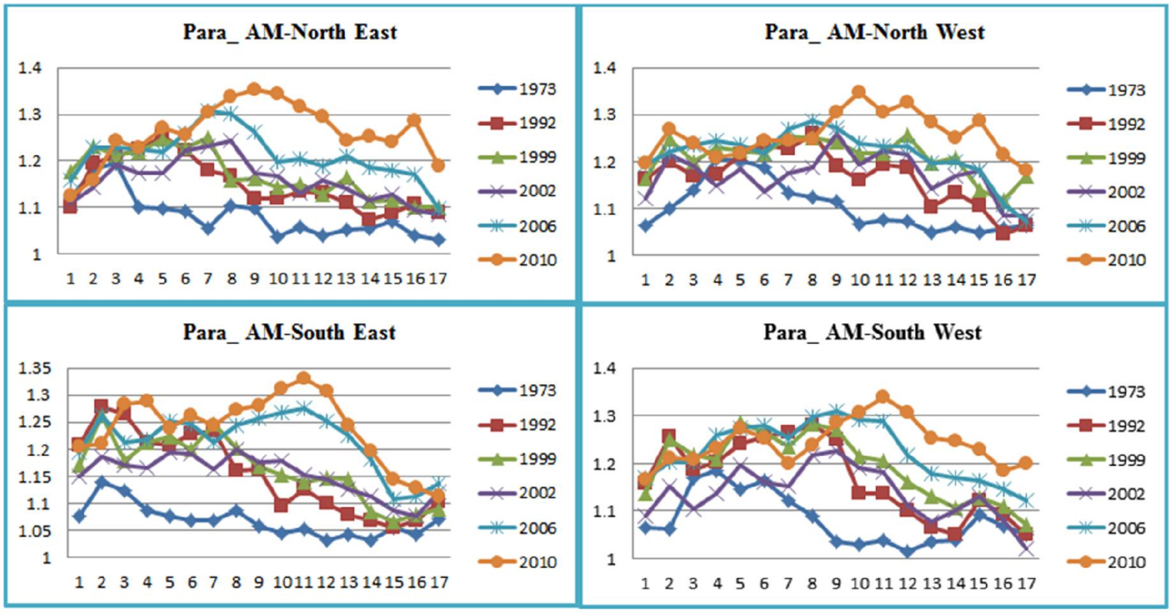


Figure 10: Number of Patches – Direction-wise/ Circle-wise.

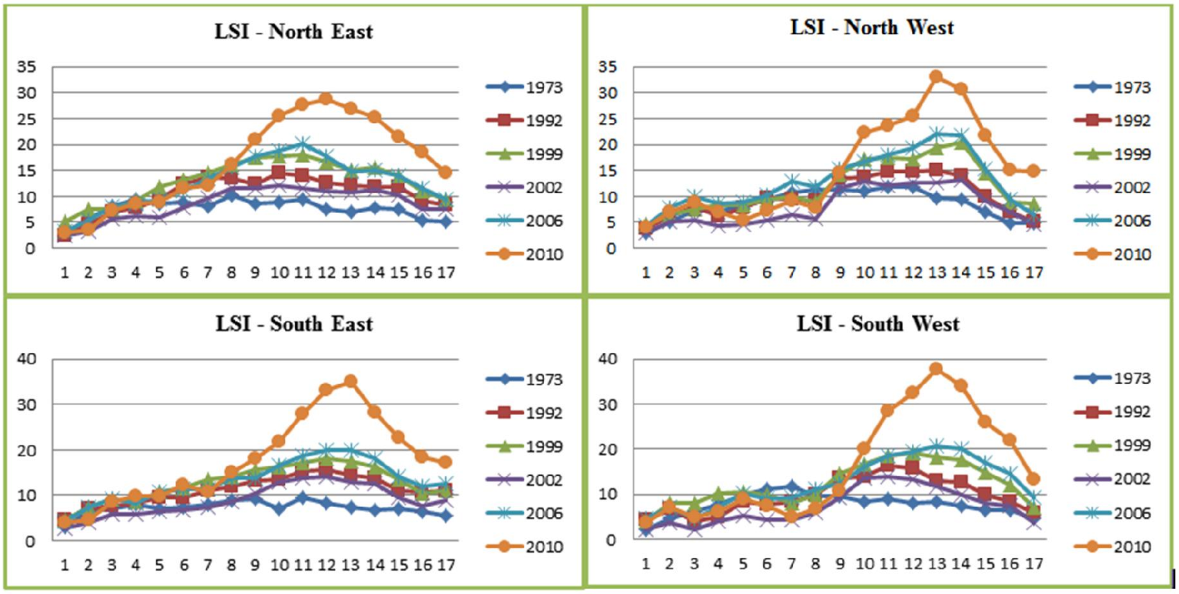

Para_ AM-North East

Para_ AM-North West

Para_ AM-South East

Para_ AM-South West

Figure 11: PARA_AM – Direction-wise/ Circle-wise.


LSI - North East

LSI - North West

LSI - South East

LSI - South West

Figure 12: LSI – Direction-wise/ Circle-wise.

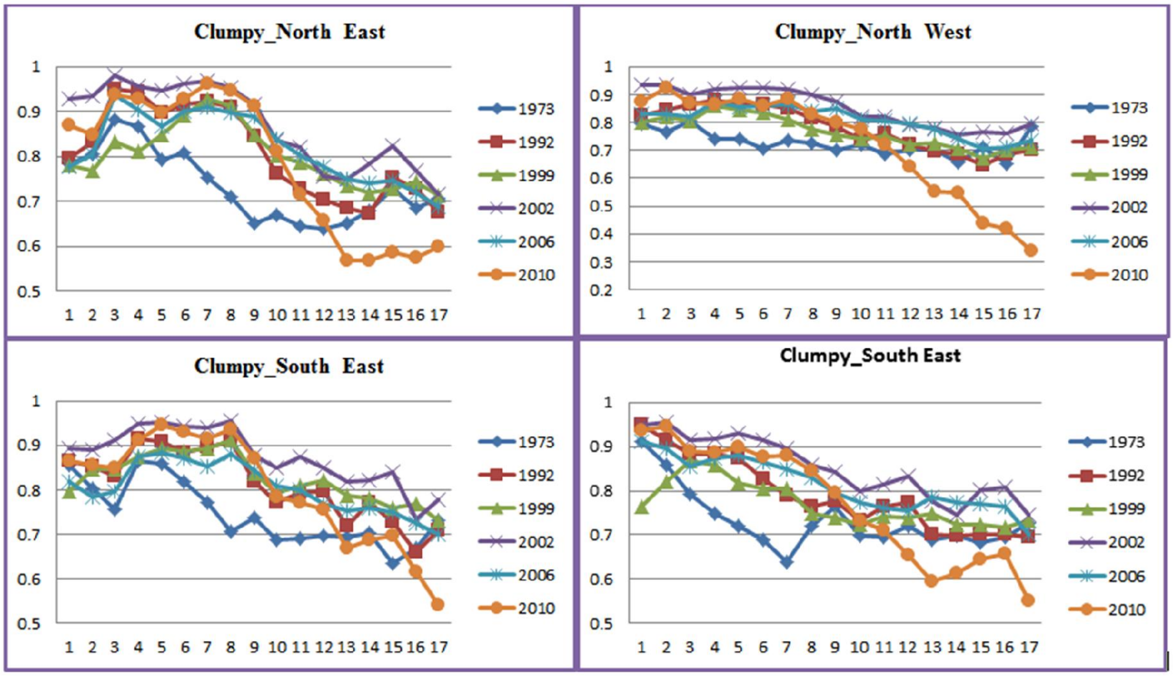


Figure 13: Clumpiness Index – Direction-wise/ Circle-wise.

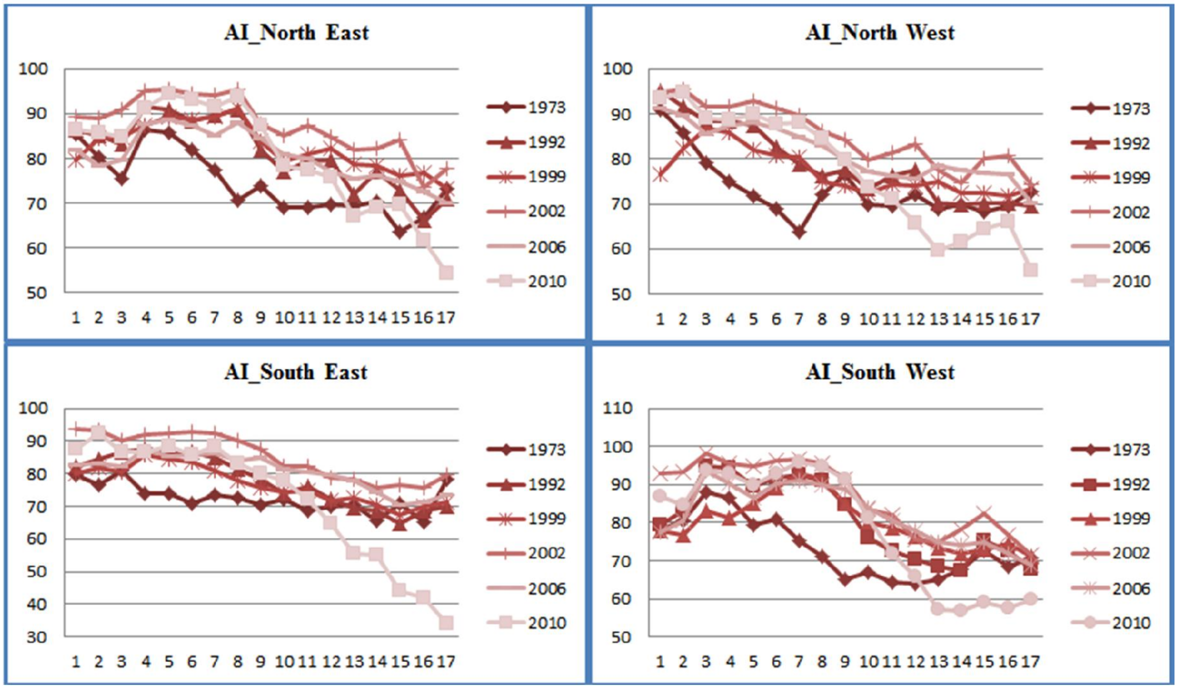


Figure 14: Aggregation Index – Direction-wise/ Circle-wise.

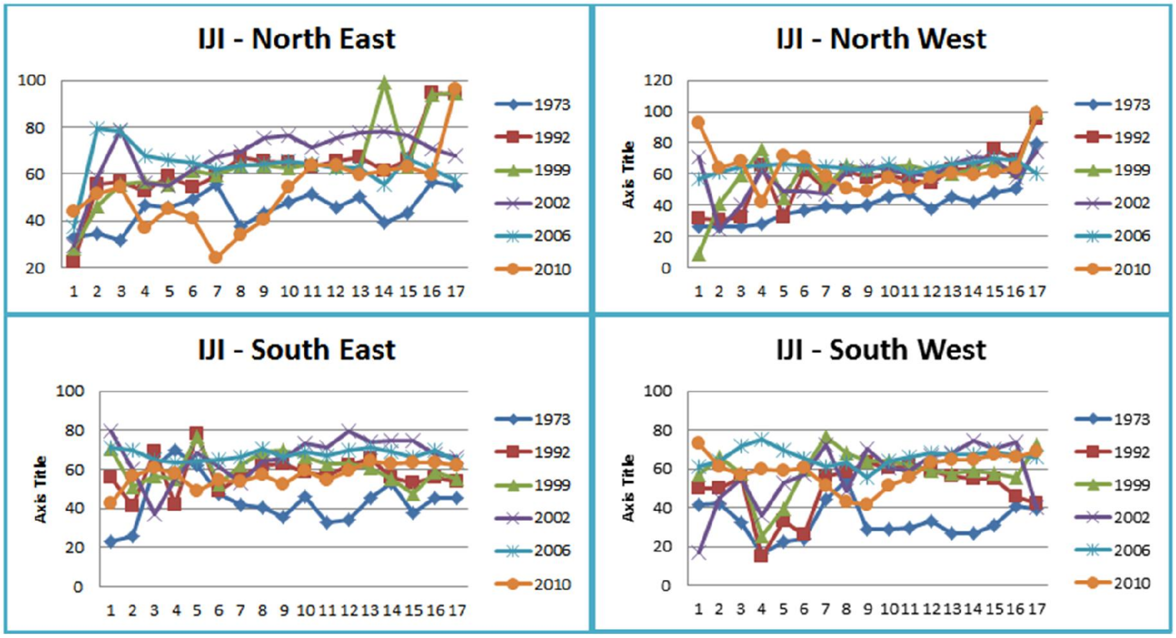


Figure 15: Interspersion and Juxtaposition – Direction-wise/ Circle-wise.

Note: X axis Represents Gradients taken from the center and y axis the metric value in Figures 9 to 14.

The discussion so far highlights that the development during 1992 to 2002 was phenomenal in NW, SW due to Industrial development (Rajajinagar Industrial estate, Peenya industrial estate etc.) in these areas and subsequent housing colonies in the nearby localities. The urban growth picked up in NE and SE (Whitefield, Electronic city etc.) during post 2000 due to State's encouraging policy to information technology and biotechnology sectors and also setting up international airport.

VI. Conclusion

Urban dynamics of rapidly urbanizing landscape – Bangalore has been analysed to understand historical perspective of land use changes, spatial patterns and impacts of the changes. The analysis of changes in the vegetation cover shows a decline from 72% (488sq.km in 1973) to 21% (145sq.km in 2010) during the last four decades in Bangalore.

Land use analyses show that there has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Temporal Analyses of Greater Bangalore reveals an increase in urban built up area by 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% from 2006 to 2010. Urban growth pattern of Greater Bangalore has been done in four directions through landscape metrics and gradient analysis across six time periods. The urban density gradient illustrates radial pattern of urbanization during 1973 to 2010 indicating of intense urbanization at central core and sprawl at outskirts, which conform with Shanon's entropy, alpha and beta population densities. Landscape metrics further highlight of compact growth in the region.

Gradients of alpha and beta densities illustrate urban intensification in the center and sprawl in NW and SW regions. Landscape metrics point towards compact growth in the region, due to intense urbanization in 2000. The analysis confirms that the nature of land use depended on the activities while the level of spatial accumulation depended on the intensity and concentration of urban builtup. Central areas have a high level of spatial accumulation and corresponding land uses, such as in the CBD, while peripheral areas have lower levels of accumulation. Unplanned concentrated growth or intensified developmental activities in a region has telling influences on natural resources (disappearance of open spaces – parks and water bodies), traffic congestion, enhanced pollution levels and also changes in the local climate.

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Appendix: Spatial Landscape Indices

	Indicators	Formula	Range	Significance/ Description
	Category : Patch area metrics			
1.	Built up (Total Land Area)	------	>0	Total built-up land (in ha)
2	Percentage of Landscape (PLAND)	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).	$0 < PLAND \le 100$	PLAND approaches 0 when the corresponding patch type (class) becomes increasingly rare in the landscape. PLAND = 100 when the entire landscape consists of a single patch type;
3 .	Largest Patch Index(Percentage of landscape)	$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$ a_{ij} = area (m^2) of patch ij A= total landscape area	$0 \le LPI \le 100$	LPI = 0 when largest patch of the patch type becomes increasingly smaller. LPI = 100 when the entire landscape consists of a single patch of, when the largest patch comprise 100% of the landscape
4 .	Number of Urban Patches	$NPU = n$ NP equals the number of patches in the landscape.	NPU>0, without limit.	It is a fragmentation Index. Higher the value more the fragmentation
5 .	Patch density	f(sample area) = (Patch Number/Area) * 1000000	PD>0,without limit	Calculates patch density index on a raster map, using a 4 neighbor algorithm. Patch density increases with a greater

				number of patches within a reference area.
6 .	Perimeter-Area Fractal Dimension PAFRAC	$\frac{2}{\frac{\left[N\sum_{i=1}^{m}\sum_{j=1}^{n}(\ln P_{ij}.\ln a_{ij})\right]-\left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}\right)\right]}{\left(N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^{2}\right)-\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}\right)}}$ Perimeter-Area Fractal Dimension a_{ij} = area (m^2) of patch ij. p_{ij} = perimeter (m) of patch ij. N = total number of patches in the landscape	$1 \leq PAFRAC \leq 2$	It approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, perimeters. PAFRAC requires patches to vary in size.
7.	Landscape Division Index (DIVISION)	$DIVISION = \left[1-\sum_{j=1}^{n}\left(\frac{a_{ji}}{A}\right)^{2}\right]$ a_{ij} = area (m^2) of patch ij A= total landscape area	$0 \leq DIVISION < 1$	DIVISION = 0,when the landscape consists of single patch. It approaches 1 when the proportion of landscape comprising of the focal patch type decreases and as those patches decreases in size.
Category : Edge/border metrics				
8.	Edge density	$ED_K = \frac{\sum_{i=1}^{n} e_{ik}}{AREA}(10000)$ k: patch type m: number of patch type n: number of edge segment of patch type k eik :total length of edge in landscape involving patch type k Area: total landscape area	$ED \geq 0$, without limit. ED = 0 when there is no class edge.	ED measures total edge of urban boundary used to compare landscape of varying sizes.
9.	Area weighted mean patch fractal dimension (AWMPFD)	$AWMPFD = \frac{\sum_{i=1}^{i=N} 2\ln 0.25\, p_i / \ln S_i}{N} \times \frac{s_i}{\sum_{i=1}^{i=N} s}$ Where s_i and p_i are the area and perimeter of patch i, and N is the total number of patches	$1 \leq AWMPFD \leq 2$	AWMPFD approaches 1 for shapes with very simple perimeters, such as circles or squares, and approaches 2 for shapes with

				highly convoluted perimeter AWMPFD describes the fragmentation of urban patches. If Sprawl is high then the AWMPFD value is high
10.	Perimeter Area Weighted Mean Ratio. PARA_AM	PARA _AM= Pij/Aij Pij = perimeter of patch ij Aij= area weighted mean of patch ij $$AM = \sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$$	≥ 0 ,without limit	PARA AM is a very useful measure of fragmentation; it is a measure of the amount of 'edge' for a landscape or class. PARA AM value increased with increasing patch shape complexity, which precisely characterized the degree of patch shape complexity.
11.	Mean Patch Fractal Dimension (MPFD)	$$MPFD = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln(0.25\,pij)}{\ln aij}\right)}{N}$$ pij = perimeter of patch ij aij= area weighted mean of patch ij N = total number of patches in the landscape	1<=MPFD <2	Shape Complexity. MPFD is another measure of shape complexity, approaches one for shapes with simple perimeters and approaches two when shapes are more complex.

12.	Total Edge (TE)	$$TE = \sum_{k=1}^{m} e_{ik}$$ e_{ik} = total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i.	TE>0, Without limit	TE equals the sum of the lengths (m) of all edge segments involving the corresponding patch type. TE includes a user-specified proportion of internal background edge segments involving the corresponding patch type
Category : Shape metrics				
13.	NLSI(Normalized Landscape Shape Index)	$$NLSI = \frac{\sum_{i=1}^{i=N} \frac{p_i}{s_i}}{N}$$ Where s_i and p_i are the area and perimeter of patch i, and N is the total number of patches.	0≤NLSI<1	NLSI = 0 when the landscape consists of single square or maximally compact almost square, it increases when the patch types becomes increasingly disaggregated and is 1 when the patch type is maximally disaggregated
14	Landscape Shape Index (LSI)	$$LSI = \frac{e_i}{\min e_i}$$ e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i = minimum total length of edge (or perimeter) of class i in terms of number of cell	LSI>1, Without Limit	LSI = 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases without limit as the patch type becomes more disaggregated

		surfaces (see below).		
Category: Compactness/ contagion / dispersion metrics				
15.	Clumpiness	$CLUMPY = \begin{bmatrix} \frac{G_i - P_i}{P_i} for G_i < P_i \& P_i < 5, else \\ \frac{G_i - P_i}{1 - P_i} \end{bmatrix}$ $G_{i=} \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right) - \min e_i} \right)$ 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. min-e_i =minimum perimeter (in number of cell surfaces) of patch type (class)i for a maximally clumped class. P_i =proportion of the landscape occupied by patch type (class) i.	-1≤ CLUMPY ≤1 .	It equals 0 when the patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated
16.	Percentage of Like Adjacencies (PLADJ)	$PLADJ = \left(\frac{g_{ii}}{\left(\sum_{k=1}^{m} g_{ik} \right)} \right)(100)$ 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	The percentage of cell adjacencies involving the corresponding patch type that are like adjacencies. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved, at least for all internal adjacencies
17.	Total Core Area(TCA)	$TCA = \sum_{j=1}^{n} a_{ij}^{c} \left(\frac{1}{10{,}000} \right)$	TCA>=0 Without limit.	TCA equals the sum of the core areas of each patch (m2) of the corresponding patch type,

				divided by 10,000 (to convert to hectares).
18.	ENND coefficient of variation	$ENN = h_{ij}$ $CV = \frac{SD}{MN}(100)$ CV (coefficient of variation) equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metrics.	It is represented in percentage.	In the analysis of urban processes, greater isolation indicates greater dispersion.
19.	Aggregation index	$AI = \left[\sum_{i=1}^{m}\left(\frac{g_{ii}}{\max \rightarrow g_{ii}}\right)P_i\right](100)$ g_{ii} =number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type class i based on single count method. P_i= proportion of landscape comprised of patch type (class) i.	1≤AI≤100	AI equals when the patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch. Aggregation corresponds to the clustering of patches to form patches of a larger size.
20.	Interspersion and Juxtaposition	$IJI = \frac{-\sum_{i=1}^{m}\sum_{k=i+1}^{m}\left[\left(\frac{e_{ik}}{E}\right).\ln\left(\frac{e_{ik}}{E}\right)\right]}{\ln\left(0.5\left[m(m-1)\right]\right)}(100)$ e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k. E = total length (m) of edge in landscape, excluding background m = number of patch types (classes) present in the landscape, including the landscape border, if present.	0≤ IJI ≤100	IJI is used to measure patch adjacency. IJI approach 0 when distribution of adjacencies among unique patch types becomes increasingly uneven; is equal to 100 when all patch types are equally adjacent to all other patch types.

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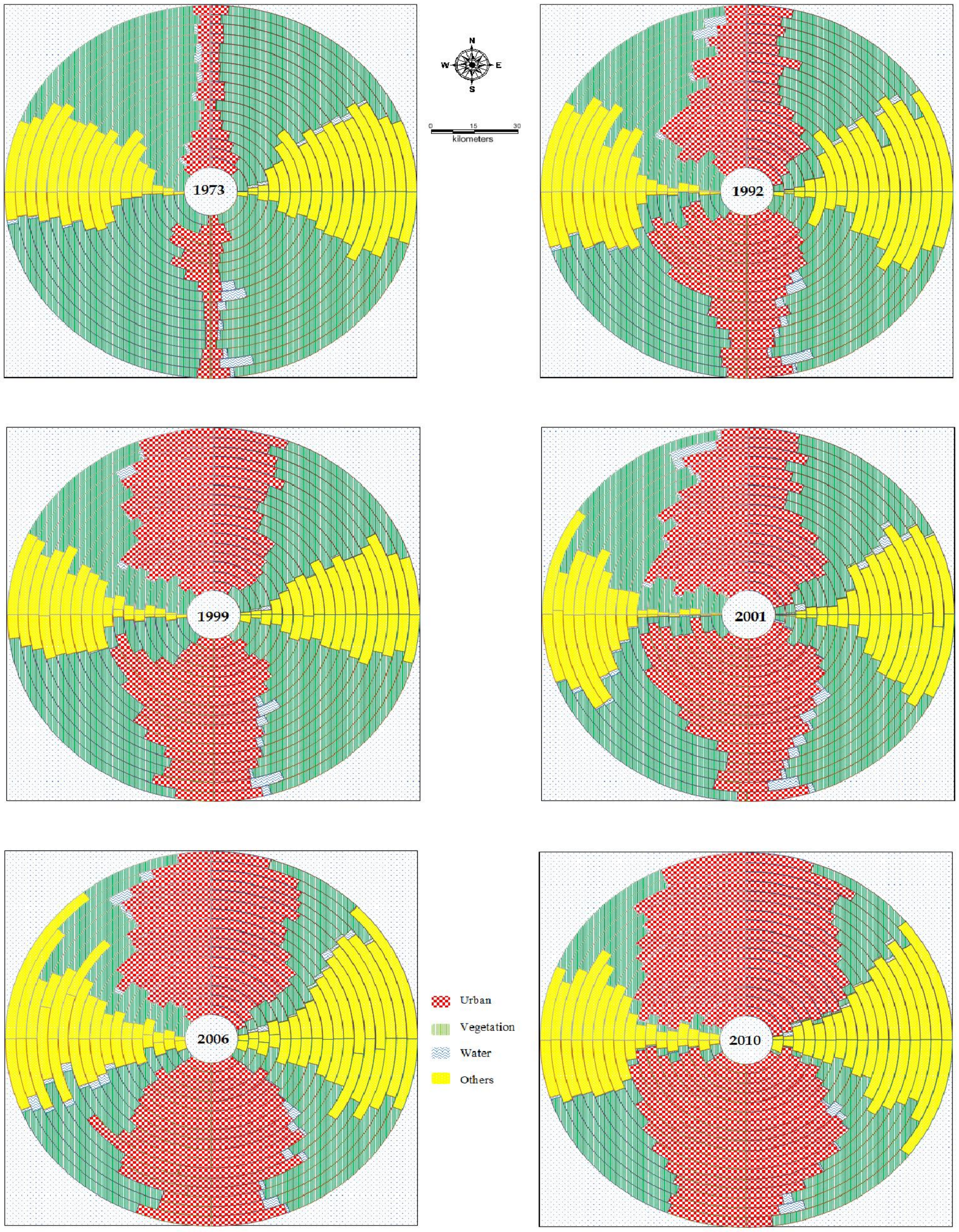

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