Spatio-Temporal Gradient Modeling Of Land cover Change

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by

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Abstract

Planners and decision-makers need efficient tools to quantitatively evaluate and compare the impact of alternative plans and designs so that more informed development choices can be made. Urban planners think about optimisation of the land use and about aesthetics when reshaping the environment.

This research provides a dynamic analysis of spatial and temporal patterns of land cover change in an urban environment. Using the LISS III images of Gurgaon, Haryana , acquired in 1999, 2001and 2004, classification was done in two classes built-up and non built-up. This study presents an approach for quantifying and capturing changes in the urban growth patterns. The method involves quantification of local built-up areas by the "moving window" technique using the Fragstats software and a gradient analysis involving sampling from a reference point to eight km in sixteen directions with a window size of 500 mts. A distance of eight kilometres was considered so as to cover the present administrative boundary and record the growth on the fringes of the city. The Head Post Office of Gurgaon city was considered as the reference point from which the gradient analysis was undertaken. The analysis revealed the changes and effects of urbanization in specific directions linked with particular locations.

The synoptic analysis revealed the overall trend of urban growth in the study area indicating considerable growth in the urban areas with increasing fragmentation i.e. formation of a number of new urban centers. The gradient analysis showed different patterns of metrics in various directions. Most of the directions indicate considerable urban development, showing maximum growth towards the north northeast, east northeast, east southeast and east, specifically in the year 2004. This signifies new urban features rapidly growing in these directions. The availability of infrastructure and the proximity towards the National Capital New Delhi can be considered the reason behind the high rate of growth. The close examination of the metrics show increasing value for the percentage of built-up in most of the directions, patch density with lot of variations had high values indicating, enhanced fragmented growth of the area. Mean patch size showed highest value at the center and drastically declined towards the fringes. The largest patch index revealed the same pattern as the percentage of landscape. The values of landscape shape index mostly signified disaggregated growth of the urban areas.

Results demonstrate that a combination of spatial metrics and gradient modeling with the sixteen directional approach can successfully quantify the spatial pattern in each local area. A combination of spatial metrics i.e. percentage of landscape, mean patch size, number of patches, landscape shape index and largest patch index can successfully quantify the patterns of urban growth in specific directions with respect to a reference point in terms of size, shape and complexity of development.

Keywords: directional analysis, spatio-temporal pattern, spatial metrics, gradient modeling

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1. Introduction

Land cover denotes the physical and biotic character of the land surface and is presently being largely studied by natural scientists. Land cover has become a central component in current strategies for managing natural resources and monitoring environmental change. Because of the rapid development in the field of mapping, there is an increase in studies of land cover change worldwide.

1.1. Land cover change

One of the important fields of study in the research on human-induced global environmental change is land use /cover change dealing with the alteration of the land surface and its biotic cover. While land use denotes the human employment of the land, land cover denotes the physical and biotic character of the land surface. The changes in both are governed by human goals, shaped by underlying social driving forces further resulting in numerous environmental consequences.

Both biophysical and socio-economic processes drive land cover change and it has important local hydrological and ecological impacts. Human intervention and natural processes are responsible for the constant change in land cover. Availability of accurate land cover information is essential for a number of applications like natural resource management, planning and monitoring programs in the fields of agriculture, urban, hydrology, forestry and ecology etc. Understanding the processes responsible for changes that occur in the spatial pattern of land cover (Dale, 1999) can help in analyzing and forecasting both positive and negative changes, thus can facilitate timely preventive measures for better management.

Land cover changes take two forms i.e. conversion from one category of land cover to another and modification of condition within a category. The former can result in a different landscape structure over the time and further development of spatial pattern, which can be quantified and assessed to achieve a better understanding of the land cover as a whole.

1.1.1. Remote sensing and land cover change

Remote sensing products can be used to map major urban features, land cover types, detailed land use or urban infrastructure, from which can be derived secondary socioeconomic parameters and the invisible elements of urban infrastructure. Remote sensing also contributes to a better representation of the spatial heterogeneity of cities, a counter tendency to the limitations of models that tend to reduce geographic space to the single dimension of distance, thereby hiding important spatial patterns in land use and landscape feature (Irwin and Geoghegan, 2001). The great strength of remote sensing is that it can provide spatially consistent data sets that cover large areas with both high detail and high temporal frequency, including historical time series. Mapping of urban areas has been accomplished at different spatial scales, e.g. with different spatial resolutions, varying coverage or extent of mapping area and varying definitions of thematic mapping objects (Herold et al., 2005). There is a growing importance of remote sensing for the study of Land cover change for which different techniques have been used.

Various models based on remote sensing information are being developed to model spatial as well as temporal changes that occurred in the past and also to predict future scenarios.

1.1.2. Urbanization

Over the past two centuries, both the human population and the economic wealth of the world have grown rapidly. These two factors have increased resource consumption significantly, registered in agriculture and food production, forestry, industrial development, transport and international commerce, energy production, urbanization and even recreational activities (Steffen et al., 2004).

Urbanization is arguably the most dramatic form of land transformation that profoundly influences biological diversity and human life (Luck and Wu, 2002). This transformation is a result of complex interaction of different processes occurring continuously on the landscape. Urbanization causes profound changes in the ecological functioning as it expands and envelops the landscape gradually impacting the environment at multiple spatial and temporal scales through climate change, loss of wildlife habitat and biodiversity, and greater demand for natural resources (Steffen et al., 2004).

A number of studies have been conducted to study urban form and function in the contexts of urban planning, urban economics, urban geography, and urban sociology. The extent and rate of urban growth described in terms change in the absolute area of urban space (a measure of extent) or the pace at which non-urban land is converted to urban uses (a measure of rate) provide indications of the aggregate size of cities and the rate at which other land is converted to urban uses. However, aggregate growth rates give limited information regarding spatial patterns of urbanization or the underlying processes that shape urban areas (Seto and Fragkias, 2005).

In recent years, the use of models of land use/ cover change and urban growth has increased, and most of these have the potential to become important tools in support of urban planning and management (Herold et al., 2005).

1.2. Landscape Ecology

Landscape ecology deals fundamentally with the impact of ecological processes on ecological patterns and also the influence of spatial and temporal patterns on ecological processes (Zhang et al., 2004).

Landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time. In addition, landscape ecology involves the application of these principles in the formulation and solving of real-world problems. Landscape ecology is largely founded on the notion that the patterning of landscape elements (patches) strongly influences ecological characteristics. The ability to quantify landscape structure is prerequisite to the study of landscape function and change. For this reason, much emphasis has been placed on developing methods to quantify landscape structure (McGarigal et al., 2002).

Growing concerns over the loss of biodiversity has spurred land managers to seek better ways of managing landscapes at a variety of spatial and temporal scales. A number of developments have made possible the ability to analyze and manage entire landscapes to meet multi-resource objectives. The developing field of landscape ecology has provided a strong conceptual and theoretical basis for understanding landscape structure, function, and change (Turner and Gardener, 1990). The development of GIS technology, in particular, has made a variety of analytical tools available for analyzing and managing landscapes. In response to this growing theoretical and empirical support and technical capabilities, public land management agencies have begun to recognize the need to manage natural resources at the landscape scale.

Specifically, landscape ecology focuses on 3 characteristics of the landscape:

- Structure, the spatial relationships among the distinctive ecosystems or "elements" present--more specifically, the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds, and configurations of the ecosystems.
- Function, the interactions among the spatial elements, that is, the flows of energy, materials, and species among the component ecosystems.
- Change, the alteration in the structure and function of the ecological mosaic over time.

Thus, landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time. In addition, landscape ecology involves the application of these principles in the formulation and solving of real-world problems. Landscape ecology considers the development and dynamics of spatial heterogeneity and its affects on ecological processes, and the management of spatial heterogeneity (McGarigal et al., 2002).

Landscape ecology is largely founded on the notion that the patterning of landscape elements (patches) strongly influences ecological characteristics. The ability to quantify landscape structure is prerequisite to the study of landscape function and change. For this reason, much emphasis has been placed on developing methods to quantify landscape structure (Turner and Gardener, 1990).

Recent developments in landscape ecology have emphasized the important relationships between spatial patterns and many ecological processes. This is the reason for the increased attention on spatial dynamics and further the need for new quantitative methods that can analyze patterns, determine the importance of spatially explicit processes, and develop reliable landscape models (Turner and Gardener, 1990).

Landscape metrics are used to quantify the spatial heterogeneity of individual patches, of all patches belonging to a common class, and of the landscape as a collection of patches. The metrics can be spatially non-explicit, aggregate measures but still reflect important spatial properties. Spatially explicit metrics can be computed as patch-based indices (e.g. size, shape, edge length, patch density, fractal dimension) or as pixel-based indices (e.g. contagion, lacunarity) computed for all pixels in a patch (Gustafson, 1998a)

1.2.1. Spatial Metrics

Applied to fields of research outside landscape ecology and across different kinds of environments (in particular, urban areas), the approaches and assumptions of landscape metrics is more generally referred to as ‘‘spatial metrics’’. Spatial metrics can be defined as measurements derived from the digital analysis of thematic-categorical maps exhibiting spatial heterogeneity at a specific scale and resolution (Herold et al., 2005).This definition emphasizes the quantitative and aggregate nature of the metrics, since they provide global summary descriptors of individual measured or mapped features of the landscape (patches, patch classes, or the whole map). Furthermore, the metrics always represent spatial heterogeneity at a specific spatial scale, determined by the spatial resolution, the extent of spatial domain, and the thematic definition of the map categories at a given point in time (McGarigal et al., 2002). When applied to multi-scale or multi-temporal datasets, spatial metrics can be used to analyze and describe change in the degree of spatial heterogeneity (Herold et al., 2005).

Spatial metrics provides rich quantitative information about spatial pattern of urban areas at the landscape level (Herold et al., 2003)showing a link between these patterns and the change processes and thus effectively capturing the changes.

Gradient can be defined as the rate of change with distance in a particular direction. Gradient analysis is used to link the spatial information with particular locations and make it possible to compare changes that occur in specific metrics and these locations and thus enhance the ability to link patterns and processes (Kong and Nakagoshi, 2005).

A combination of spatial metrics and gradient analysis can be used to study spatial pattern of urbanization and further determine its impact on the ecological attributes of the environment (Zhang et al., 2004)

1.3. Problem Statement

During the last few years, there has been large impact on the landscape ecology due to urban sprawl. For this reason, planners and designers need efficient tools to quantitatively evaluate and compare the impact of alternative plans and designs so that more informed development choices could be made. Urbanization is mainly studied from social and economical viewpoints. Urban planners think about optimisation of the land use and about aesthetics when reshaping the environment. Landscape ecology is lacking in urban planning because of different goals and concepts, but mostly because of missing significant information about these highly dynamical landscapes.

A number of remote sensing techniques have been used to map urban environment and also for the analysis and modeling of urban growth and land cover change (Batty and Howes, 2001). One of the techniques that have been widely used is the change detection technique. This technique reveals the spatial as well as temporal changes over the years. It can provide information on changes occurring for each land cover class, amount of change and their spatial location. The important factor that this technique lacks is the temporal variations in pattern and its spatial location with respect to a reference point.

There is a growing interest in using the concept of spatial metric for the analysis of urban environments. It has also been found that a combination of spatial metrics and gradient analysis can be used to study spatial pattern of urbanization and further improve representation of spatial urban characteristics, interpretation and evaluation of modeling results (Herold et al., 2005; Zhang et al., 2004). This study proposes the approach involving the use of spatial metrics and gradient analysis to quantify the spatial pattern in different directions. The core goal involves explaining the amount, location, and patterns of observed land cover changes in an urban environment.

1.4. Research Objective

The objective of the study is to analyze the spatio-temporal gradient for land cover change and focuses on the techniques to extract quantitative information in a specific direction with respect to a reference point. The study would call for evolving spatial metrics and indices to quantify the land cover change in different directions from the reference point.

1.5. Research Questions

- Can urbanization gradients be detected using spatial pattern modeling?
- How does spatial pattern change with respect to distance and direction from a reference point?
- How does the relation between spatial pattern and distance, change with time?

2. Literature Review

2.1. General

Tremendous expansion of urban population and urbanized area worldwide, have affect on the human as well as natural systems at all geographic scales (Herold et al., 2005). An understanding of landscape dynamics has tremendous implications for landscape management and reserve planning (Farina, 1998; Li et al., 2004).

The rapid urbanization and urban sprawl, in particular, in the developing world require a scientific understanding of complex urban growth patterns and processes. This knowledge is crucial to sustainable land management and urban development planning. Progress in modern remote sensing and GIS techniques has opened up great opportunities, and significant success has already been achieved in monitoring and managing fast urban growth. However, these techniques are still poor when it comes to supporting decision making on sustainable development, as reasonable theories and methods have not been sufficiently and systematically developed to understand the complexity inherent in urban growth. Understanding the urban growth system is a prerequisite for modeling and forecasting future trends of urban land use/cover change and its ecological impacts. As urban growth involves various actors with different patterns of behavior, scientific understanding must be based on elaborated complexity theory and a multidisciplinary framework. The theoretical analysis can provide a guideline for selecting modeling methods currently available in complexity modeling and in remote sensing and GIS environments (Cheng, 2003).

Although historical maps and aerial photography remain valuable sources of urban land-use information, satellite remote sensing offers a tremendous advantage, as it provides recurrent and consistent observations over a large geographic area, reveals explicit patterns of land cover and land use, and presents a synoptic view of the landscape (Jensen and Cowen, 1999; Schneider et al., 2005). In most parts of the world, land-use/land cover can be considered an interface between natural conditions and anthropogenic influence (Lausch and Herzog, 2002).

Remote sensing data are primary sources extensively used for change detection in recent decades. Many change detection techniques have been developed and used for understanding relationships and interactions between human and natural phenomena in order to promote better decision making. These algorithms vary in their merits and are applicable for specific purposes. Timely and accurate change detection of Earth’s surface features provides the foundation for better understanding relationships and interactions between human and natural phenomena to better manage and use resources. In general, change detection involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the phenomenon (Lu et al., 2004).

2.1. Land cover Change modeling

The study of the theoretical and practical aspects of land cover change modeling has shown that a wide variety of approaches and techniques exists, rooted in a multitude of disciplinary backgrounds, to model land cover change. A first assessment already makes clear that different modeling groups have focused on different concepts to elaborate upon and that a further integration of the different approaches and techniques will enable progress (Verburg et al., 2004). Land cover change models are expected to represent complexity of land cover systems.

The advances in geo-informatics, coupled with the availability of spatial and temporal information from remotely sensed data have enabled researchers to investigate and model the environmental systems. These models are executed for different scenarios or alternatives depending upon the specific objectives. Modeling the spatial and temporal dimensions has been an intense subject of discussion and study for philosophy, mathematics, geography and cognitive science (Sudhira, 2004)

2.2. Modeling progress in predicting location versus quantity of land cover change

Remote sensing offers an important means of detecting and analyzing temporal changes occurring in our landscape. It provides spatially consistent data sets that cover large areas with both high spatial detail and temporal frequency. The availability of remote sensing data suitable for urban analysis has significantly increased in the past few years. Such data can provide unique views of urban change dynamics in terms of spatial and temporal resolution based on highly detailed, consistent mapping products over large areas and long time periods. This can now be done at all relevant geographic scales, provided that the appropriate sensors are selected wisely based on their spatial and spectral characteristics. More generally, the recent developments in remote sensing and in the digital analysis of thematic data layers with spatial metrics, as well as the increased opportunities for applying urban modeling techniques in planning and management, invite a systematic evaluation of the potential of combining the strengths of these techniques. Spatial metrics can be a useful tool for quantifying structure and pattern in thematic maps. There has been a lot of interest in applying spatial metrics techniques in remote sensing applications, which is recently being focused in urban environment to model the dynamic growth processes. It has been found that a combination of remote sensing and spatial metrics leads to an improved understanding and representation of urban dynamics and can help to develop alternative conceptions of urban spatial structure and change, thus supporting the modeling of change processes (Herold et al., 2005).

Spatial metrics have already been used widely in the quantification of structure and pattern in the field of landscape ecology, commonly referred to as landscape metrics (Gustafson, 1998a). A number of ongoing studies aim at finding location of changes versus quantity of change. These were focussed on finding the impact of fragmentation on species habitat. Research has been carried out using remote sensing to quantify land use/land cover changes, and landscape metrics to track ecological impacts. A post-classification algorithm was applied to derive land cover changes, and landscape metrics were used to analyze specific habitat classes (Narumalani et al., 2004).

(Kong and Nakagoshi, 2005) substantiate the importance of landscape metrics to quantify the dynamic green space patterns. This research proposed a method comprising quantification of local area green spaces by “moving window” technique, and a gradient analysis involving sampling from the urban center to the fringe. A set of eight metrics were chosen to quantify the urban green space pattern. Based on the grid maps of each landscape metric, 286 spatial sample points were selected at a distance of 200 mts in eight directions from the urban center. The combined and integrated application of remote sensing, landscape metrics, and gradient analysis represented an innovative approach for the study of spatio-temporal gradient change of urban green spaces and further to be effective in linking patterns and the underlying ecological and socio-economic processes. Overall, both the class and landscape-level metrics indicated that dramatic change occurred over the course of the study period.

The importance of landscape metrics in monitoring land-cover change over time have been recognized in the field of forestry also. Specific metrics were used to address the relationship between trajectories of forest-cover change and the biophysical and social characteristics of the landscape. It was evident that a combination of metrics could infer patterns of land-cover change effectively (Southworth et al., 2002).

A study carried out in Jinan city, China used GIS and landscape metrics to determine hedonic price model variables. It was found that this approach could provide a better performing hedonic price model (Kong et al., 2006).

In the studies related to urban growth, attempts have been made to simulate future urban growth.
There has been a lot of research carried out to understand, represent and model complex urban systems. Data availability, improved methods and theory in modeling urban dynamics are the few challenges to be addressed. A study was carried out to explore the combined application of remote sensing, spatial metrics and spatial modeling for the analysis and modeling of urban growth.The study could reveal the importance of spatial metrics to quantify the temporal and spatial properties of urban development, and showed the impacts of growth constraints imposed on expansion by topography and by local planning efforts in the study area. It could be concluded that a combined and integrated application of remote sensing, spatial metrics, and urban growth models represent an innovative approach for the study of spatiotemporal urban growth patterns. A combination of selected metrics was found to be an important tool for the analysis of remote sensing derived mapping products in an urban environment and effective in providing rich quantitative information about the structure and pattern of the dynamic urban landscape pattern. The results encourage the future exploration and integration of the metrics in model calibration processes (Herold et al., 2003).

A combination of gradient analysis with landscape metrics was used to analyze the landscape pattern and the impact of road corridors on urban landscape pattern with variable grain size. Landscape metrics were computed using moving window, along a 51 x 9 sq.km transect cutting across the study area. The results showed that the urban landscape pattern was greatly changed when road corridors were merged with urban patches and the variation of patch density altered when grain size was changed. As a linear land use type, road corridors exhibited a different spatial signature comparing with other land use types and distinctive behavior with increasing grain size. Merging road and urban patches resulted in a sharp reduction in patch density, mainly caused by segmentation of roads corridors. The results suggested that grain size around 7.5 m might be optimal for urban landscape analysis. It could be concluded that landscape patch density is significantly correlated with road percent coverage and the most important effect of road corridors in urban landscape is increased habitat fragmentation. The study could provide insight on the impact of road corridors on the quantification of urban landscape patterns (Zhu et al., 2006).

Another study, based on the context of combining gradient analysis with landscape metrics was attempted by computing landscape metrics along a 165 km long and 15 km wide transect with a moving window. The results revealed that the spatial pattern of urbanization could be reliably quantified using landscape metrics with a gradient analysis approach, and the location of the urbanization center could be identified precisely and consistently with multiple indices. It was found that quantifying the urbanization gradient can be an important input to further studies based on linking patterns with processes in urban ecology (Luck and Wu, 2002).

Quantifying landscape pattern and its change is essential for the monitoring and assessment of ecological consequences of urbanization. Another attempt was made to quantify the spatial pattern of urbanization by combining gradient analysis with landscape metrics. It was found that transect analysis with class-level and landscape-level metrics could provide reliable quantified information about the spatial pattern. The result revealed that increasingly urbanized landscape became compositionally more diverse, geometrically more complex, and ecologically more fragmented leading to dramatic increases in patch density (PD), edge density (ED), and patch and landscape shape complexity, and sharp decreases in the largest and mean patch size (MPS), agriculture land use type, and landscape connectivity. To detect the urbanization gradient of landscape pattern, a series of analyses was conducted along the west-east and south-north transects cutting across the urban center of the study area which were 64 km long and 6 km wide, and 66 km long and 6 km wide respectively. Both transects had three adjacent rows numerically reliable for depicting landscape patterns. A series of moving windows were sampled across these two transects from west to east and south to north. The results also supported the hypotheses that, with increasing urbanization, patch density increases while patch size and landscape connectivity decrease, whereas reject the hypothesis that patch shape becomes more regular as human modification to landscapes intensifies. A total of sixteen landscape metrics were chosen to depict landscape pattern in terms of spatial composition as well as configuration (Zhang et al., 2004).

One more attempt was made to study the landscape pattern, formed as a result of rapid urbanization process. It was found that a combination of GIS – based landscape index and remote sensing analysis could prove to uniquely assess landscape pattern and dynamics. In order to study pattern of landscape and its dynamics, two categories of landscape indices with supplementary ecological meanings were chosen. They were patch-based indices and spatial heterogeneity based indices. Specifically, for the first category, three representative indices (Patch size coefficient variation, Landscape shape index, and Area-weighted mean patch fractal dimension) were calculated. For the latter category, Shannon's diversity index, Contagion index, Proximity index, and Fragment index were chosen and computed. Based on the derived indices, a general trend of landscape change could be revealed successfully (Tang et al., 2005).

(Seto and Fragkias, 2005) conclude that a spatio temporal landscape metrics analysis across buffer zones can lead to better understanding of the shapes and trajectories of urban expansion then only urban growth rates. The study was the first comparative analysis of a system of rapidly developing cities including inter and intra city analysis of spatial and temporal patterns of urban land use change with the help of landscape metrics. The choice of metrics was made in order to describe three aspects of the urban landscape which are: absolute size, relative size, and complexity of urban form. Six landscape metrics were calculated over the temporal period for three buffer zones drawn at 0-3km, 3-

10km and 10-20km from the city centers of four cities considered in the study. The reasons for considering three buffer zones with the specified widths were to capture the temporal variations in all the zones, closer to and distant from the center of the cities, effectively and also to extract information about the urban-rural fringe dynamics. The results could infer that the observed patterns were a function of social, economic, and political processes.

(Schneider et al., 2005) mapped changes in land cover using remotely sensed data and investigated the spatial distribution of development with use of landscape metrics along seven urban-to-rural transects identified as key corridors of growth in the study area. To understand the fragmentation - infill process of the city, pattern metrics were combined with gradient analysis. Instead of applying metrics to the landscape as a whole, the city was partitioned into corridors extending outward from the city core. The basic assumption of the gradient approach was that different levels of economic activity or demographic composition create different distributions of built-up land within each corridor. In this way, patterns of urban growth could be plotted across both space and time. Seven corridors were defined stretching outward from the study area's CBD along major transportation corridors, identified by the municipal planning bureau as key areas of growth. Spatial pattern metrics were calculated in a 4 x 4 km moving window along each corridor for the temporal period and could quantify patterns of urban growth successfully.

A study based to determine land use transition rate among land use types over the years and to quantify the dynamic spatial pattern concluded that the integration of satellite remote sensing and GIS was an effective approach for analyzing the direction, rate and spatial pattern of land-use change. A total of 20 landscape metrics were selected for the analysis of the landscape structure (Li et al., 2004).

A study carried out on urban sprawl, substantiated the importance of GIS and remote sensing in modeling the pattern and extent of sprawl using spatial – temporal data. There was an attempt made to describe some landscape metrics required for quantifying sprawl and further modeling of the dynamic process considering prominent causative factors (Sudhira et al., 2004).

In a study carried out by (Yu and Ng, 2006b), a combination of remote sensing images, landscape metrics and gradient analysis were employed to analyze and compare both the spatial and temporal dynamics of urban sprawl in the study area. This approach was helpful in detailed understanding of landscape changes along the urban–rural gradient to provide a useful tool to compare the structural and functional differences of landscape patches at different orientations. The study also confirmed the hypothesis of the diffusion-coalescence urban dynamics model in the process of urbanization. It demonstrated that in order to reveal the complexity of landscape pattern, temporal data are needed to capture the baseline as well as the spatio-temporal dynamics of landscape changes along the gradient. Combining temporal data with gradient analysis could characterize the complex spatial pattern of urbanization.

A study conducted by (Yu and Ng, 2006a) demonstrated that landscape metrics can be a useful indicator in land use change analysis and are vital for integrated landscape evaluation. The criteria used to select landscape metrics were to fully reflect their conceptual basis, and to well describe landscape changes in the study area. It could also be concluded that landscape metrics analysis can be a useful tool for land use monitoring and assessment. It can provide essential information on the temporal and spatial changes of land use.

It is a major task for urban landscape planners to construct an effective and harmonious urban ecological network and maintain a sustainable urban development environment. The results of a study conducted in China, indicated that methods which integrate landscape metrics with network analyses could not only quantitatively assess the present situation and the rationality of planning for urban greenway systems, but also facilitate the design of planning scenarios for urban ecological networks, enabling them to meet the principles of conformity, harmony, circulation, safety, diversity and sustainability. The results also concluded that the greenway augment plan prevalent in the study area could improve the greenway system considerably. The improvements were indicated by decrease in patch density, and increase in total class area and edge density on the patch level, landscape diversity, landscape evenness and landscape connectivity on the landscape level (Zhang and Wang, 2006).

3. Study Area

3.1. Description of Study area

Gurgaon is a city situated in Gurgaon tehsil of Gurgaon district in the north Indian state of Haryana. The origins of the city's name are rooted in Hindu mythology. The legend tells that Gurgaon is the ancestral village of Guru Dronacharya, the teacher of the Pandavas and Kauravas in the Indian epic, Mahabharata. The name Gurgaon comes from Guru (from Guru Dronacharya) and Gaon (meaning village). The village was gifted by the Pandavas and Kauravas to their Guru (Dronacharya), and was known as Guru ka Gaon, (Village of the Guru), and later Gurgaon.

The study area extends between $28^{0}24'$N to $28^{0}35'$N Latitudes and $76^{0}57'$ to $77^{0}08'$E Longitudes. Gurgaon is one the four major satellite cities and is about 32 kms away from New Delhi, the National Capital of India. It has a population of about 2, 28,820 according to the 2001 national census with a decadel growth of 68.39 %(1991-2001) (Source: NCR Regional Plan 2021).

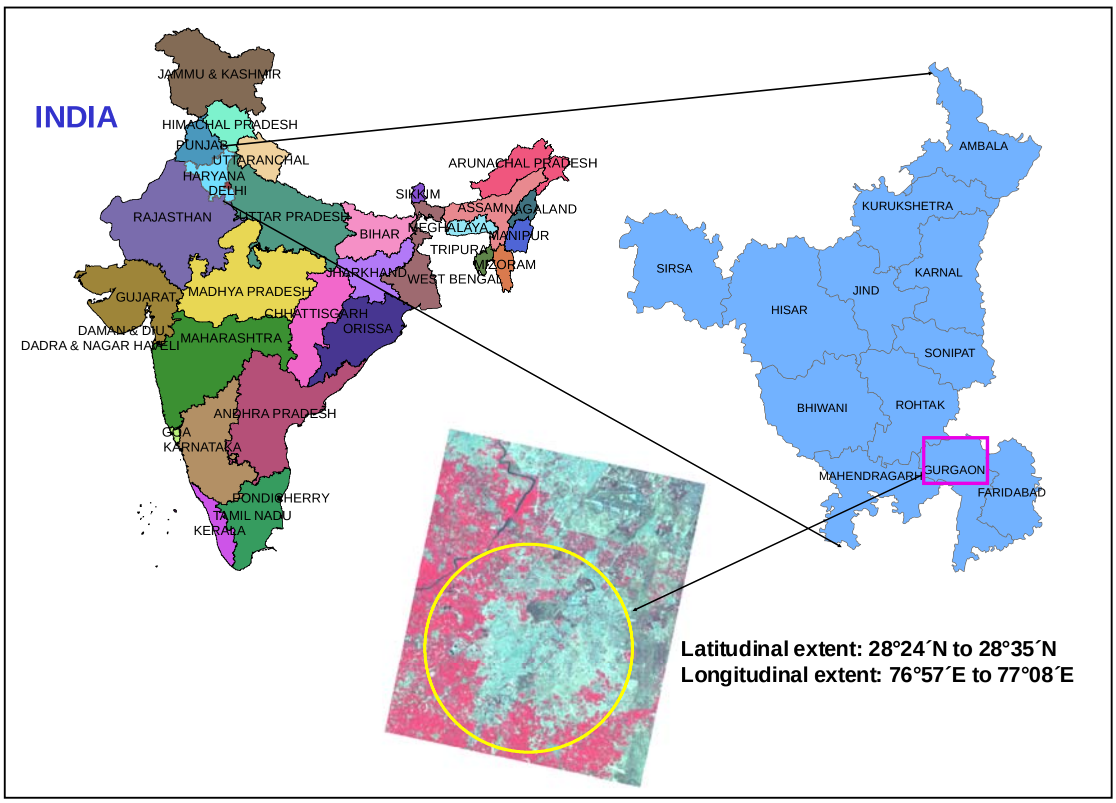

Figure 3-1 The location of study area.

Gurgaon is a city trying hard to shake off its small-town past and embrace modernity and a globalized economy. In the process of building a world-class city, it has become imperative to address the infrastructure issues that plague it. The sustainability of Gurgaon's growth depends on it. Until very recently, it was a sleepy town on the outskirts of New Delhi. Its potential was quickly recognized after the liberalisation of the Indian economy, in the 1990's, because of its proximity to New Delhi, and the smart policy initiatives of the Haryana government. Today, skyscrapers and modern shopping malls dot this suburb, which has seen a major real estate boom since the late 1990s.

Gurgaon has become one of India's major outsourcing hubs, housing major multinationals .The biggest car manufacturer in India, Maruti Udyog, and Hero Honda also have plants in Gurgaon. Thousands of professionals have recently made their home in Gurgaon, living in apartments in newly constructed colonies and condominiums with world-class facilities. The fast growing population, with increasing purchasing power, has created a huge demand for housing, resulting in escalating property prices in recent years.

3.1.1. Physical Aspects

The physiography of the region is characterised by a plain area with a gentle slope. It also comprises an undulating terrain towards the east. The region is an alluvial plain consisting of sand, silt and gravel. The rocks found in the area are mostly covered by quaternary sediments and are exposed in isolated residual and structural hills and pediments. These hills are found in the eastern part of the study area with some valley fills.

3.1.2. Climate

The year may be broadly divided into four seasons, viz. winter, summer, monsoon and the post monsoon or the transit period. The winter starts late in November and continues up till the beginning of March. The summer is from March till the end of June. The period from July to mid September is the south west monsoon season. Mid September to end of November constitutes the post monsoon or the transition period. The climate, except during the monsoon, is characterized by the dryness in air, a hot summer and a cold winter.

3.1.3. Rainfall

The normal annual rainfall in the district is 553.00 mm. The rainfall in the district increases from the west towards the east. About 77% of the annual rainfall in the district is received during the south-west monsoon months.

3.1.4. Temperature

From about the beginning of March, temperatures begin to increase rapidly. May and June are the hottest months when the mean daily maximum temperature is about 41° C. While days are little hotter in May than in June, nights are warmer in June than in May. From April onwards, hot dust-laden winds locally known as loo blows and weather is unpleasant. The mean daily maximum temperature in January is about 21° C and the mean daily minimum temperature about 7° C.

3.1.5. Demographic Profile

As per the 1991 census, the population of Gurgaon was 135,884 and the population growth in the last ten years (1981-1991) was about 35%. The average annual population growth was about 3200 persons in 1961-1981, and 3500 persons in 1981-1991. The population of Gurgaon according to census 2001 is 228,820.

Table 3-1 Population of Gurgaon, 1961-2001

Year	Population	Variation	Annual Increase (%)
1961	37,869	-	-
1971	57,161	19,292	50.9
1981	100,877	43,716	76.5
1991	135,884	35,007	34.7
2001	228,820	92,936	68.39

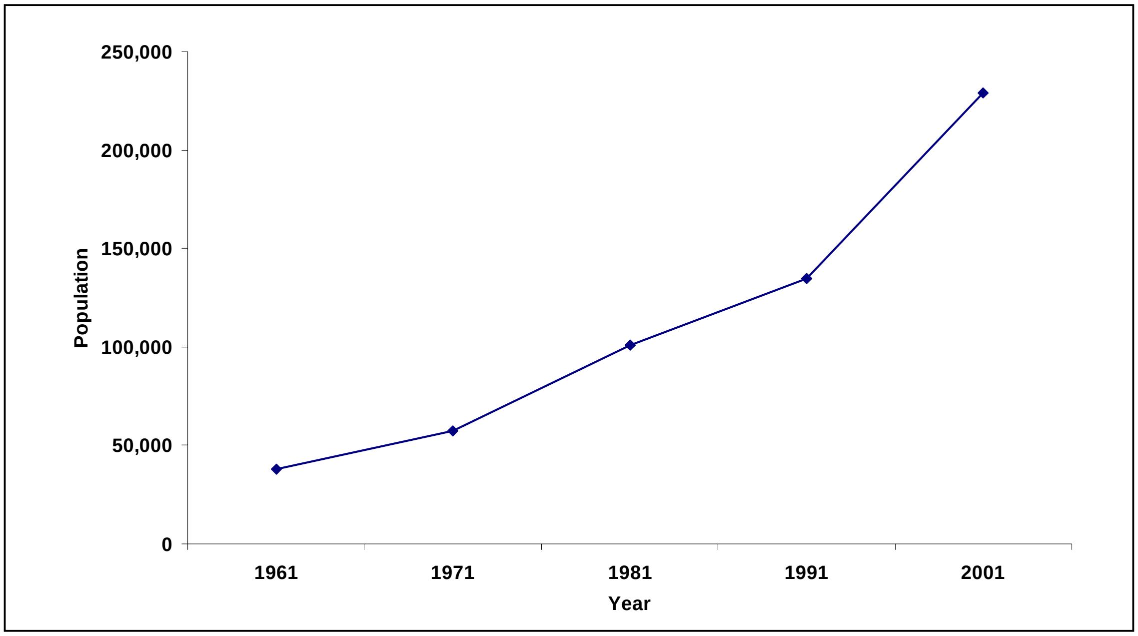

Figure 3.1 : Urban Population of Gurgaon

Source : Census of India

4. Material and Methods

4.1. Material

4.1.1. Data

Data used for this study can be categorized in the following two types: Temporal Earth Observation Data and Field Survey Data.

4.1.1.1. Earth Observation Data

The details of image data used are as follows:

Table 4-1 Image data used in the study

Satellite	Sensor	Date
IRS-P6	LISS III	02/23/2004
IRS 1D	LISS III	03/02/2001
IRS 1D	LISS III	10/19/1999
Landsat	ETM+	09/13/2000

LISS III Images: The images used for the study were for the years 1999, 2001 and 2004 respectively. The LISS III image has four bands red, green, blue and near infra red. The red, green, blue and near infra red bands are of 23.5 m resolution.

Table 4-2 Characteristics of LISS III sensor

Resolution	23.5 m (Visible and near IR region) 70.5 m (Shortwave IR region)
Swath	141 km (Visible and near IR region) 148 km (Shortwave IR region)
Revisit	25 days
Spectral Bands	0.52 - 0.59 microns (B2) 0.62 - 0.68 microns (B3) 0.77 - 0.86 microns (B4) 1.55 - 1.70 microns (B5)

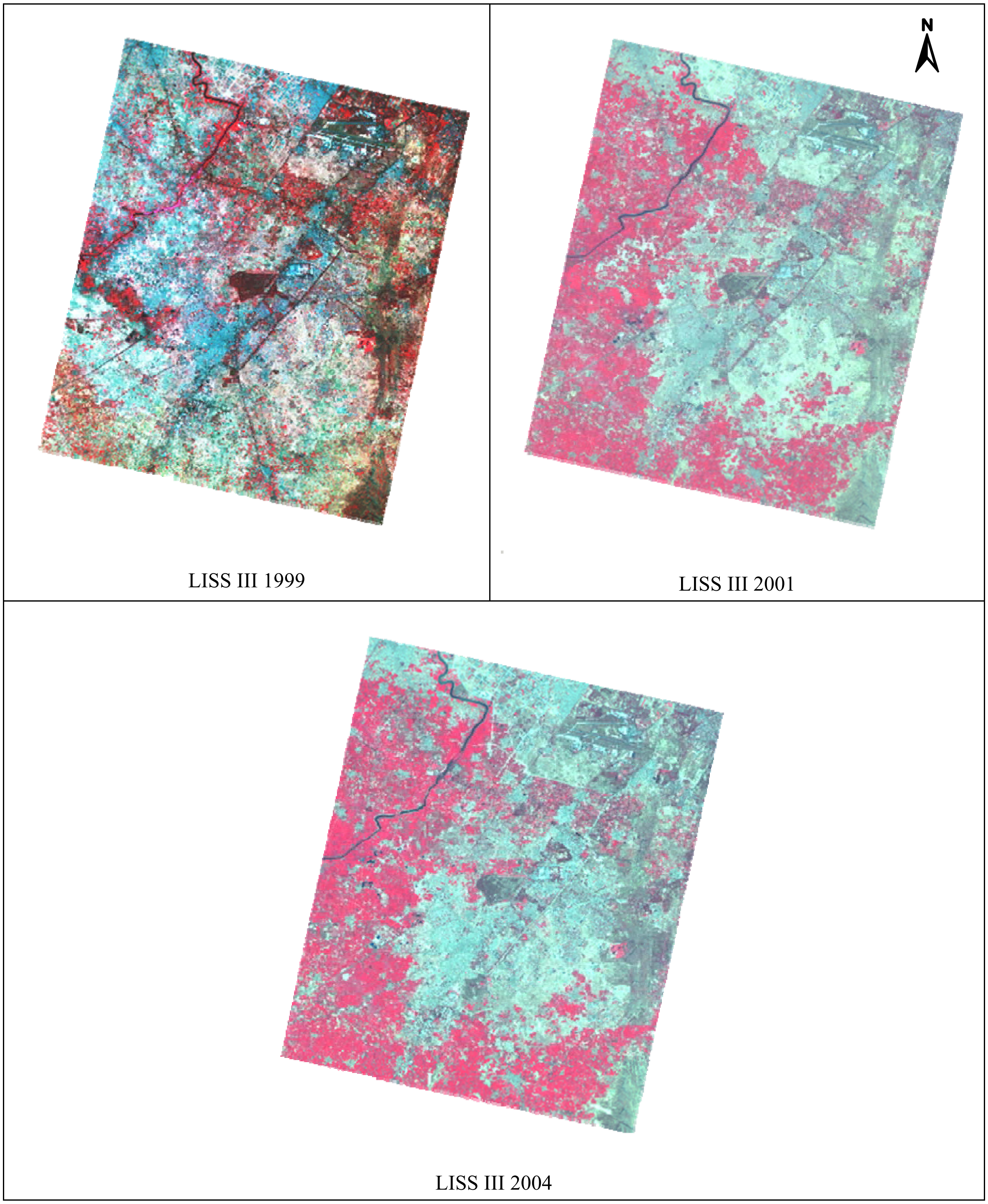

Figure 4-1 The images covering the study area in 1999, 2001 and 2004

ETM+ Image: The orthorectified ETM+ image of the year 2000 used to georeference the LISS III images.

Table 4-3 Characteristics of ETM+ Sensor

Resolution	30 m (Visible , near IR region and Shortwave IR region) 60 m (thermal IR region) 15 m (panchromatic)
Swath	141 km (Visible and near IR region) 148 km (Shortwave IR region)
Revisit	16 days
Spectral Bands	0.450 - 0.515 microns (B1) 0.525 - 0.605 microns (B2) 0.630 - 0.690 microns (B3) 0.750 - 0.90 microns (B4) 1.550 - 1.75 microns (B5) 10.40 - 12.5 microns (B6) 2.090 - 2.35 microns (B7) 0.520 – 0.90 microns (B8)

4.1.2. Field Survey Data

The field visit for the study was carried out from September12, 2006 to September 21, 2006. It comprised of two important tasks relevant to the study as explained as below:

4.1.2.1. Ground Truth Data Collection

During the field visit, ground truth for classification of images was done. GPS points were also collected for important locations in the field. The directions towards which maximum growth was occurring were also identified for verification of initial results and further final output. The location of reference point was identified as the Head Post Office of the Gurgaon City since all the distances in the city were measured from this point and has much significance as the centre of the old city.

4.1.2.2. Secondary data collection

Master plans for the year 2001 and 2021 for the area were procured. This was in the view of getting the administrative boundary and future planned development. Since Gurgaon falls in the National Capital Region, the regional development plan was also procured.

4.1.3. Softwares Used

Erdas Imagine 8.7
ArcGIS 9.1
ArcInfo Workstation 9.1
FragStats tool 3.3

4.1.4. Other Instruments Used

Hand held GPS (Magellan)

4.2. Methods

4.2.1. Methodology

Following is the methodology developed for the study briefing the steps covered for the final output.

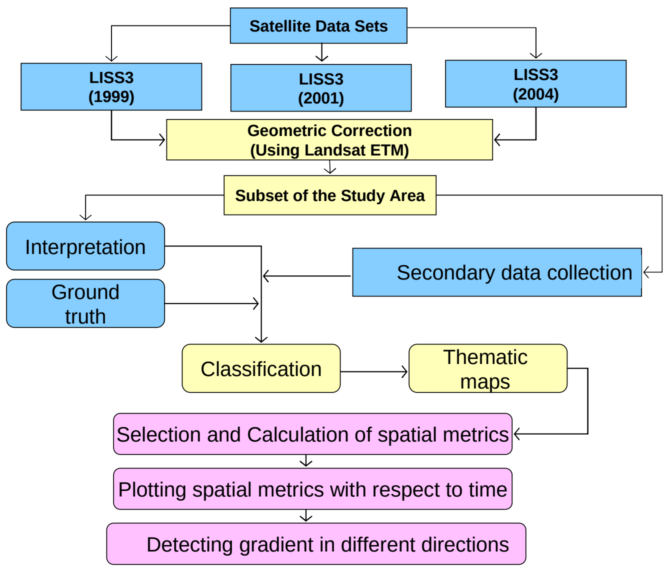

Figure 4-2: Overall approach of the study

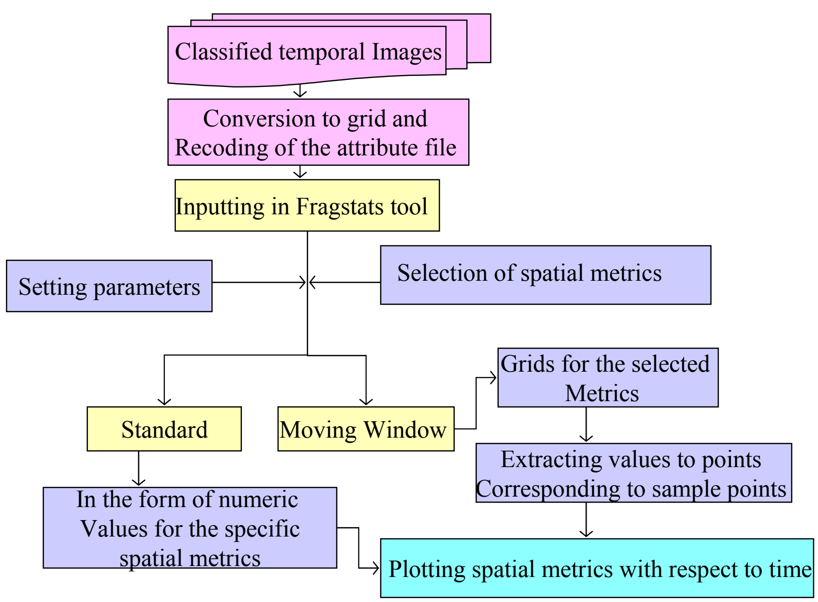

Figure 4-3: Detailed methodology to derive spatial metrics

4.2.2. Geometric correction of the Data

The LISS III and ETM+ images were procured from IIRS data library. The LISS III images were not geometrically corrected. The Landsat ETM+ image (Orthorectified) of the year 2000 was used as the reference image for georeferencing the LISS III images for the years 1999, 2001 and 2004. A first order polynomial equation was used to geometrically correct the images. After sub setting the images according to the extents of the study area, 28 to 30 ground control points were used to georeference the LISS III images with the root mean square error less than 0.6 pixels for all the images. The accuracy of geo-registration could be confirmed by overlaying the images. The images were also geo-linked to check sub-pixel registration. The projection of the images was set to be the same as the ETM+ image and the details are as mentioned below:

Table 4-4 Projection details of the data

Projection Type	UTM
Spheroid Name	WGS 84
Datum Name	WGS 84
Central Meridian	75.000000
Latitude of Origin	0.000000
False Easting at Central Meridian	500000.000000
False Northing at Origin	0.000000

Since the present study focuses on the modelling of land cover change, the images were resampled using the nearest neighbour technique. The nearest neighbour algorithm preserves the original image spectral information by assigning DN value of the closest pixel in the original image.

4.2.3. Classification of the images

Supervised classification was performed using maximum likelihood function to classify the images as built-up and non-built-up. The accuracy assessment showed accuracy over 80% for all the three images which was considered to be good enough to proceed with the analysis.

Figure 4-4 Classified images of 1999, 2001 and 2004

4.3. Selection of Spatial Metrics

As discussed in section 1.2.1, spatial metrics are quantitative measurements of spatial heterogeneity. They can be used to quantify the spatial heterogeneity of the individual patches, all patches sharing a common class, and the landscape as a collection of patches. When applied to multi-scale or multi-temporal data sets, these metrics can be used to analyze and describe change in the degree of spatial heterogeneity. They have been broadly used in the field of landscape ecology and for the recent years are being used in urban environment.

Over 100 different metrics on shape, complexity, and interspersion, among other things have been reported. However, some authors have reported that very few of these metrics contain unique information, and thus the calculation or reporting of all of them is redundant (Gustafson, 1998b; Schneider et al., 2005).

The selection of metrics for this research was based on the past work carried out on urban modeling using spatial metrics and also the understanding of these metrics to represent the dynamics of urban spatial pattern efficiently. The most commonly used metrics for urban studies are class area (Juan et al., 2006; Seto and Fragkias, 2005), percentage of landscape (Herold et al., 2005; Juan et al., 2006; Luck and Wu, 2002), edge density (Herold et al., 2005; Seto and Fragkias, 2005; Zhang et al., 2004), landscape shape index (Luck and Wu, 2002; Zhang et al., 2004), mean patch size (Luck and Wu, 2002; Seto and Fragkias, 2005; Zhang et al., 2004) and number of patches (Seto and Fragkias, 2005), largest patch index(Zhang et al., 2004), total edge. These metrics were found to be sufficient to analyse and extract quantitative information of dynamic spatial pattern of urban growth and thus used in this study. Some of these metrics were used only for the standard analysis to reduce redundant information in the gradient modeling. The definitions of the metrics and there significance is explained as follows, selected from the documentation of the Fragstats software(McGarigal et al., 2002).

4.3.1. Class Area (CA)

CA equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares), that is, total class area.

$$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10,000}\right)$$ **Equation 4-1**

where,
a_{ij} = area (m^2) of patch ij.
CA approaches 0 as the patch type become increasing rare in the landscape. CA = TA when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch. Class area is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular patch type. In addition to its direct interpretive value, class area is used in the computations for many of the class and landscape metrics.

4.3.2. Percentage of Landscape (PLAND)

PLAND equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, PLAND equals the percentage the landscape comprised of the corresponding patch type.

$$\%LAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$$ **Equation 4-2**

where
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).

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; that is, when the entire image is comprised of a single patch.

Percentage of landscape quantifies the proportional abundance of each patch type in the landscape. Like total class area, it is a measure of landscape composition important in many ecological applications. However, because PLAND is a relative measure, it can prove to be a more appropriate measure of landscape composition than class area for comparing among landscapes of varying sizes.

4.3.3. Number of Patches (NP)

NP equals the number of patches of the corresponding patch type (class).

$$NP = n_i$$ **Equation 4-3**

Where
n_i = number of patches in the landscape of patch type (class) "i".
NP ≥ 1, without limit.
NP = 1 when the landscape contains only 1 patch of the corresponding patch type; that is, when the class consists of a single patch. Number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type.

4.3.4. Edge Density (ED)

ED equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).

$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$$ **Equation 4-4**

Where,
e_{ik} = total length (m) of edge in landscape involving patch type (class) "i".
A = total landscape area (m^2).
ED = 0 when there is no class edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of the corresponding patch type and it is specified that none of the landscape boundary and background edge could be treated as edge.

4.3.5. Mean Patch Size (MPS)

MPS equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares).

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10,000}\right)$$ **Equation 4-5**

Range: MPS > 0, without limit.
The range in MPS is limited by the grain and extent of the image and the minimum patch size.

4.3.6. Landscape Shape Index (LSI)

LSI equals the total length of edge (or perimeter) involving the corresponding class, given in number of cell surfaces, divided by the minimum length of class edge (or perimeter) possible for a maximally aggregated class, also given in number of cell surfaces, which is achieved when the class is maximally clumped into a single, compact patch. If a_i is the area of class i (in terms of number of cells) and n is the side of the largest integer square smaller than a_i (denoted) and $m = a_i - n^2$, then the minimum edge or perimeter of class i, min-e_i, will take one of the three forms

min-e_i = 4n, when m = 0, or

min-e_i = 4n + 2, when $n^2 < a_i \leq n(1+n)$, or

min-e_i = 4n + 4, when $a_i > n(1+n)$.

$$LSI = \frac{e_i}{\min e_i}$$ **Equation 4-6**

Where,
e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces
min e_i =minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces
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 (i.e., the length of edge within the landscape of the corresponding patch type increases). Landscape shape index provides a simple measure of class aggregation or clumpiness.

4.3.7. Patch Density (PD)

PD equals the number of patches of the corresponding patch type divided by total landscape area (m2), multiplied by 10,000 and 100 (to convert to 100 hectares).

$$PD = \frac{n_i}{A}(10,000)(100)$$ **Equation 4-7**

where
n_i =number of patches in the landscape of patch type (class) *i*.
A =total landscape area (m^2).
Patch density is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as number of patches as an index, except that it expresses number of patches on a per unit area basis.

4.3.8. Largest Patch Index (LPI)

LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); i.e. LPI equals the percentage of the landscape comprised by the largest patch.

$$LPI = \frac{\max_{j=1}^{n}\left(a_{ij}\right)}{A}(100)$$ **Equation 4-8**

Where,
a_{ij} = area (m^2) of patch *ij*.

A = total landscape area (m^2).
$0 < LPI \leq 100$
LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small and LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; that is, when the largest patch comprises 100% of the landscape.

Largest patch index at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.

4.4. Database Creation

The calculation of metrics was done with the help of public domain software Fragstats. The gradient changes in different directions were detected by conducting a “moving window” analysis supported by the software Fragstats which quantified the built-up using spatial metrics in local areas. Spatial metrics were computed using a 500 m radius window. The window moved over the study area, and calculated the selected metric within the window, returning the value to the center cell. The result was a continuous grid for each selected metric. In this research, spatial metrics were used to quantify the spatial pattern in different directions. Based on the grid maps of each metric, 257 spatial sample points were selected at a distance of 500 mts, taken from the reference point in 16 directions. Even though, radially oriented sampling would result in an over sampling of the city center and under-sampling of the periphery, the samples cannot cover the whole study area but it is best to cover a larger area, especially the typical areas (Kong and Nakagoshi, 2005). Therefore, in this study a 16-direction sampling was conducted to cover maximum percentage of the study area covering all the typical areas than the earlier work that considered two or four directions as elaborated in the literature review. This could be done with the combination of “moving window” analysis with spatial metrics. Gradient analysis enabled to link the spatial information with particular locations and make it possible to compare changes that occur in specific metrics. The output for the spatial metrics is obtained by two types of analysis:

4.4.1. Standard analysis

Using standard analysis, output was obtained in the form of numeric values for the study area which could help in the synoptic analysis of the urban area in the study area as a whole. The circular area of 8 km radius from the reference point was considered for the analysis.

4.4.2. Moving window analysis

Moving Window analysis: Moving window analysis is utilized when the scope of analysis is local landscape structure as opposed to focal patch or global landscape structure. In moving window analysis, a window of the specified shape and size is passed over every positively valued cell in the grid. However, only cells in which the entire window is contained within the landscape are evaluated. Within each window, each selected metric at the class or landscape level is computed and the value returned to the focal (center) cell. Since the scope of the present study is to calculate metrics for each local area, moving window analysis was used. After the classification of the images for the years 1999, 2001 and 2004 in two classes built-up and non built-up as mentioned in the previous section, these images were used to calculate the selected spatial metrics. This was done with the help of public domain software FRAGSTATS. The gradient change of built-up was detected by conducting “moving window” analysis using a window size of 500m. The window moved over the entire image and calculated the value of the selected metric within it, returning that value to the center cell and thus outputting a new continuous surface grid map (Kong and Nakagoshi, 2005; McGarigal and Cushman, 2002). This window size could show maximum fluctuations in the selected metrics. A total of six metrics was selected in the present research to quantify the spatial pattern of urban growth. The grid maps for the selected metrics are shown in the following figures:

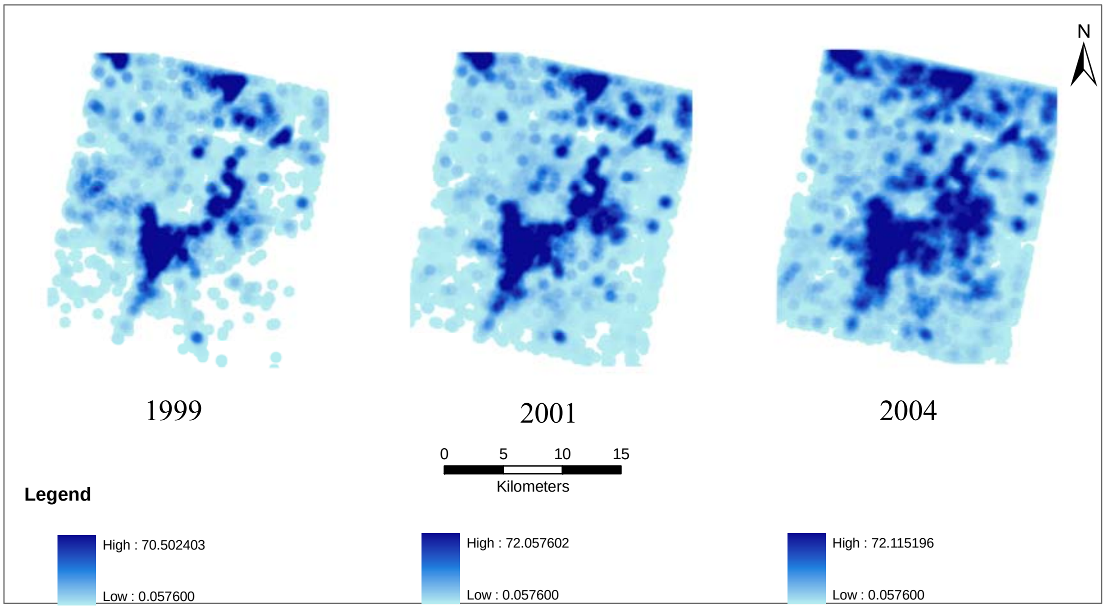

Figure 4-5 Grid maps of the class area metric for built-up.

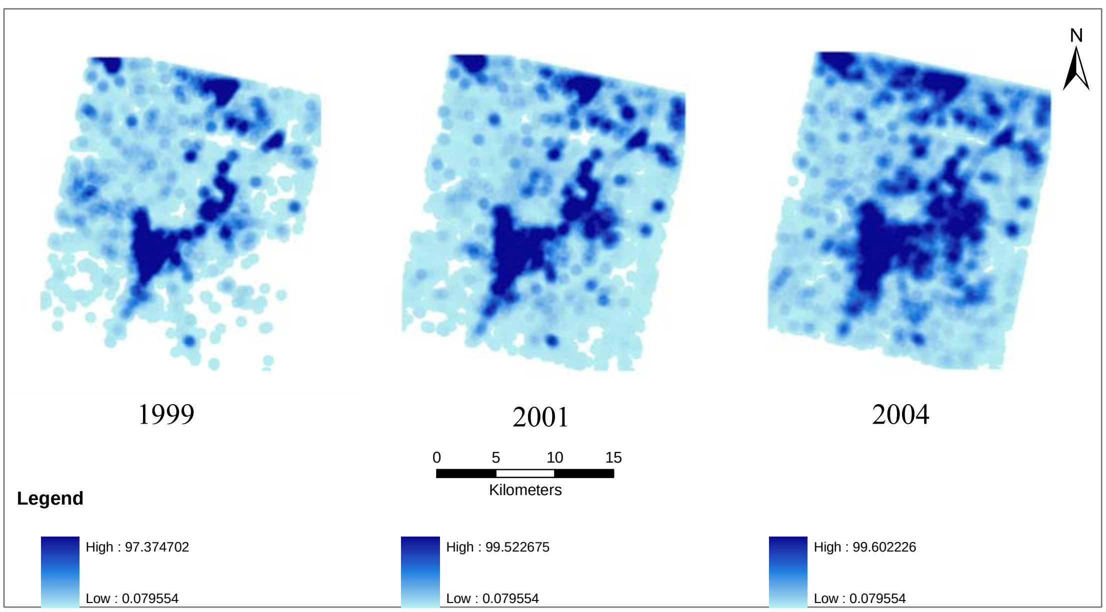

Figure 4-6 Grid maps of the Largest Patch Index metric for class built-up.

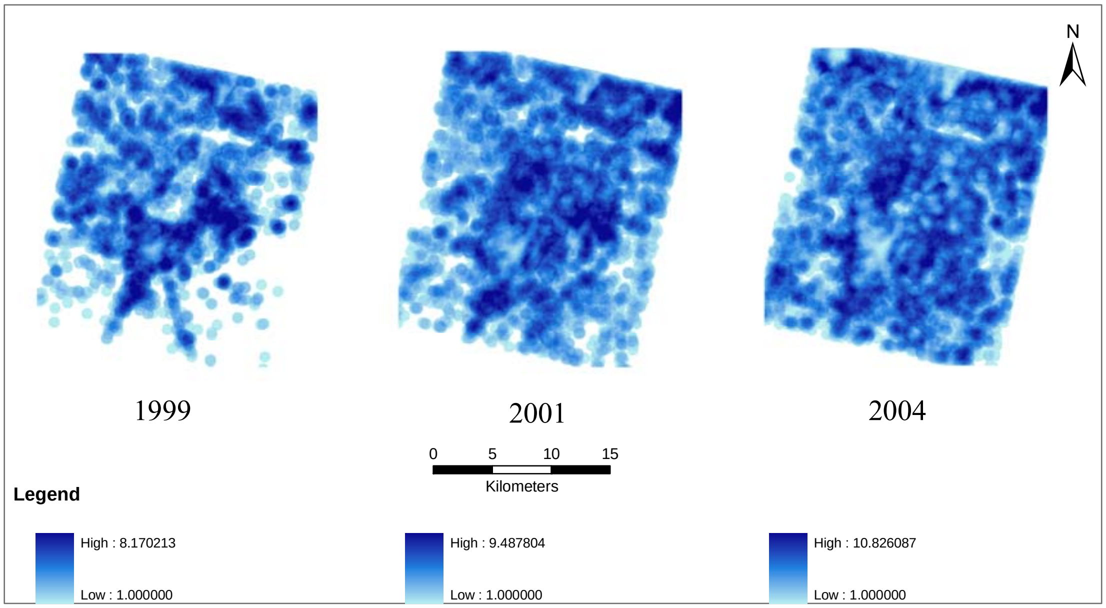

Figure 4-7 Grid maps of the landscape shape index metric for built-up

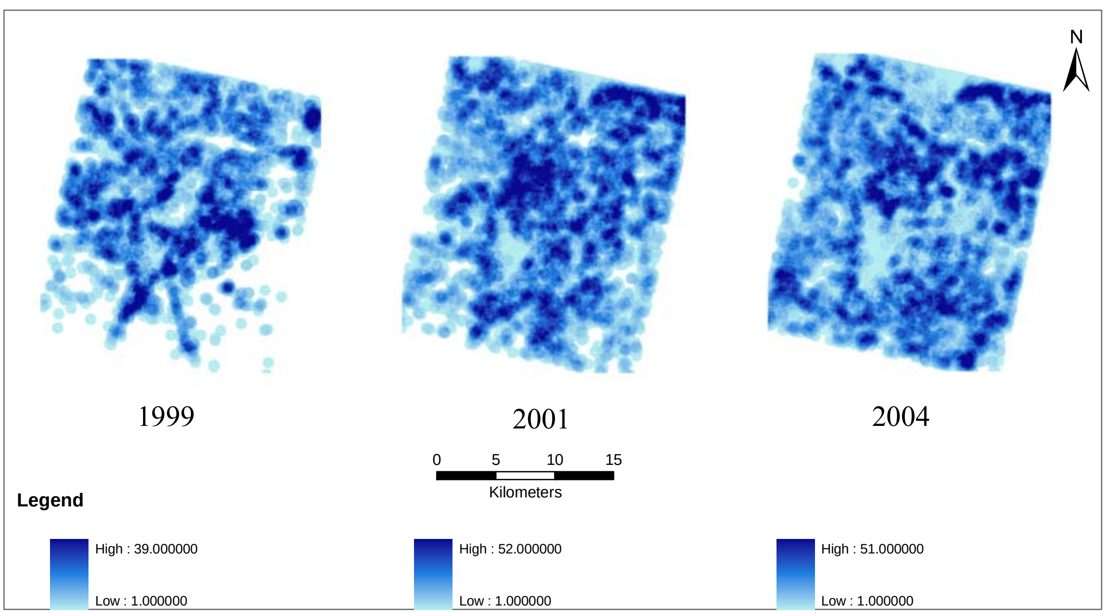

Figure 4-8 Grid maps of the number of patches metric for built-up.

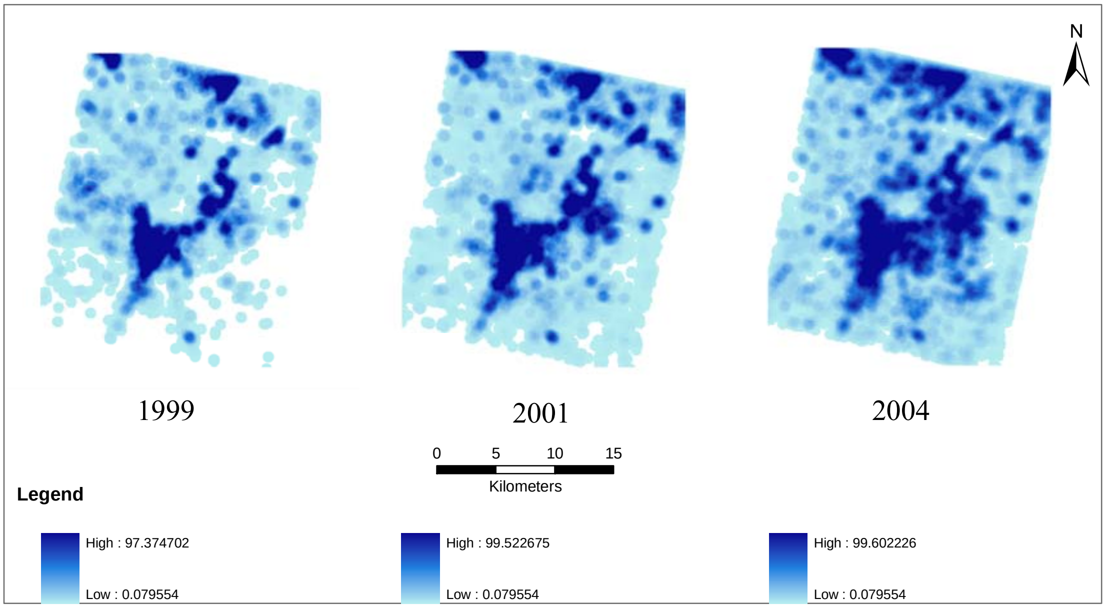

Figure 4-9 Grid maps of the percentage of landscape metric for built-up

4.4.3. Extraction of values of spatial metrics in sixteen directions

A point layer was created in Arc GIS with the coordinates of Head post office of Gurgaon city as the reference point. A distance of eight kilometres in each of the sixteen directions was considered from this reference point. The grid maps of the metrics obtained, as mentioned in the above section were overlaid by this point map with 257 spatial sample points, selected at an interval of 500m. Considering the reference point at the centre, a single line pointing towards the true north was formed.

This line was rotated by a uniform angle of 22.5 degrees resulting in 16 directions from the reference point. These lines were merged and further converted to a point layer by taking samples at a uniform interval of 500m.These points were assigned unique IDs and thus represented particular directions with specified angles i.e. each alignment at an angle of 22.5 degrees from the other.

The values of the grids for the corresponding point layer were extracted and database created for the selected metrics. For the above, a point layer was created to extract value of corresponding grid (of a particular metric) at sample points in 16 directions keeping in mind the angular aspect also i.e.

The approach involved in this study proposes to quantify the spatio temporal gradient and find the patterns of changes in 16 directions from a reference point. Following the above approach, patterns of urban growth across both space and time could be revealed. Based on the analysis of spatial indices divided in different directions, understanding the gradient characteristics of urban constructed area is being aimed.

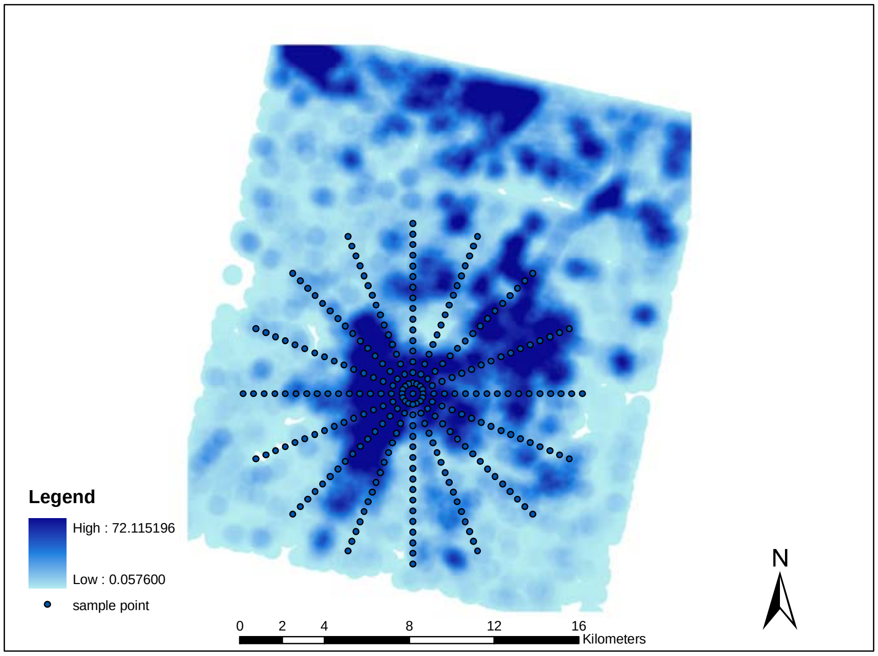

Figure 4-10 Grid map of Class area for 2004 overlaid by the 257 sample points at an interval of 500m from the reference point extending to 8 km in sixteen directions.

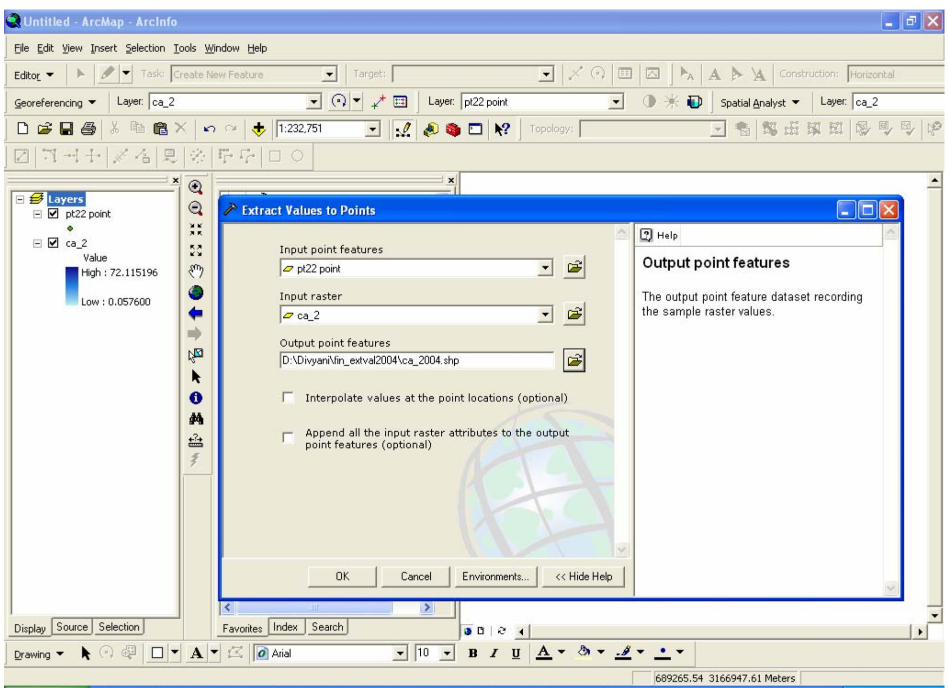

Figure 4-11 The window showing the "extract values to points" tool.

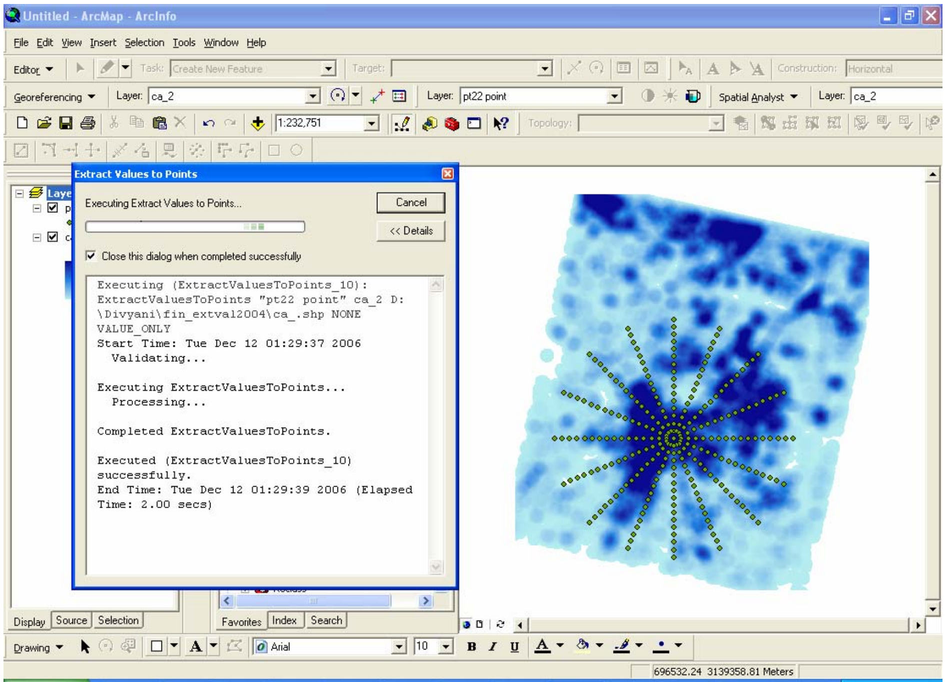

Figure 4-12 Window showing the extraction of sample point values from the corresponding grid map

The outputs and the analysis of the values thus extracted for the different spatial metrics is discussed in the subsequent chapter.

5. Results and Discussions

5.1. The synoptic analysis of the urban dynamic pattern

A comparison of the data from the standard output of the three years indicates an overall increase in the urban areas. The total built-up area in 1999, 2001 and 2004 was 1868, 3491and 6264 hectares respectively. A synoptic analysis of the dynamics of built-up in the study area is discussed by considering the following spatial metrics over the entire study area.

Table 5-1 Values for Spatial Metrics obtained from standard analysis

Metric / Year	CA	PLAND	NP	PD	LPI	TE	ED	LSI
1999	1868.198	7.29	2024	7.90	3.01	908664	35.46	52.73
2001	3491.654	13.63	3175	12.39	6.05	1511832	59.00	64.07
2004	6264.634	24.45	2850	11.12	16.95	2308368	90.08	73.46

The values for the percentage of landscape (PLAND) also confirm the same with the area of built- up almost becoming double for the periods 1999-2001 and 2001 - 2004 respectively. This confirms the fast phase of urbanization in the study area. The number of patches (NP) increases from 2025 to 3175 initially for 1999-2001, indicating sparse growth with the development of new urban nuclei and further decreases slightly to 2850 in 2004 representing the merging of some patches. The patch density (PD) metric which is the proportion of number of patches to the total landscape shows a significant rise from 7.90 to 12.39 during 1999 to 2001 indicating growth of many small urban patches in this period and then slight decline in 2001-2004 from 12.39 to 11.12 indicating the merging of some patches .The largest patch index (LPI) also increases throughout, first from a low value of 3 to 6 approximately from 1999 to 2001 and then 16.95 for 2004. The index almost becomes triple the value of 2001 indicating a progressive increase in the proportion of total area occupied by the largest patch of built-up. This index is a clear indicator that urban core is increasing in a rapid manner and forming the largest patch for the area, resulting from the merging of smaller patches in the vicinity mostly by the infill process. The total edge (TE) of the built-up increases progressively from 1999 to 2001 and then 2004. Considering the proportion of total edge to the total landscape in the form of edge density (ED), the forming of new urban nuclei become quite evident throughout 1999 to 2004. The high value for landscape shape index (LSI) proves the same, signifying high degree of fragmentation in the urban landscape, which increased from 1999 to 2004. The synoptic analysis of the indices over the entire landscape shows a rise in patchiness for built-up in throughout the temporal period.

5.2. Gradient analysis with spatial metrics

In order to quantify the changes in the spatial pattern of the built-up over the study period i.e. from 1999 to 2004, the selected spatial metrics were calculated and plotted for 16 directions from the reference point to find the variation that occur for specific metric over the study period. This period has been identified as the period of maximum growth for the study area. The direction vice interpretation of the spatial and temporal pattern with each metric plotted for three different years and sixteen different directions is explained as follows:

5.2.1. Percentage of Landscape

The information by the indices plotted from the percentage of landscape index in 16 directions show several fluctuations with a peak at the center showing the proportion of built-up being maximum at the reference point of the study area. The overall trend shows peaks in some directions at specific locations, signifying maximum urban growth. The percentage of landscape shows a temporal pattern with the rank 2004>2001>1999 which is obvious for built-up, that it grows over the years.

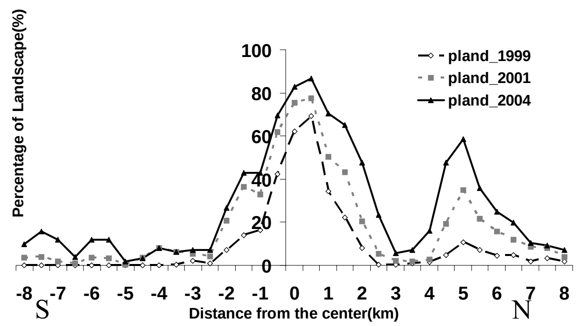

Figure 5-1 Gradient changes in percentage of landscape along south-north direction

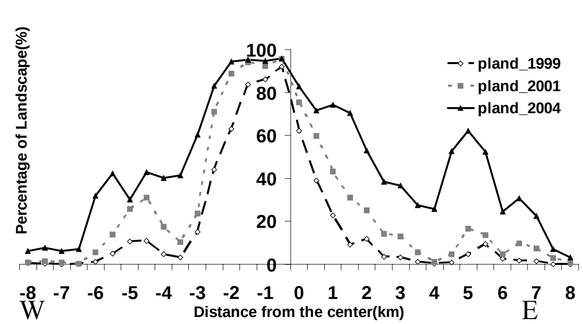

Figure 5-2 Gradient changes in percentage of landscape along west-east direction.

5.2.1.1. South-North (S-N)

This metric, in addition to the peak at the center, shows a peak towards the north at about 5.5 km from the reference point .This peak was evident in the year 2001, and since the built-up grew in this particular region, resulted in a further growth in 2004 as well. The proportion of built-up declines towards the fringe from 7 to 8 km in the north. The south shows slight development in terms of urban growth, mostly in the period 2001-2004 towards the fringes from 5 to 6 km and 7 to 8 km from the reference point. (Shown in fig 5-1)

5.2.1.2. West-East (W-E)

The percentage of landscape increases progressively towards the east from 2001 to 2004, specifically from 4 to 7 km from the reference point, the metric shows high development. There seems to be significant growth in this direction as a result of urbanization. The metric shows fluctuations from 3 to 6 km towards the west from the reference point. For the same location, the proportion of built-up seems to be consistently growing from 1999 to 2004. On the fringe, the growth seems to be negligible. (Shown in fig 5-2)

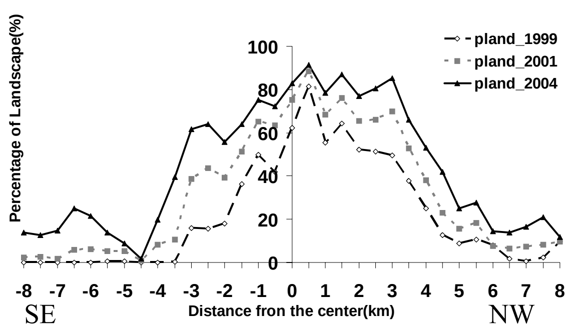

Figure 5-3 Gradient changes in percentage of landscape along southeast-northwest direction

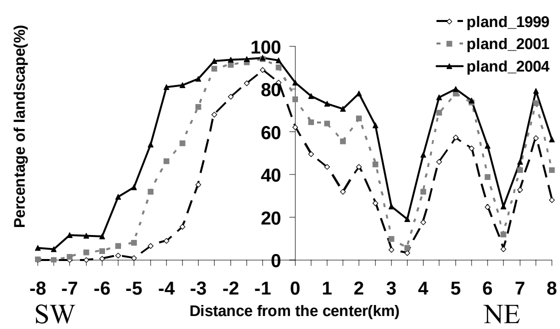

Figure 5-4 Gradient changes in percentage of landscape along southwest-northeast direction.

5.2.1.3. Southeast-Northwest (SE-NW)

The urban growth in these directions as revealed by the percentage of landscape shows a consistent growth over the years with already high values for the 1999 concentrated between 5 km southeast to 5 km northwest. The temporal pattern shows just an addition to the existing built-up over the period. The proportion of built-up declines suddenly from 3 to 4.5 km towards the southeast consistently for all the years and then there is a sudden growth towards the fringe which becomes evident in 2004. Along the northwest, there seems to be a uniform growth extending to the fringes with low development from 5 to 8 km from the reference point. (Shown in fig 5-3)

5.2.1.4. Southwest-Northeast (SW-NE)

The metric in these directions reveal a pattern consisting of several peaks over the temporal period starting from the 1999 itself, the years 2001 and 2004 adding to the existing built-up at the same peaks or distances. There seems to be a considerable development towards the southwest up till 5 km from the reference point, the rate of development being very low towards the fringes. The temporal pattern in the northeast direction for this metric shows several peaks. The dips for the value, which continues to be there for all the years under study, signify the presence of some restricting factor, restraining urban growth at these locations. These dips occur at 3.5, 6.5 and 8 km from the reference point. Between these locations, the proportion of built-up being considerably high. (Shown in fig 5-4)

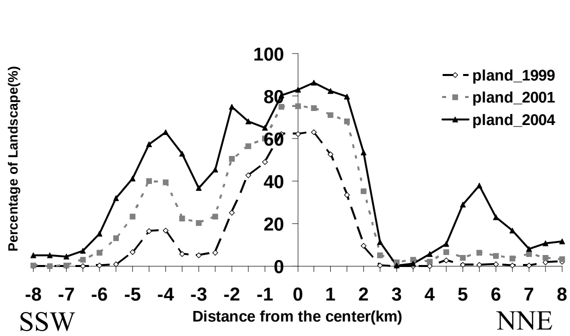

Figure 5-5 Gradient changes in percentage of landscape along south southwest-north northeast direction.

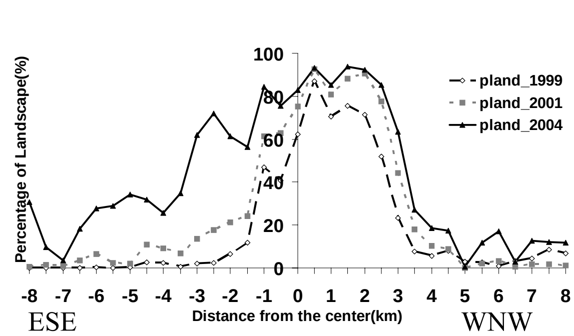

Figure 5-6 Gradient changes in percentage of landscape along east southeast-west northwest direction.

5.2.1.5. South southwest-North northeast (SSW-NNE)

The spatial signature suggests a considerable growth in the SSW direction specifically at 2 km and between 3 and 5.5 km from the reference point. The peaks and dips signify the different growth rates for different locations and negligible growth towards the fringe. The metric shows highly developed area in terms of built–up till about 2 km from the reference point towards the NNE direction. There seems to be no built-up beyond 2 km up till 4 km, after which the metric shows a peak in the year 2004 between 5- 6 km signifying built-up activities expanding towards the fringe areas that were totally undeveloped areas. (Shown in fig 5-5)

5.2.1.6. East southeast-West northwest (ESE-WNW)

This metric shows a progressive growth in the built-up towards the ESE direction from 0 to 6.5 km from the reference point and again increasing at the fringe. Looking at the spatial signature for the years 1999, 2001 and 2004, there seems to be a significant rise in percentage of landscape towards the ESE direction. Whereas the WNW direction seems to have grown significantly by the year 1999 from 0 to 3 km from the reference point, the proportion of built-up declining beyond this distance with slight development occurring at the fringe. (Shown in fig 5-6)

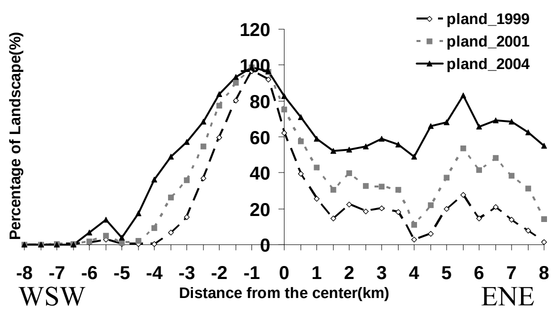

Figure 5-7 Gradient changes in percentage of landscape along west southwest-east northeast direction.

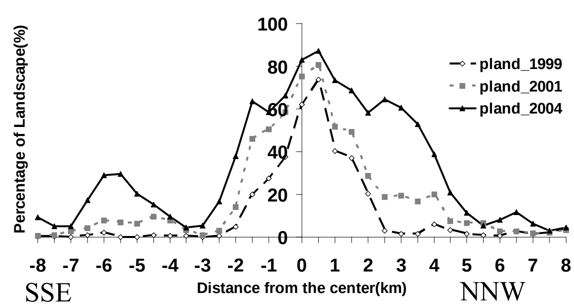

Figure 5-8 Gradient changes in percentage of landscape along south southeast-north northwest direction

5.2.1.7. West southwest-East northeast (WSW-ENE)

The WSW direction shows uniform increase in percentage of built-up between 0 to 5 km from the reference point and also slight increase between 5 and 6 kms, declining towards the fringe. The spatial pattern shows a remarkable growth in the ENE direction with a consistent peak between 5 and 6 kms. The pattern of growth is similar for the temporal period i.e. for all the years 1999, 2001 and 2004 with the peaks and dips at the same locations for all the years.(Shown in fig 5-7)

5.2.1.8. South southeast-North northwest (SSE-NNW)

The SSE direction experienced remarkable growth between 4 and 7 km from the reference point in the temporal period of 2001 to 2004. But there seems to be some constraint to growth at 3 km. Towards the NNW also, there is considerable rise in the percentage of built-up specifically in the time period 2001-2004 from between 1 and 5 kms and declines after that. (Shown in fig 5-8)

5.2.2. Mean patch size

Mean patch size is a function of the number of urban patches and the size of each urban area, and can either increase or decrease through time. Decreasing values of mean urban patch size implies that new urban centers are growing faster than existing urban areas. That is, urban growth occurs more as a process of new and multiple urban nuclei formation than of envelopment or annexation (Seto and Fragkias, 2005).The metric size shows the highest value at the reference point for the year 2001 compared to 2004 and 1999, which is common in the spatial pattern of all the plotted indices in different directions. In general, the spatial pattern for this metric seems to be similar in all the directions, except southwest-northeast, with mostly low values and certain peaks close to the reference point.

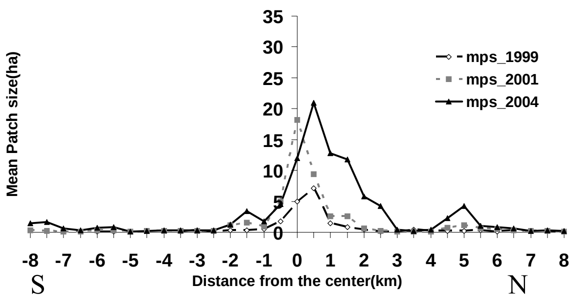

Figure 5-9 Gradient changes in mean patch size along south-north direction.

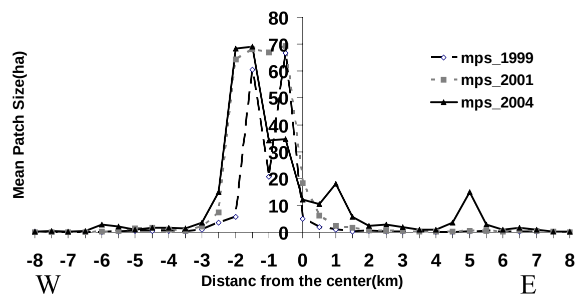

Figure 5-10 Gradient changes in mean patch size along west-east direction.

5.2.2.1. South-North (S-N)

Towards the south, the metric shows very low values for all the years except a rise in value at 1.5 km from the reference point with the temporal trend of 2004>2001>1999. The north also follows the same temporal trend with substantial increase in the value (from 0.5 to 2.5 km) and a slight peak at 5 km for the year 2004 indicating the growth of new built-up. (Shown in fig 5-9)

5.2.2.2. West-East (W-E)

The metric displays an increase in values in the west (from 1.5 to 3 km) between 1999 and 2004 (2004>2001>1999) but then a gradual dip in value at 1 km with the temporal pattern, in which 2001>2004>1999, signifying a decrease in mean patch size at this location from 2001 to 2004.Towards the east, the values remain low with two peaks at 1 km and 5 km for the year 2004. (Shown in fig 5-10)

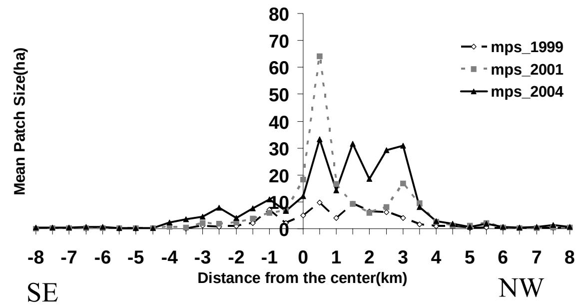

Figure 5-11 Gradient changes in mean patch size along southeast-northwest direction.

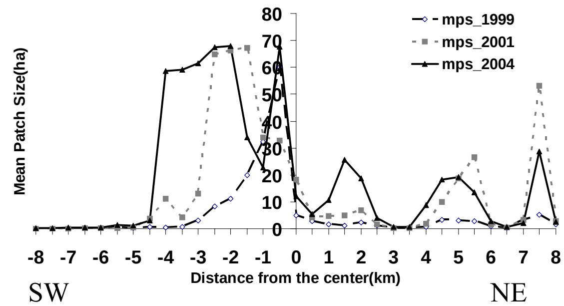

Figure 5-12 Gradient changes in mean patch size along southwest-northeast direction.

5.2.2.3. Southeast-Northwest (SE-NW)

Southeast direction shows less variation in the temporal pattern with a rise in value of the metric for the locations close to the reference point generally with ranking 2004>2001>1999. Whereas, along the northwest direction, the metric value exhibits peaks at 0.5 km with the ranking of 2001>2004>1999, specifying the order of variation in temporal pattern. Further along northwest (from 1 to 3 km) the metric for 2004 displays the highest value with the trend 2004>2001>1999. (Shown in fig 5-11)

5.2.2.4. Southwest-Northeast (SW-NE)

There a significant rise in the mean patch size along the southwest direction (from -4 to -2 km) through the year 1999 to 2004 i.e. 2004>2001>1999. But then a gradual fall in value for the year 2004 at 1 km which again increases at 5 km, exhibiting a peak. Along the northeast direction, a peak shows a rise in the value of metric between 0.5 km and 2.5 km from 1999 to 2004. This direction also exhibits two peaks at 5.5 and 7.5 km for the year 2001. (Shown in fig 5-12)

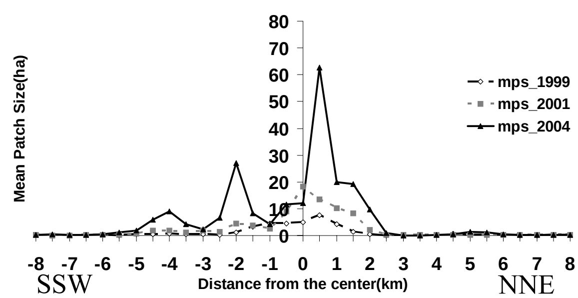

Figure 5-13 Gradient changes in mean patch size along south southwest-north northeast direction.

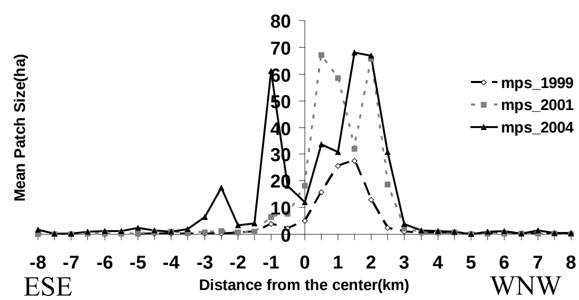

Figure 5-14 Gradient changes in mean patch size along east southeast-west northwest direction.

5.2.2.5. South southwest-North northeast (SSW-NNE)

The SSW direction shows two peaks for the metric at 4 and 2 km for the year 2004 rising from very low values of 1999 and 2001 respectively. The mean patch size for the NNE direction exhibits a temporal pattern in which 2004>2001>1999 up till a distance of 2 km from the reference point also showing a significantly high value at 0.5 km for the year 2004. (Shown in fig 5-13)

5.2.2.6. East southeast-West northwest (ESE-WNW)

In the vicinity of the reference point, the metric shows two peaks for the ESE direction at 2.5 and 1 km for the year 2004 and low values for the years 1999 and 2001. Along the WNW direction, the mean patch shows the temporal pattern with the rank 2001>2004>1999 from 0 to 1 km. The value for the metric also coincides for the years 2001 and 2004 at 2 km, showing no change in the mean patch size at that location. (Shown in fig 5-14)

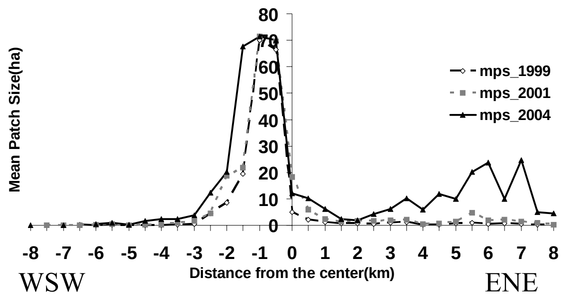

Figure 5-15 Gradient changes in mean patch size along west southwest-east northeast direction

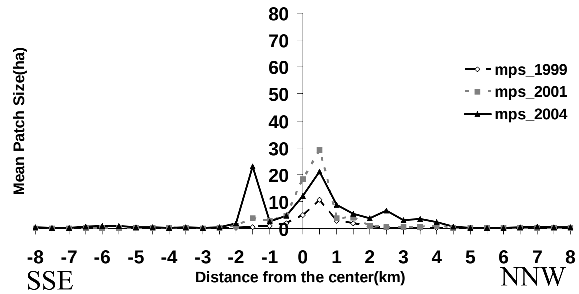

Figure 5-16 Gradient changes in mean patch size along south southeast-north northwest direction

5.2.2.7. West southwest-East northeast (WSW-ENE)

The WSW direction shows an increase in the value of the metric (from 1 to 3 km) with the temporal ranking of 2004>2001>1999.Along the ENE direction, there seems to be a temporal pattern different from other directions wherein there is an increase in metric value including the fringes also (from 2.5 to 8 km) with the same rank 2004>2001>1999. (Shown in fig 5-14)

5.2.2.8. South southeast-North northwest (SSE-NNW)

The SSE direction shows a single peak at 1.5 km, value increasing in the temporal order 2004>2001>1999 and declines further till -8 km. Along the NNW direction, the value varies with a peak at .5 km in the temporal order 2001>2004>1999, signifying a decrease in the value of mean patch size over the temporal period of 2001 to 2004. From 1.5 to 4 km the mean patch size increases through the 3 years with maximum value for 2004. (Shown in fig 5-15)

5.2.3. Number of patches

The more are the number of patches, signifies the growth of the urban area in a fragmented way. Number of patches is a measure of discrete urban areas in the landscape and is expected to increase during periods of rapid urban nuclei development and may decrease if urban areas expand and merge into continuous urban fabric (Seto and Fragkias, 2005). The spatial signature of the metric in different directions and the temporal variation provides information about the urbanization process. In general, for number of patches, in different direction shows several peaks and dips. (Shown in fig 5-16)

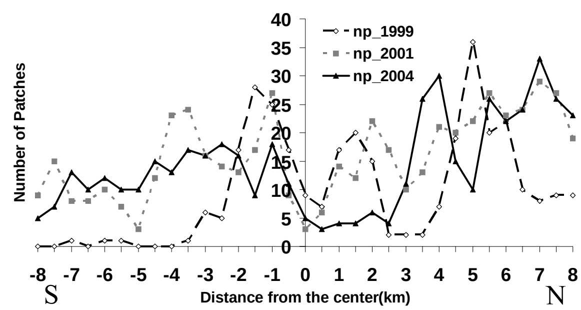

Figure 5-17 Gradient changes in number of patches along south-north direction.

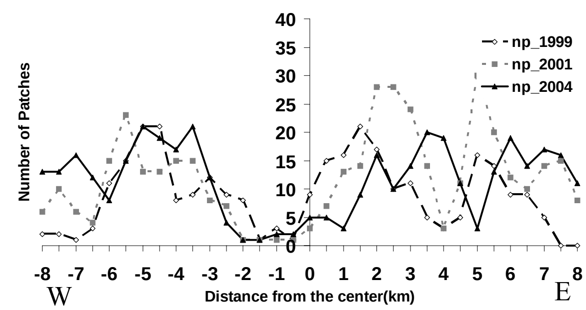

Figure 5-18 Gradient changes in number of patches along west-east direction.

5.2.3.1. South-North (S-N):

Along the north direction, the metric shows several peaks for the year 1999 (between 1 to 2 km and at 5 km) towards north which, through the year 2001 drops to low values in 2004. This can be a result of merging of independent urban nuclei. Whereas for the year 2004, there are high values in the north (between 3 to 4 km and at 7 km), indicating the growth of new urban patches. Towards the south also, there seems to be maximum disaggregation in the year 2001(from 5 to 3 km from the reference point). Overall, the fragmentation decreased with the temporal variation 2001>2004>1999 in the south. (Shown in fig 5-17)

5.2.3.2. West-East (W-E):

These directions show quite a variation with maximum peaks in the year 2001 signifying maximum fragmentation of the urban area which merges to form continuous urban area through the year 2004. But even in 2004, there is a growth of new urban patches at the fringes (i.e. from 6 to 8 km on either side) of the reference point. (Shown in fig 5-18)

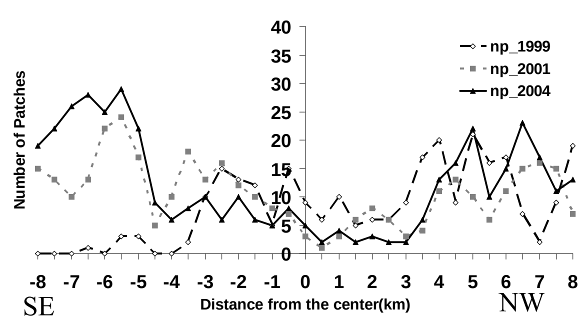

Figure 5-19 Gradient changes in number of patches along southeast-northwest direction.

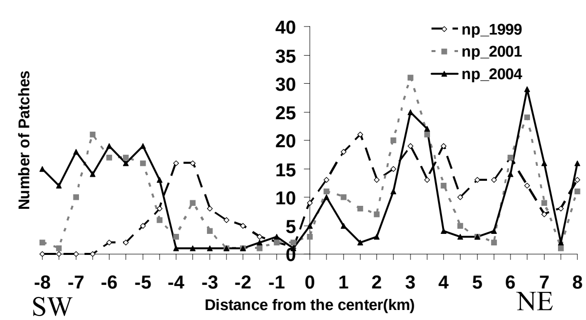

Figure 5-20 Gradient changes in number of patches along southwest-northeast direction.

5.2.3.3. Southeast-Northwest (SE-NW):

The metric shows an increase in number of urban patches towards southeast direction (from 5 to 8 km from the reference point) signifying the growth towards the fringes. In the same direction, (from 0 to 4 km) the old urban patches merged through the year 2001 to 2004 to form less number of patches. Towards the northwest, till about 3 km from the reference point, 2004 shows low values but a sudden peak at 5 km which continues to be there since 1999 and also a peak between 6 and 7 km. (Shown in fig 5-19)

5.2.3.4. Southwest-Northeast (SW-NE):

The temporal variation in southwest direction show maximum values for the year 2001 from reference point to 4 km and then increases for the years 2001 and 2004 indicating rapid growth of urban nuclei. Along northwest, the pattern consists of a number of peaks throughout the temporal period with merging of patches occurring from 1 to 2 km and 4 to 5 km from the reference point. The trend shows fragmentation in 1999 and also at some locations in 2001 and 2004 indicated by high values at the peaks. (Shown in fig 5-20)

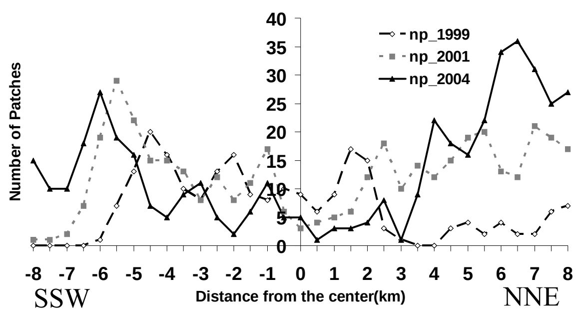

Figure 5-21 Gradient changes in number of patches along south southwest-north northeast direction.

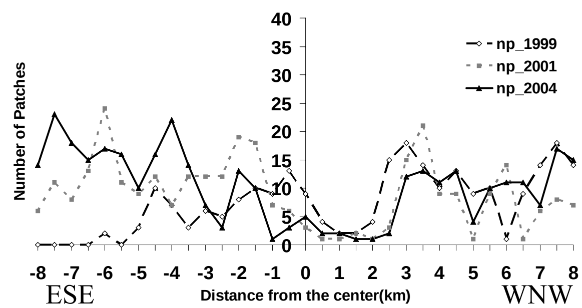

Figure 5-22 Gradient changes in number of patches along east southeast-west northwest direction.

5.2.3.5. South southwest-North northeast (SSW-NNE):

The urban patches in the NNE direction become more disaggregated from 5 to 8 km including peaks at 6.5 km and at 4 km from the reference point in the year 2004. Same trend is evident in the fringe, from 7 to 8 km in the SSW direction. The patches from 0 to 7 km from the reference point seem to have more or less merged through the year 1999 to 2004. (Shown in fig 5-21)

5.2.3.6. East southeast-West northwest (ESE-WNW):

The ESE direction shows several peaks with maximum number of patches for the temporal period occurring at 2001 and 2004. The metric shows the increase in number of patches at 7.5 km and 4 km from the reference point till 2004 whereas the number of patches decrease (from 3.5 to 1 km and at -6 km) with the temporal ranking of 2001>2004>1999 in the WNW direction. (Shown in fig 5-22)

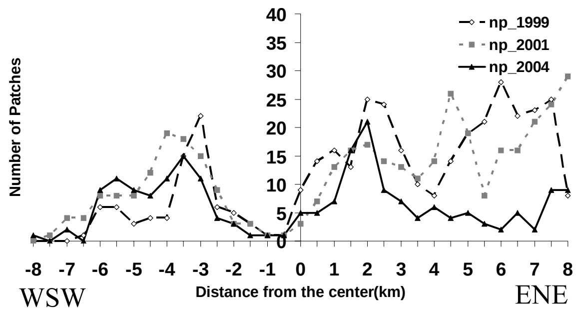

Figure 5-23 Gradient changes in number of patches along west southwest-east northeast direction

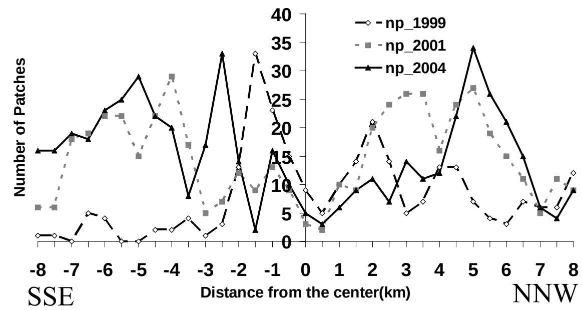

Figure 5-24 Gradient changes in number of patches along south southeast-north northwest direction

5.2.3.7. West southwest-East northeast (WSW-ENE):

Along WSW, there seems to be decrease in number of patches from 2001 to 2004 in general. The temporal pattern of ENE direction shows several peaks with mostly low value of the metric for 2004 compared to 1999 and 2001 signifying formation of continuous and bigger urban patches. (Shown in fig 5-23)

5.2.3.8. South southeast-North northwest (SSE-NNW):

The temporal pattern for the metric varies with different locations. The SSE direction shows several peaks, without following a general trend. Towards NNW, the metric shows low values for 2004 mostly signifying a decrease in number of patches and then a sudden peak at 5 km from the reference point. (Shown in fig 5-24)

5.2.4. Landscape shape index

The LSI, in contrast, provides a simple measure of shape: the greater the amount of `edge', the more fragmented the growth (the LSI is calculated as the sum of the perimeter of all patches relative to the amount of edge that would be present in the same landscape with simple shapes). The shape of new development is less meaningful in urban studies (that is, it does not matter whether new urban land is rectangular or square) but shape is relevant nonetheless for its ability to quantify the complexity of the perimeter and, hence, to quantify fragmentation. An increasing LSI is a clear indicator that urban areas are becoming more fragmented, whereas a decreasing LSI results as the urban fabric becomes more continuous (Schneider et al., 2005).

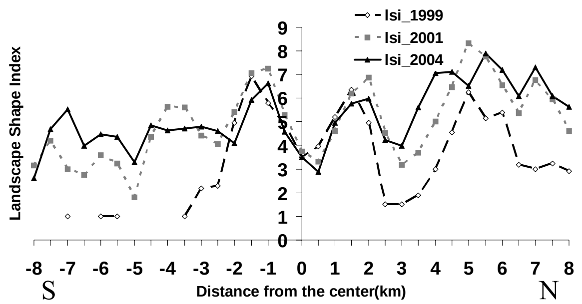

Figure 5-25 Gradient changes in Landscape shape index along south-north direction.

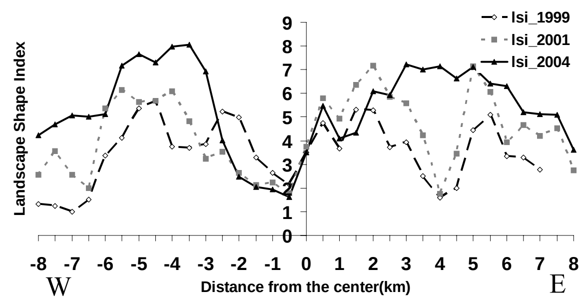

Figure 5-26 Gradient changes in Landscape shape index along west-east direction.

5.2.4.1. South-North (S-N):

The landscape shape index shows values mostly greater than 1 for the years 2001 and 2004 indicating fragmented urban growth. Along the north, it is evident that the urban development has been more of dispersed from 1999 to 2004. The south also shows dispersed growth. (Shown in fig 5-25)

5.2.4.2. West-East (W-E):

Along the west, the metric shows a decrease in value (from 2.5 to 0.5 km) signifying the merging of urban patches to form a continuous fabric from 1999 to 2004. The locations beyond this (from 3 to 8 km) shows dispersed growth with the temporal rank of 2004>2001>1999. Towards the east, only between 1 and 2 km, the urban area becomes compact showing a temporal pattern with 2001>2004>1999. For locations beyond this, urban area grows in a fragmented manner. (Shown in fig 5-26)

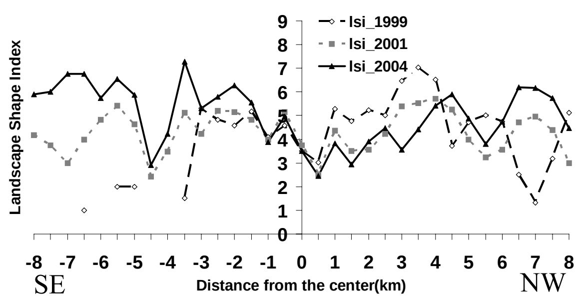

Figure 5-27 Gradient changes in Landscape shape index along southeast-northwest direction.

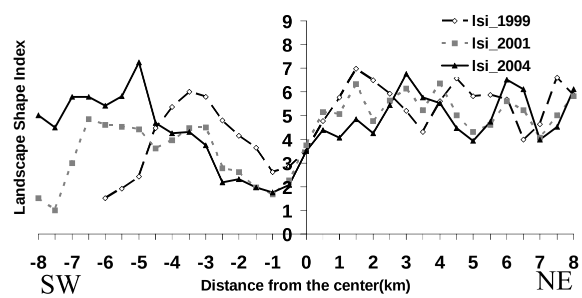

Figure 5-28 Gradient changes in Landscape shape index along southwest-northeast direction.

5.2.4.3. Southeast-Northwest (SE-NW):

The southeast direction shows dispersed urban growth for the year 2004 throughout expect a dip at -4.5 km signifying compactness at this location. Along the northwest direction, the urban area was more fragmented in 1999 and merged to form continuous urban area, mostly from 0 to 4 km with the temporal rank of 1999>2001>2004. Beyond this there seems to be disaggregation between 6 and 8 km with the rank 2004>2001>1999. (Shown in fig 5-27)

5.2.4.4. Southwest-Northeast (SW-NE):

Maximum disaggregation occurs along the southwest (from 4.5 to 8 km) through the years 1999, 2001 to 2004. After this, towards the reference point, there seems to be increased compactness between urban patches with the temporal pattern of values having a ranking of 1999>2001>2004. The northeast shows generally high values for all the three years, with several peaks and the compactness through the year 1999 to 2004, occurred, between 1 and 2 km from the reference point. (Shown in fig 5-28)

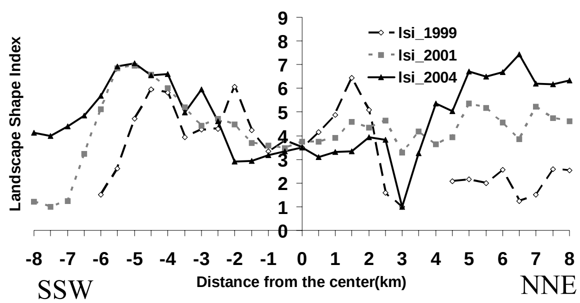

Figure 5-29 Gradient changes in Landscape shape index along south southwest-north northeast direction.

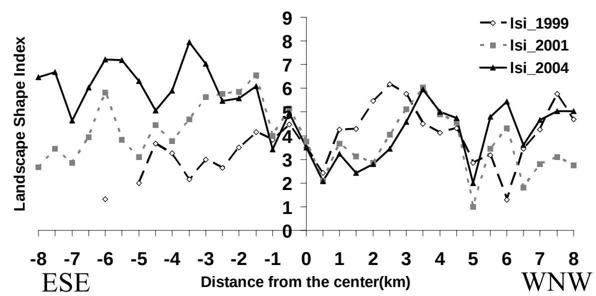

Figure 5-30 Gradient changes in Landscape shape index along east southeast-west northwest direction.

5.2.4.5. South southwest-North northeast (SSW-NNE):

A high degree of fragmentation is evident in the SSW direction (from 3 to 8 km) with the values for the metric showing the temporal ranking of 2004>2001>1999. Whereas, towards the reference point, before 3 km, the urban patches become compact with the rank of values being in the order 1999>2001>2004. Along the NNE direction, fragmentation of urban patches decreases up till 2 km with the same temporal order 1999>2001>2004 and then becomes compact at 3 km. The growth further becomes dispersed from 4 to 8 km in the rank 2004>2001>1999 temporally. (Shown in fig 5-29)

5.2.4.6. East southeast-West northwest (ESE-WNW):

The temporal pattern for ESE direction shows the highest index values for the year 2004 from 3 to 8 km from the reference point, thus signifying growth in the form of dispersed urban patches. Along the WNW direction, the temporal pattern tend towards contiguity initially with the rank 1999>2001>2004 till 3 km and then follows varying trend with few peaks and dips for the index value of the year 2004. (Shown in fig 5-30)

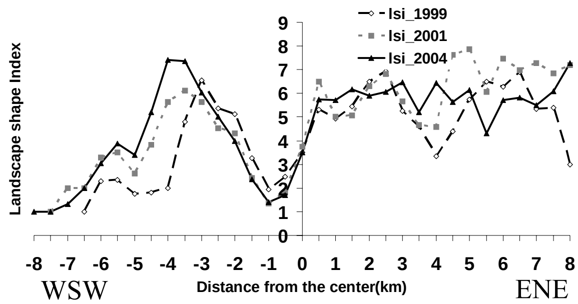

Figure 5-31 Gradient changes in Landscape shape index along west southwest-east northeast direction.

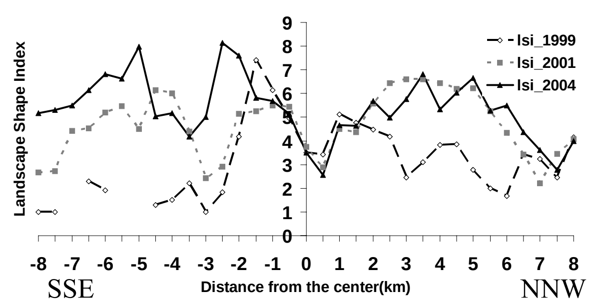

Figure 5-32 Gradient changes in Landscape shape index along south southeast-north northwest direction.

5.2.4.7. West southwest-East northeast (WSW-ENE):

The index shows maximum compactness from 0.5 to 1.5 km from the reference point for the year 2004 which remained unchanged from 2001 in the WSW direction. Beyond that, towards the fringe the fragmentation seems to increase over the temporal period. Along the ENE direction, there seems to be dispersed urban patches in general throughout the 8 km interval. (Shown in fig 5-31)

5.2.4.8. South southeast-North northwest (SSE-NNW):

The SSE direction shows mostly an increase in the value of the landscape patch index and thus maximum disaggregation in the year 2004 for most of the locations. Along the NNW direction, there seems to be a rise in number of urban patches leading to increase in dispersion from a contiguous urban fabric of 1999 from 3 to 6 km. (Shown in fig 5-32)

5.2.5. Largest Patch Index

The largest patch index provides the ratio of the area of the largest patch to the total area of the landscape i.e. proportion of total area occupied by the largest patch of a patch type. Though the results of the metric reveals the similar spatial and temporal pattern as the percentage of landscape, it is included in the analysis to give insight about the urban patches as in most the directions the largest patch is occupying the maximum area in each local area.The plotted indices are as follows:

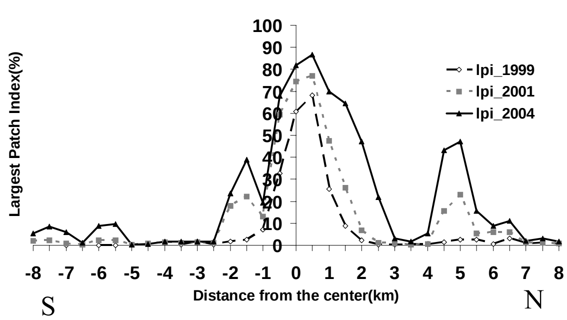

Figure 5-33 Gradient changes in Largest patch index along south-north direction.

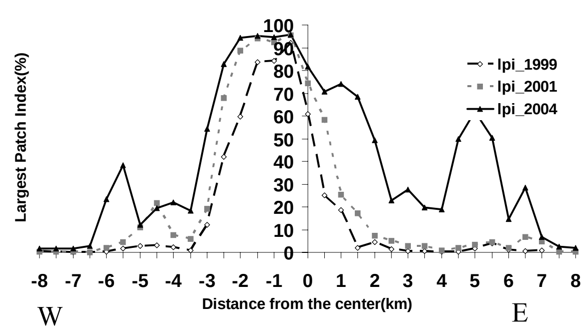

Figure 5-34 Gradient changes in Largest patch index along west-east direction.

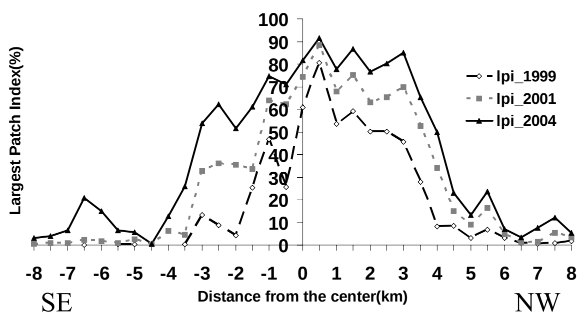

Figure 5-35 Gradient changes in Largest patch index along southeast-northwest direction.

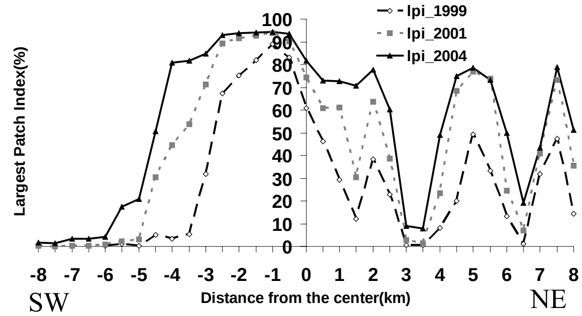

Figure 5-36 Gradient changes in Largest patch index along southwest-northeast direction.

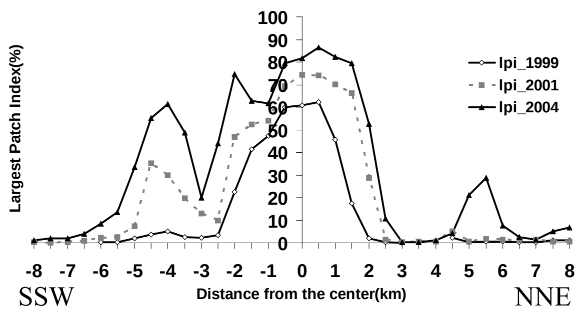

Figure 5-37 Gradient changes in Largest patch index along south southwest-north northeast direction.

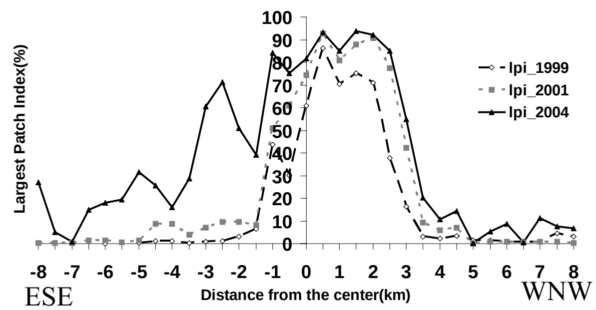

Figure 5-38 Gradient changes in Largest patch index along east southeast-west northwest direction.

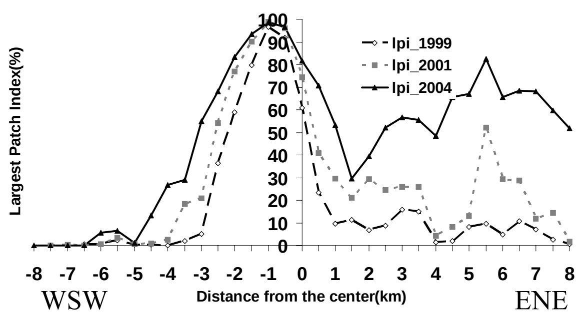

Figure 5-39 Gradient changes in Largest patch index along west southwest-east northeast direction.

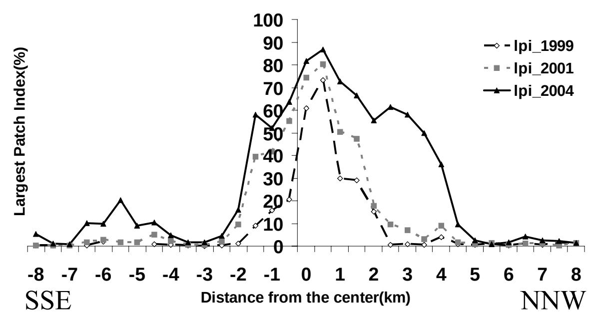

Figure 5-40 Gradient changes in Largest patch index along south southeast-north northwest direction.

The explanation of each directional index is excluded to avoid redundancy with the percentage of landscape. But the important information this metric conveys is that the urban area in 2004 with several peaks in some directions signify the merging of small patches to form a single patch and thus the largest patch is covering the maximum percentage of area in local areas. This trend is present for study area considered in this study, but can reveal different pattern for any other study area. Reason being, that largest patch not necessarily can cover the entire area but is more of relative value to other patches.

6. Conclusion and Recommendations

6.1. Conclusion

The study could answer the research questions successfully by considering location versus changes using spatial metrics for two temporal periods of 1999-2001 and 2001-2004. The variation in the spatial signature of different metrics could reveal important information about the pattern of change. To explain the spatial pattern for urban development, the percentage of landscape, mean patch size, number of patches, landscape shape index etc. are very useful. The synoptic analysis could reveal the overall trend of urban growth in the study area indicating considerable growth in the urban areas with increasing fragmentation i.e. formation of a number of new urban centers. The gradient analysis could reveal different patterns of metrics in various directions Most of the directions show considerable urban development, showing maximum growth towards the north northeast, east northeast, east southeast and east, specifically in the year 2004. This signifies new urban features rapidly growing in these directions. The availability of infrastructure and the proximity towards the National Capital New Delhi can be considered the reason behind the high rate of growth. This was also an initial observation during the field visit. The close examination of the metrics show increasing value for the percentage of built-up in most of the directions, patch density with lot of variation with high values indicating, enhanced fragmented growth for the area. Mean patch size showing the highest value at the center and drastically declining towards the fringes. The largest patch index reveals the same pattern as the percentage of landscape and landscape shape index mostly signifying disaggregated growth of the urban areas.

Results show that the spatial signature of the same metric is different for different years and for different metrics. This could reveal temporal pattern as well as the spatial pattern in sixteen directions covering almost the entire study area, providing reliable and detailed information. The study successfully achieves the objectives of extracting quantitative information on spatial pattern in relation to distance and direction from a reference point and further analyzing the spatio-temporal gradient for land cover change. The consideration of a reference point could provide a consistent yardstick for comparing the spatial pattern for different metrics in different years. The overall result of the spatio-temporal gradient modeling in sixteen directions by using a number of parameters in the form of spatial metrics could reveal the pattern of urban growth over the study period.

The technique adopted in the present study provides the quantitative analysis of spatial pattern of urban development considering a number of parameters and gradient analysis linking the spatial information with the local areas. It made possible to compare changes in specific metrics and particular locations over the study period and thus provided quantitative information about the structure and pattern of urban growth at local landscape level instead of just averaging the metrics over the entire study area. Variation among the parameters or metrics could be assessed simultaneously using directional indices and therefore resulted in better understanding of the urban dynamics. The directional analysis of different spatial metrics could yield results that are not only unbiased but also require less manual interpretation and interference compared to other change detection techniques. The added information that this approach provides is the amount, location and pattern of change during the study period. By applying a moving window analysis over the entire study area, every local area could be assessed in terms of different metrics, representing the various aspects like the shape, size and regularity of urban growth.

Thus the contribution of this study proves that use of spatial metrics with gradient analysis with a directional approach is a valuable tool to find the urban growth trend that can be important for decision making. This study substantiates the importance of sixteen directional analysis at local landscape level to capture the changes over a temporal period in a precise and detailed manner involving growth at local level. This study can prove to be equally beneficial to compare urban development at different places in the same way as the comparison of the urban growth of a single city over time. A study by Seto and Fragkias (2005) successfully compare urban development in four cities, considering three buffer zones and a set of landscape pattern metrics. Similarly the present study can give a rigorous comparison between cities considering directional development and overall impact of urbanization.

Full spatial analysis like the change detection algorithms; provide precise location and amount of changes. But, since the changes are not same in all directions, over different time periods, gradient analysis provides quantitative information with respect to distance. Gradient analysis provides a consistent yardstick to compare changes in different directions linked with specific locations with respect to a reference point and also the temporal variation in the pattern of growth that can prove to be an important input for efficient decision making.

6.2. Recommendations

Since the present study, considering directional development and overall impact of urbanization over a period of time, in a single city gives a better understanding of the patterns of urban growth, further research to study the potential of this method in comparing the urban development at different places over a period of time can be done.

The study could reveal the spatial pattern of land cover change in terms of urban growth, which is a result of the urbanization process. The study could be extended to incorporate a more comprehensive framework to include the geographical, socio-economic and political considerations resulting in spatial pattern for different directions.

For gradient analysis, a window size of 500 m has been used in this study. Though there was an attempt made to compare the results of some of the metrics with 1000 m window also, to reveal maximum fluctuations, 500 m window provides better results as small changes can be recorded at this window size. A further analysis considering different window sizes with the directional approach can be studied and analysed.

The present study exudes a possibility that some important features may be missed out, when considering a larger study area due to an increasing space between axes. A possible solution to this could be to consider further subdivisions in the directional axes. Further research could be carried in this direction.

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