Quantitative measures of urban land cover change: The case of Sancaktepe district of Istanbul metropolitan city, Turkey

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by

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Abstract

Urban landscapes are complex systems, exhibiting a non-stationary temporal dynamics and complicated spatial heterogeneous land cover patterns. Thus, the characterisation and measurement is riddled with challenges to directly address the question of how patterns of urban development affect landscape dynamics. Based on a rapidly growing Sancaktepe district of Istanbul metropolitan city in Turkey, we tested how spatial or landscape metrics, derived from remotely sensed imagery and GIS data could provide objective information and useful descriptions of urban land cover change for urban planning purposes. Land cover data from classified satellite images of Landsat TM of 2002 and 2009 were used to analyse land cover changes, NDVI for spatial and temporal variation in biomass, landscape metrics for landscape configuration and composition (distribution, structure of discrete land cover classes on the landscape), the basic properties of a landscape mosaic. Key results indicate that the landscape pattern of Sancaktepe district underwent fundamental transition from bareland dominant landscape to built-up dominant landscape between 2002 to 2009. It was accompanied by the decline of vegetated land cover categories of forest and grassland, thus suggesting conversion of undeveloped land cover categories into developed land. The NDVI method also showed that the total amount of vegetation cover in Sancaktepe district declined over this period. Landscape metrics like number of patches, mean patch size, and total edge indicated that there was an increase in agglomeration of built-up patches while bareland showed fragmentation process which both attributed to densification and increase of unplanned urban development respectively in the study area. As a result, built-up showed high complexity in patch shape and irregular patterns, though bareland and forest showed irregularity patterns but became less complex in patch shapes, while grassland showed simple shapes and regular patterns as measured by Area Mean Weighted Shape index and Area Weighted Patch Fractal Dimension index. Landscape heterogeneity and evenness slightly decreased. It was concluded that landscape metrics are robust quantitative measures for analysing landscape composition and configuration change and also to monitor dynamic processes of agglomeration or coalescing, disintegrating and fragmentation of land cover patches. Consistent monitoring the direction, magnitude, distributions and patterns of urban land cover changes using the research methodology presented here could be useful and flexible framework for supporting urban planning and management purposes of a rapidly growing district like Sancaktepe in the Istanbul metropolitan city.

Key words: Land cover, change detection, NDVI, remote sensing, landscape metrics, landscape structure and composition, usability, grain size.

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Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWPFDI	Area Weighted Patch Fractal Dimension index
AWMSI	Area Mean Weighted Shape index
DEM	Digital Elevation Model
DN	Digital Number
EROS	Earth Resources Observation and Science
GIS	Geographical Information Systems
Ha	Hectares
ILWIS	Integrated Land and Water Information System (ILWIS
IMP	Istanbul Metropolitan Planning and Urban Design Centre
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared band
R	Red band
PCA	Principal Component Analysis
SPOT	Satellite Pour l'Observation de la Terre
SPSS	Statistical Package for Social Scientists
µm	micrometer
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
SHDI	Shannon’s diversity Index
SHEI	Shannon Evenness Index

Chapter one

1.1. Introduction

Processes of urban growth, urbanization and development across the world are changing urban landscapes, patterns and dynamics which results in a complex pattern of intermixed high and low-density built-up areas and fragmented patches (Forman 1995). Over half of the 6 billion people on Earth currently live in cities and metropolitan areas, up from just 5 per cent in 1900 (United Nations 2005). Henceforth, worldwide metropolitan cities are growing at unprecedented rates due to high population concentration and urban sprawl creating extensive mosaic of urban landscapes that are highly heterogeneous, spatially nested and hierarchically structured (Forman 1995). Urbanisation of the world's population and human modification of the environment are among the most visible, irreversible and rapid transformations of these changes. Throughout the past two centuries land cover changes associated with increasing urbanization have had impacts that resonate at local, regional, and even national scales (FAO & UNEP 2002; Berry 1990).

Changes in urban land cover patterns have significant implications and adverse impacts on urban environment. Potential social and economic impacts of changes in urban land cover and land use patterns include increased costs of providing public services, increased congestion and infrastructure pressure (Ludlow 2009). Potential ecological impacts include loss of habitat, fragmentation of habitat, degradation of air and water quality and alteration of the hydrological regime. Other ecological impacts of changes in urban land cover include loss of productive agricultural land and open spaces and increased fragmentation of forest biome, thereby diminishing the positive functions of the ecosystem. In most cases, changes in urban land cover generate large-scale patterns that have far-reaching impacts on communities, local and regional economies and the environment (Ludlow 2009).These changes affect the quality of life for hundreds of millions of people and should be managed to preserve or enhance the quality of life, and to ensure social, economic and environmental sustainability as enshrined in the UN Millennium Development Goals and UNCED Agenda 21 (Ludlow 2009).

The increasing awareness of the importance of sustainability in urban environment is also stimulating the improvement in the current knowledge of understanding and monitoring urban land cover change patterns (Turner 1987). However, before effective urban policies can be developed to respond to these demands, concerns and needs, better information, techniques and methods are required on how to quantify urban land cover in terms of type, magnitude, direction and extent of changes over time. In most cases, this requires and involves the ability to quantify the urban land cover change pattern using multi-temporal satellite data sets (Singh 1989). Satellite remote sensing technique has the capability of accessing both historical data and up-to-date imagery that can be analyzed at time intervals more frequently over a large geographical area and with less cost and less subjective interpretation due to the higher information content of multispectral data (Howarth and Boasson 1983; Ehlers et al. 1990; Jensen and Cowen 1999; Seto et al. 2000; Seto et al. 2002; Schneider et al. 2003). By providing a vast amount of data with continuous temporal and spatial coverage, remote sensing can therefore contribute to a successful means for monitoring urban land cover changes.

In addition, understanding urban land cover changes has traditionally involved computer-modeling approaches based on quite complex techniques such as hexagonal-packing models, general neural network models, agent based models, cellular automata and others which are either deterministic and stochastic (Forman 1995). Although the results of these computer and explanatory models are promising and find applications in urban planning practice, their empirical base is limited. Torrens et al. (2000) identified following weaknesses for traditional computer urban models: their centralized approach, a poor treatment of dynamics, weak attention to detail, shortcomings in usability, reduced flexibility, and a lack of realism in addressing the concerns of current urban planning, policy analysis and decision making.

However, spatial metrics are used in landscape ecology and some of them could be very useful for practical applications for quantifying and providing more detailed objective information about spatial and temporal changes in urban cover and growth patterns (Gustafson and Parker 1992). Spatial metrics are commonly used in landscape ecology, where they are known as landscape metrics (Gustafson and Parker 1992). The research seeks therefore to explore a set of spatial or landscape metrics that can be used in practical urban planning applications, which are not be too complicated or time consuming and the outcomes should be easy for planners, decision makers to understand and apply. It is also the expectation of this study that these techniques will help decision makers and urban planners in managing and planning cities and metropolitan areas that facing are rapid urban land cover change.

1.2. Background of urban development in Istanbul

The Istanbul metropolitan city in Turkey stretches both east and west direction from the southern shores of Bosporus. It is surrounded by the provinces of Tekirdag to the west, Kocaeli to the east and the Black Sea to the north, and the Sea of Marmara to the south. Urban development in Istanbul metropolitan city has been rapid in the recent years after highways were constructed towards the end of 1980s and also after the construction of the Trans European Motorway (TEM) and the second Bosporus Bridge as it facilitated accessibility (Torrens and Alberti 2000).

Since the 1950s, Turkey has experienced rapid industrialization and urbanization and Istanbul has been the main destination of influx of large scale rural to urban migrants. Due to continuous migration from other regions of Turkey to Istanbul metropolitan area, its population has increased rapidly (TUIK, 2007). Between 1950 and 2000, the city has grown by an average of 4.5% annually and according to the Turkish Statistical Institute data for the year 2000, Istanbul's population had exceeded 10 million (TUIK, 2007).

Istanbul has been the most preferred destination particularly due to large numbers of low skilled rural migrants who seek employment in various informal sectors and also by capital owners looking for a large scale cheap labour source and an extensive local market. The rapid growth of the city since the 1950s, due to rural migration, has affected urban spatial development and its structure is also constantly changing (IMP 2008).

Table 1.1 : **shows population growth rates of the city of Istanbul in the (1950-1970, and 1970-2000)**

Years	**Provincial population**	**Annual rate of increase(Provincial)**	**Urban population**	**Annual rate of increase (Urban)**
1950	1.166.477		1.002.085	
1955	1.533.822	5,6	1.297.372	5,3
1960	1.882.092	4,2	1.506.040	3,0
1965	2.293.823	4,0	1.792.071	3,5
1970	3.019.032	5,6	2.203.337	4,2
1975	3.904.588	5,3	2.648.006	3,7
1980	4.741.890	4,0	2.909.455	1,9
1985	5.842.985	4,3	5.560.908	13,8
1990	7.309.190	4,6	6.753.929	4,0
2000	10.018.735	3,2	9.085.599	3,0
Average		**4.4**		**4.5**

Source: DİE, Census 2000(TUIK 2007).

As a result of this significant transformation, it generates problems like inadequate transportation networks, illegal settlements development, increasing densities and congestion at the center, reduction of public and green space, dramatic change of land use and increasing lack of urban infrastructure like basic sewerage facilities especially in illegal settlements. Due to rapid urban growth of Istanbul, illegal or informal settlements have been assumed to have expanded and invaded the water resource basins, forests and high quality agricultural land (Torrens and Alberti 2000).

Meanwhile, a regulation in city planning of April 2008, divided Istanbul province into 39 municipal districts from 32 municipal districts, each of them has a local municipality elected by the people living in the neighborhoods belonging to that district (IMP 2008). The 39 municipal districts of Istanbul according to the beginning of 2008 with their populations are listed on the Appendix 1. There is a layered local governmental system that exists for the Istanbul metropolitan city: Greater Municipality and District Municipalities *(*see Figure 1.1*).* The Greater Istanbul Municipality authority is responsible for a coordinating function through the submission of the development Plans made by the District Municipalities. For instance the Istanbul Metropolitan Municipality authority is responsible for coordinating and controlling the activities of the municipal districts for instance selecting solid waste disposal sites, building and maintaining city roads and bridges providing burial facilities, operating a public transport system (IMP 2008).

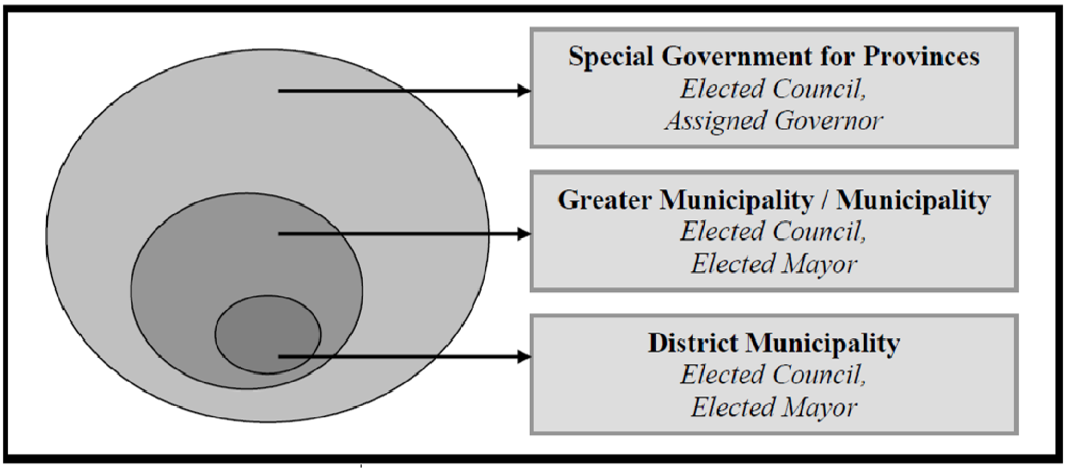


Figure 1.1: Local Governmental System (source IMP 2008)

1.2. 1. The case of Sancaktepe district

The Sancaktepe district was formed after merging Sarigazi, Samandira and Yenidogan regions to form a larger new region under Sancaktepe's name (IMP 2008). The district covers approximately 61.74 square kilometres of total surface area. It is located on the north of Asian side of Istanbul and had in 2008 an estimated population to be around 223 755. Fig 1.2 shows the location map of Sancaktepe district in Istanbul metropolitan area. On the bottom left corner of the map it is located on the UTM coordinate of 683784 meters East and 4535170 meters North. On the top right corner of the map it is on 698336 meters East and 4548175 North of the zone 35 UTM coordinate system. The climate is temperate which is located within a climatic transition zone between Black Sea and Mediterranean climates.

The large part of the district is situated on the Sancaktepe granitic pluton (Gr) which is a monzonite–monzonitic granite intrusion into the Paleozoic units during Hercynian orogeny (Ketin 1983). Generally the greater part of Sancaktepe district is on a low lying plain with the lowest elevation being around 57 meters above sea level. As shown on Fig 1.1, areas with high elevation are above 387 meters concentrated mainly in southern and northern part of the study area. In addition the slopes are gentle (0-8 degrees) as found in the greater part of the western side of the study area. Steep slopes

(19-40 degrees)   are mainly in the northern part while moderate slopes (8-13 degrees) are usually found north--eastern side of Sancaktepe district.

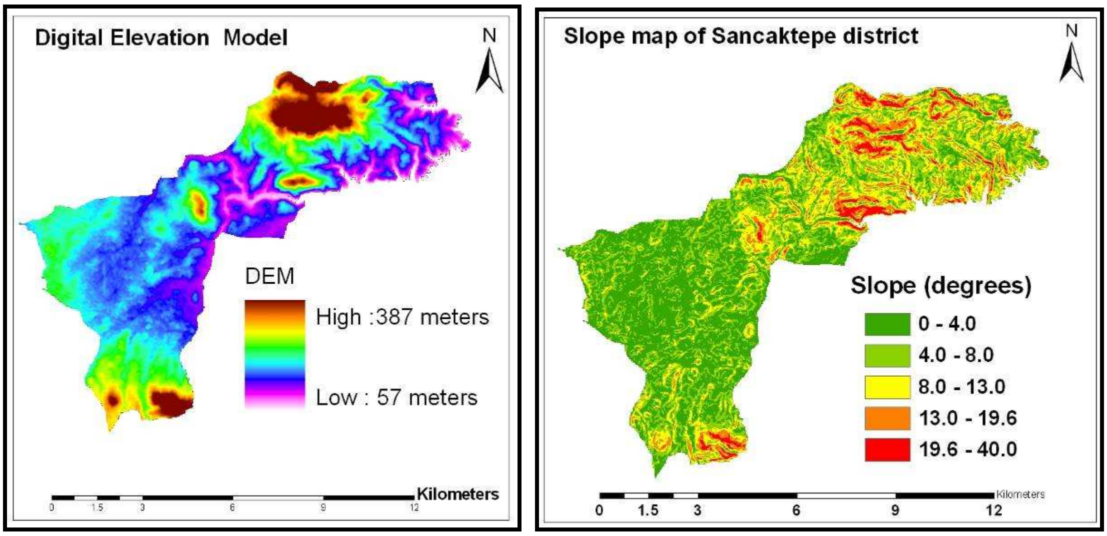


Figure 1.2 (a) the Digital elevation model (b) slope map of Sancaktepe district

Sancaktepe district was selected for this study because it is one of the fastest growing district (IMP 2008). Also, many new construction and urban development projects in this district are a signal to Sancaktepe's potential to become the next popular urban development centre in the Istanbul (IMP 2008). Conversion of undeveloped vacant or bareland to residential lands due to urban development may alter the landscape through a range of processes including fragmentation, isolating habitat patches, loss of productive agriculture land and open space.

Urban spatial development, growth and sprawl can overtime affect change in landscape configuration or spatial heterogeneity (i.e., form, structure, pattern of variation in land cover and land use) (Turner et al. 2001; McGarigal and Marks 1995; Herold et al. 2002). Like many other districts throughout Istanbul, sprawling and urban development have become important challenges facing Sancaktepe district in Istanbul (IMP 2008). Thus the Sancaktepe district presents a good case for studying spatial and temporal urban land-cover changes because of the period of general rapid settlement and urbanization in the region over the past years.

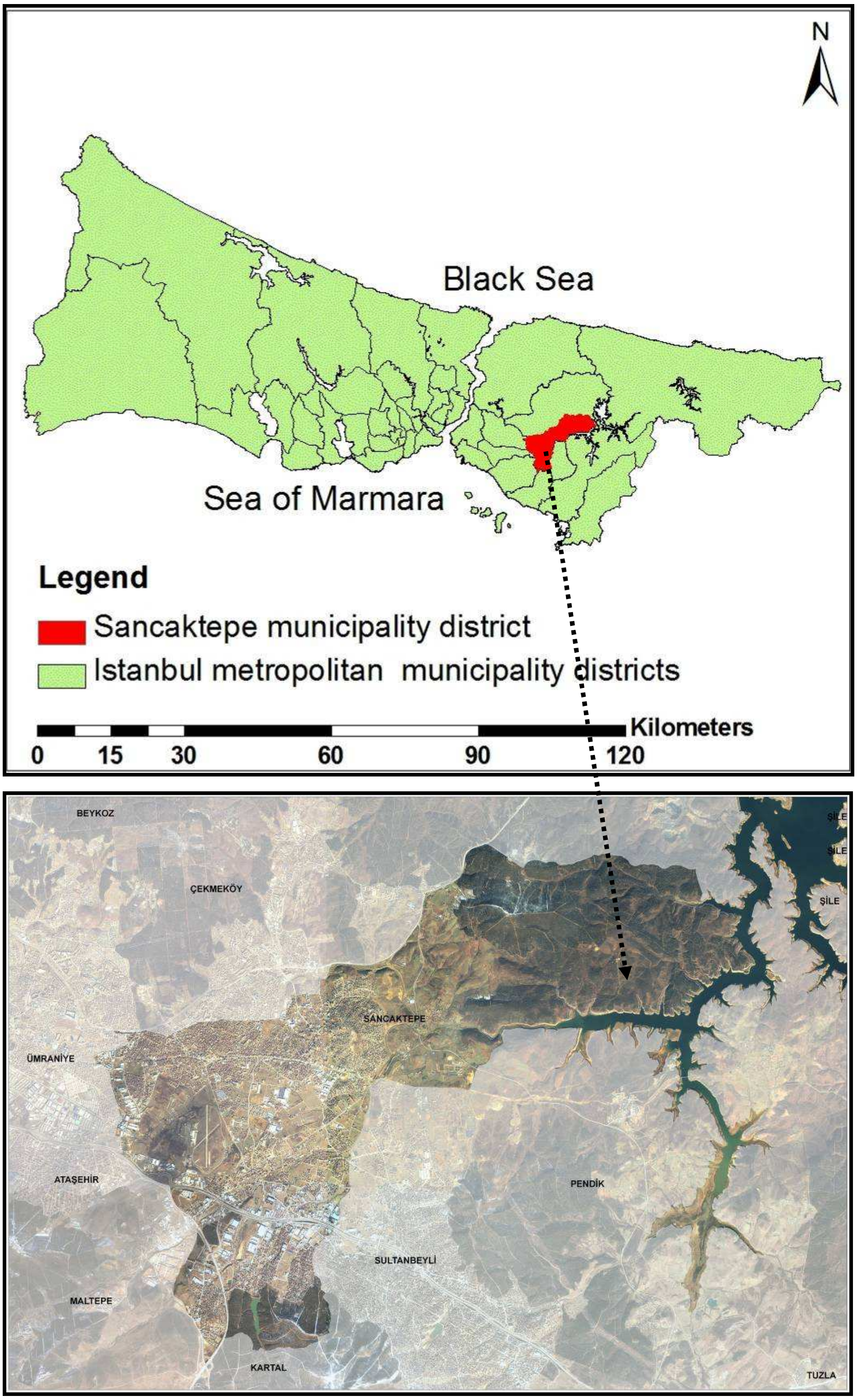


Figure 1.3. Location map of Sancaktepe district in Istanbul metropolitan area

1.3. Justification of the study

Understanding urban land cover dynamics is viewed as a major scientific and societal challenge in the effort to analyse and project local, regional and global change (Cihlar et el 2000; FAO and UNEP 2002). Urban land cover change can affect the ability of the land to sustain human activities through the provision of multiple ecosystem services and other resultant economic activities with feedbacks that affects many facets of local, regional and global change. More importantly, the need to quantify and monitor urban land cover changes is derived from multiple intersecting forces, including the physical climate, ecosystem health, and societal needs (Turner 1987). Economic development and population growth have triggered rapid changes to Earth's land cover over the last two decades, and there is every indication that the pace of these changes will accelerate in the future especially in metropolitan regions or cities (Ludlow 2009). Thus understanding and quantifying urban land cover patterns and its change is also fundamental for monitoring and assessing ecological and socioeconomic consequences or impacts that can be anticipated from current and future urban growth and urbanization.

Moreover, against the background of the current sustainable development debate there is an increasing demand for reliable and timely information about urban land cover change patterns and processes (FAO & UNEP 2002). In addition to quantifying and analyzing temporal and spatial urban land cover patterns, rates of change and trends, the research can also provide insight into how towns and metropolitan cities develop under varying social and economic conditions and also to identify the processes that affected its spatial development. Planners use urban land cover dynamics data to evaluate environmental impacts, to delineate urban growth boundaries or service areas, to develop land use zoning plans, and to gauge future infrastructure requirements and contribute to an understanding of urban sustainability. Urban land cover change data can also be used to generate alternative land suitability and predictions on the basis of different land use policies and environmental constraints.

Consistent and efficient characterization of the urban land cover change therefore provides the basis for urban planning and decision making, and facilitates the study of local and regional environmental processes in the broader context of global environmental change and the sustainability of cities and their hinterlands or fringe areas. Thus, the knowledge of these dynamics is required to develop policies related to sustainable urban development and decision-making on change.

1.4. Problem statement

The main issue of great importance in understanding areas in metropolitan cities experiencing urban growth includes spatial and temporal dynamics, spatial heterogeneity and land fragmentation associated with the urban land cover change. But lack of consistent, empirical and systematic historical urban land cover changes, trends and patterns detection, and a lack of clarity on what are the most appropriate and informative methods and indicators to measure them, pose a problem for the assessment of urban planning policies for metropolitan cities in many countries. The lack of systematic procedure or methods to update urban land cover changes has hindered many urban planning agencies and management programmes from keeping accurate and up-to-date spatial information and records. As a result of the absence of reliable and comparative spatio-temporal urban land cover change information and methods to measure them, important debates on urban policies continue to take place with little or not realistic data to support one policy or another.

Though remote sensing and Geographical information systems (GIS) techniques have been widely applied in providing the knowledge of where, how much, and what kind of land cover change has occurred, considerable uncertainty continues to exist in the scope of understanding urban land cover change patterns and processes. In particular, there is need for more informative methods for incorporating remote sensing and GIS data into the urban cover change detection. The problem analysis, planning and monitoring phases of a sustainable urban planning and management policy, thus require reliable, objective and timely information of urban land cover data on more regular updates. This research aims to determine the potential of spatial metrics to characterize spatial and temporal urban land cover change patterns for urban planning purposes.

1.5. Main Objective of the study

The main objective of the research is to determine how spatial metrics, derived from remotely sensed imagery and GIS data can provide objective information and useful descriptions of urban cover change for urban planning purposes.

1.5.1. Specific Objectives

(1) Determine and analyze trends and rates of land cover change in the study area between 2002 and 2009

(2) To measure vegetation cover change in the study area between 2002 and 2009 using NDVI

(3) Characterise the urban growth form or morphological patterns and landscape fragmentation (and spatial heterogeneity) patterns that have occurred using spatial metrics indices

(4) To assess the usability of spatial metrics in the study area for urban planning purposes

1.5.2. Research questions

The research attempts to answer the following questions:

Objective 1 Land cover change trends

How can we determine and quantify accurate land cover change types, magnitude, direction using Landsat TM data of 2002 and 2009?

Which land cover types in the study area experienced a decrease and increase between 2002 and 2009?

What is the magnitude of change for each land cover type that experienced conversion between 2002 and 2009?

Objective 2 Vegetation cover change

Is there evidence of vegetation cover loss due to urban growth change between 2002 and 2009?

Which areas experienced a decrease and decrease of vegetation cover between 2002 and 2009?

Objective 3 Urban forms or morphological patterns and landscape fragmentation change

What landscape metrics indices can we use to characterise and quantify urban forms, morphological patterns and landscape fragmentation change patterns of study area?

Which land cover types experienced landscape agglomeration and coalescence between 2002 and 2009?

Which land cover types experienced landscape dispersal, scattering and fragmentation between 2002 and 2009?

How do the landscape indices behave with variation in remote sensing spatial resolution (changing grain size) of IKONOS image?

Objective 4 Usability of spatial metrics for urban planning

Determine, where, how and which spatial metrics can most effectively assist in urban planning efforts?

What is the relevance of spatial metrics in the urban planning context?

How could spatial metrics help to complement existing change detection techniques in urban land cover change and growth?

1.5.3. Hypothesis

Remote sensing data can be used to derive estimates of the extent of urban land cover changes.

There is a significant difference between the mean NDVI of 2002 and 2009.

Spatial metrics can provide detailed and objective measures of the spatial structure and patterns of urban land cover change.

1.5.4. Expected Results

Maps of urban land cover changes of the Sancaktepe district.

To convey how the progress of urbanization results in changes to the landscape patterns for the study area.

Demonstrate the utility to monitor urban landscape change on a regular time frame using satellite data.

Demonstrate the utility of remotely sensed data, GIS and spatial metrics to successfully map changing urban land cover patterns and structures for Sancaktepe district.

Chapter Two: Literature Review

This chapter starts by giving a brief summary of main general approaches to land cover change detection using multi-temporal satellite data. The next section of this chapter discusses the potential and utility of using remotely sensed NDVI for accurately detecting vegetation cover change at local, regional and global scale. Previous and current trends in use of different quantitative methods as indicators of urban form or morphology patterns are elaborated. This is followed by discussion of the theoretical conceptual framework, definition and levels of landscape pattern metrics, brief examples of their application in urban landscape change and the relevance in urban planning are given. The last section of the chapter reviews general approaches of conducting usability testing procedures of method, technique, software or prototype.

2.1. Land Cover Change Detection Approaches

There are two main general approaches to change detection: (1) comparative analysis of independently produced classifications and (2) simultaneous analysis of multi-temporal satellite data (Singh 1989). Examples of the simultaneous analysis techniques include image differencing, image ratioing (Howarth and Wickware 1981) and Principal Component Analysis (Ribed and Lopez 1995). Singh (1989) provides a good discussion of the strengths and weaknesses of these approaches.

However, the most common technique for detecting change is the comparison of land cover classifications from two dates. The use of independently produced classifications has the advantage of compensating for varied atmospheric and phenological conditions between dates, or even the use of different sensors between dates, because each classification is independently produced and mapped to a common thematic reference (Gordon 1980; Stow et al. 1980; Singh 1989). The method has however, been criticized, because it tends to compound any errors that may have occurred in the two initial classifications (Gordon 1980; Singh 1989). The image differencing procedure has been widely used for a variety of land cover change investigations, including assessing deforestation (Massart et al.1995) and urbanization (Dimyati et al.1996).

The image differencing technique involves taking the mathematical difference between geo-registered images from two dates. The input data can be radiometrically calibrated raw imagery, or transformed data such as NDVI imagery. The procedure has been used for monitoring forest change (Vogelmann 1988) and detecting urban expansion (Jensen and Toll 1982). While often producing excellent results, it has been suggested that image differencing alone may be too simple a procedure to adequately describe many surface changes (Jensen and Toll 1982; Sohl 1999).

2.2. Remote sensing of urban land cover change

Determination of spatial and temporal urban land cover changes requires the systematic and consistent measurement and modelling (Herold et al 2005). Consistent long term observations from multiple satellite sensors sources have shown to be prerequisite for quantifying urban land cover change (Webster 1996; Jensen and Cowen 1999; Herold et al 2005).

Satellite remote sensing imagery for instance high-resolution data, as well as medium-resolution (MR) time series has proved to be an important data source for monitoring and modelling urban land cover change (Jensen and Cowen 1999). This is because satellite remote sensor data supply repetitive, consistent, and global measurements for process-related research and modelling, a relatively long time series of data acquisition which facilitates retrospective monitoring studies. These advantages have made satellite remote sensing the preferred choice for the timely production of geospatial datasets at local, regional to global scales that contain land cover information (FAO 2002).

Remote sensing data of high-resolution, medium-resolution (MR) as well as low resolution at different time interval can help in analysing the rate of land cover changes. Hence, it has a significant role in urban planning at different spatial and temporal scales. Thus, remote sensing can provide data needed to detect and measure a variety of elements relating to the morphology of cities, such as the amount, shape, density, textural form, and spread of urban areas (Mesev et al.1995; Webster 1996). Remote sensing data are especially important in areas of rapid land cover changes where the updating of information is tedious and time-consuming (Herold et al 2005). The spectral reflectance characteristics of earth surface materials can be used to quantify the spatial distribution of land cover.

Geographic Information System (GIS) is an integral part of developing spatially explicit methodology of urban land cover change (Clarke et al. 2002). In addition to providing an efficient means of storing spatially referenced urban land cover and other data, primary uses of GIS in this context include identifying spatial patterns of urban land cover or land use change. Given urban land cover data from two points in time, GIS can be used to derive a map of the land cover changes. Such a map in urban environment can be used to visually explore the pace; extent and pattern of land cover changes associated with urban growth or urbanization process and to identify “hot spot”, areas of particularly rapid change. In turn this pattern of urban land cover change can be visually compared with the spatial distribution of roads, zoning, public water and sewer, and other determinants of land use change to qualitatively explore the extent to which these factors influence land cover patterns.

2.3. Monitoring vegetation cover change using NDVI

Though many vegetative indices exist, the most widely used index is the Normalized Difference Vegetative Index (NDVI = (Near infrared band – Red band)/ (Near infrared band + Red)) to measure photosynthetic output or biomass, the amount of green vegetation in a pixel in a satellite image (Lillesand and Keifer 1972; 2000). It can be used to distinguish the differences between vegetation and non-vegetation land cover classes. The NDVI is a type of product known as a transformation, which is created by transforming raw image data into an entirely new image using mathematical formulas (or algorithms) to calculate the colour value of each pixel (Jensen 2005). This type of product is especially useful in multi-spectral remote sensing since transformations can be created that highlight relationships and differences in spectral intensity across multiple bands of the electromagnetic spectrum (Lillesand and Keifer 1972; 2000).

The NDVI, like most other vegetative indices, is calculated as a ratio between measured reflectivity in the red and near infrared portions of the electromagnetic spectrum (Jensen 2005). These two spectral bands are chosen because they are most affected by the absorption of chlorophyll in leafy green vegetation and by the density of green vegetation on the surface. Also, in red and near-infrared bands, the contrast between vegetation and soil is at a maximum. The Red and NIR images are obtained and used to calculate an NDVI value for each pixel. The NDVI equation produces values in the range of -1.0 to 1.0, the resulting index value is sensitive to the presence of vegetation on the Earth's land surface and can be used to address issues of vegetation type, amount, and condition. Vegetated areas will typically have values greater than zero and negative values indicate non-vegetated surface features such as water, barren, ice, snow, or clouds. Many satellites have sensors that measure the red and near-infrared spectral bands, and many variations on the NDVI exist.

Past researches have demonstrated the potential and utility of using NDVI to study vegetation dynamics for accurately detecting forest or vegetation cover change at local, regional and global level using for instance the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on board the Terra platform, and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on board both the Terra and Aqua platforms (Stefanov and Netzband 2005; Townshend and Justice 1986). Since NDVI is also strongly related to the extent of vegetation cover, it can therefore be used to detect land cover changes (e.g., forest replacement with built-up) and can also be used as an indicator of spatial heterogeneity in the landscape (Kerr and Ostrovysky 2003). Fernadez et al. (1997) used NDVI has been used to map surfaces affected by large forest fires.

Temporal NDVI data analysis using remote sensing data have largely focused on the Advanced Very High Resolution Radiometer (AVHRR) to detect land cover and biomass change on board the

National Oceanic and Atmospheric Administration (NOAA) meteorological satellites (Townshend and Justice 1986). The Advanced Very High Resolution Radiometer (AVHRR), is a 5 channel radiometer with channels in the red (channel 1) and near infrared (channel 2) potion of the spectrum data to monitor natural vegetation condition on regional and national level, identify deforestation in the tropics, and monitor areas undergoing desertification and drought. For example, the United States Geological Survey developed Land cover characterization dataset based primarily on the unsupervised classification of 1km AVHRR 10 day NDVI composites (Jensen 2005).

The AVHRR, however has a resolution that is much lower than the Landsat TM/ETM+ sensors. AVHRR NIR data is transmitted at a maximum resolution of 1 km, and the NDVI product is generally produced at an even further reduced resolution (usually 8 km) in favour of providing global or large scale coverage. The Landsat NDVI is produced at a resolution of 30 m, which offers far greater detail, though it is able to provide less aerial extent. Thus, the AVHRR data is more appropriate for creating frequent global NDVI products while the Landsat TM data are most useful for creating images with greater detail covering less area (Townshend and Justice 1986).

2.4. Quantitative research on patterns of urban form or morphology

Urban form can be defined by a number of quantifiable spatial characteristics, such as density, land use mix, and street network connectivity, compactness and sprawl (Chinitz 1965). Chinitz (1965) made some early attempts to quantify patterns of urban form by focusing on the growth of suburbs relative to central cities. Such studies have shown that suburbs especially in United States of America have grown and continue to grow more rapidly than the central cities they surround (Mills 1980). Such an attempt to measure urban growth form using density has been used to compare growth in urban populations with growth in urbanized land areas in attempts to identify the intensity of urban sprawl (Fulton et al. 2002).

Similarly, Tsai (2005) developed a set of quantitative variables to characterise urban forms at the metropolitan level and in particular, to distinguish compactness from ‘sprawl’. Four quantitative variables were used to measure four dimensions of urban form at the metropolitan level: metropolitan size, activity intensity, the degree that activities are evenly distributed, and the extent that high-density sub-areas are clustered. Another dimension used is the global Moran coefficient, to distinguish compactness from sprawl. It is high, intermediate and close to zero for monocentric, polycentric and decentralised sprawling forms respectively. In addition, the more there is more local sprawl, composed of discontinuity and strip development, the lower is the Moran coefficient (Tsai 2005).

Complex measures of urban form were developed by Galster et al. (2001) by identifying eight dimensions of urban form: density, continuity, concentration, clustering, centrality, nuclearity, and proximity. For instance each dimension reflects spatial relationships among subsectors of the city, where subsectors are defined by one- or one-half mile grids. While the measures by Galster et al (2001) provide new and interesting information about urban form, they provide little information that can be used for public policy. It is often a quite difficult to imagine how and whether policy makers in involved in urban planning are concerned with ranking of cities in terms of dimensions like clustering and nuclearity.

In addition, Ewing et al (2002) created a sprawl index of urban form that combines six sets of variables that measure residential density, land use mix, development concentration and street network patterns to compute an overall measure of sprawl. Ewing et al (2002) created a sprawl index, considered policy relevant was tested in US counties in the largest 101 metropolitan areas. Quite essential is the fact that the sprawl index, provided information which can be used to compare the urban form of one geographic region to another that is, an index of which region sprawls the most. Moreover it is used to explore the influence of urban form on human behavior, human health, and environmental quality. That is, policy makers can use the index to inform zoning and subdivision regulations that control density, street network connectivity, and the location of schools, road infrastructure and services areas. However, like previous measures, the index by Ewing et al (2002) is geographically coarse. That is, since the index is computed at the county and metropolitan level, it is unable to provide information on how urban form varies within counties and metropolitan areas and how urban form varies over time.

The exposition of fractal geometry by Mandelbrot (1983) provided a critical tool for the study of urban form, and since then a large body of literature has grown with an emphasis on the use of fractals to study these complex irregularities. Mandelbrot (1983) in his introduction of fractal geometry explained that most forms in nature do not conform to Euclidean geometry based on straight lines and smooth curves. The topological dimension of a point is zero, the topological dimension of a straight line is 1, and the topological dimension of a surface is 2. But the dimension of the edge of an irregular, fragmented object (such as the coastline of Britain) is a fraction somewhere between 1 and 2. Similarly mathematical modeling of fractal growth has been used to simulate and understand urban growth patterns (White and Engelen 1993; Andersson et a.l 2002a; Andersson et al. 2002b; Onural 1991; Batty et al.1994:1999). Makse et al. (1995: 1998) used correlated percolation simulation to produce a pattern similar to the growth of Berlin from 1850 through 1945.

Recently, Huang et al (2007) employed spatial or landscape metrics to describe urban form using dimensions like complexity, centrality, compactness, porosity and density for the 77 metropolitan areas in Asia, US, Europe, Latin America and Australia. The result demonstrated that spatial metrics or landscape metrics were able to capture the urban agglomerations of developing world which showed distinct patterns that are more compact and dense than either in Europe or North America. In addition there have been wide range of studies in the application of landscape metrics studies for not only urban form change but also landscape change in rural and urban environments (Herold et al. 2002). This is because landscape or spatial metrics describe various properties of the spatial heterogeneity and configuration of land cover in a given area (Turner et al. 1989 ; 2001)

2.5. Landscape Pattern Metrics

The terms spatial or landscape metrics' refers exclusively to indices developed for categorical maps (McGarigal and Marks1995). Landscape metrics were developed in the late 1980s and incorporated measures from both information theory and fractal geometry based on a categorical, patch-based representation of a landscape (Mandelbrot 1983; Shannon & Weaver 1964). Gustafson 1998) stated that although a large part of landscape pattern analysis deals with the identification of scale and intensity of pattern, spatial or landscape metrics are focused on the characterization of the geometric and spatial properties of categorical map patterns represented at a single scale (grain and extent).

2.5.1. Patches and Patchiness (Spatial heterogeneity) and Levels of Landscape Metrics

Patches form the building blocks for categorical maps (McGarigal and Marks 1995). In most applications, once patches have been established, within-patch heterogeneity is ignored. Landscape metrics instead focus on the spatial character and distribution of patches. While individual patches possess relatively few fundamental spatial characteristics (e.g. size, perimeter, and shape), collections of patches may have a variety of aggregate properties, depending on whether the aggregation is over a single class (patch type) or multiple classes (McGarigal and Marks 1995). Landscape metrics may be defined at three levels (McGarigal and Marks 1995; O'Neill *et al*, 1988).

(1) patch-level metrics

Patch-level metrics are defined for individual patches, and characterize the spatial character and context of patches. McGarigal and Marks (1995) argues that patches represents relatively discrete areas (spatial) or periods (temporal) of relatively homogonous environmental conditions that are perceived by or relevant to the organism or ecological phenomenon under consideration for instance the geographical extent type of vegetation within a larger forest that contains several species of plant. In an urban environment the concept of patches can be used to represent discrete areas of land cover (an urban forest) and land uses (single family residential) either for ecological and social economical processes (Barnsley and Barr 1997; Forman 1995; Turner et al. 2001).

(2) Class-level metrics

Class-level metrics are integrated over all the patches of a given type. These may be integrated by simple averaging, or through some sort of weighted-averaging scheme that biases estimate to reflect the greater contribution of large patches to the overall index (DiBari 2007).

(3) Landscape level metrics

Landscape-level metrics are integrated over all patch types or classes over the full extent of the data (i.e. the entire landscape). Like class metrics, these may be integrated by a simple or weighted averaging, or may reflect aggregate properties of the patch mosaic (McGarigal and Marks 1995:2002). It is important to note that while most metrics at higher levels are derived from patch-level attributes, not all metrics are defined at all levels (McGarigal and Marks 1995). In particular, collections of patches at the class and landscape level have aggregate properties that are undefined at lower levels. McGarigal and Marks (1995) and O'Neill et al (1988) noted that the fact that most high-level metrics are derived from the same patch-level attributes has the further implication that many of the metrics are correlated.

2.6. Spatial landscape configuration and composition

Turner (1989) and Turner et al. (2001) stated that metrics of landscape patterns aim to measure two major characteristics of the landscape that its composition and spatial configuration.

2.6.1. Landscape composition

Landscape composition refers to the presence and amount of different patch types within the landscape, without explicitly describing its spatial features, placement, or location of patches within the mosaic (McGarigal and Marks 2002). Since landscape composition requires integration over all patch types, landscape composition metrics are only applicable at the landscape-level. There are many quantitative measures of landscape composition, including the proportion of the landscape in each patch type, patch richness, patch evenness, and patch diversity. For instance landscape composition is assessed using metrics such as landscape diversity, Shannon Weaver diversity and Shannon Evenness Index (McGarigal et al. 2002).

2.6.2. Spatial configuration

Landscape configuration refers to the spatial distribution of patches within the class or landscape and this basically means the specific spatial arrangement of different land cover types on a landscape. (Turner et al. 2001; McGarigal and Marks 2002). Some of the components of landscape configuration are (1) patches, (2) edges, (3) probability of adjacency, and (4) patch contagion (McGarigal et al. 2002). Other aspects of configuration, such as shape and core area, are measures of the spatial character of the patches. Spatial configuration also can be quantified in terms of the spatial relationship of patches and patch types (e.g., nearest-neighbour, contagion) (McGarigal et al. 2002).

These metrics are spatially explicit at the class or landscape level because the relative location of individual patches within the patch mosaic is represented in some way. For example, perimeter-area and fractal dimension are measure of shape complexity (Mandelbrot 1983) that can be computed for each patch and then averaged for the class or landscape, or it can be computed from the class or landscape as a whole by regressing the logarithm of patch perimeter on the logarithm of patch area. Figure 2.1 provides the conceptual framework of landscape metrics while Table 2. I. provides specific description and general overview of the common landscape metrics indices based on the description by McGarigal et al. (2002) and on Herold and Clarke (2003).

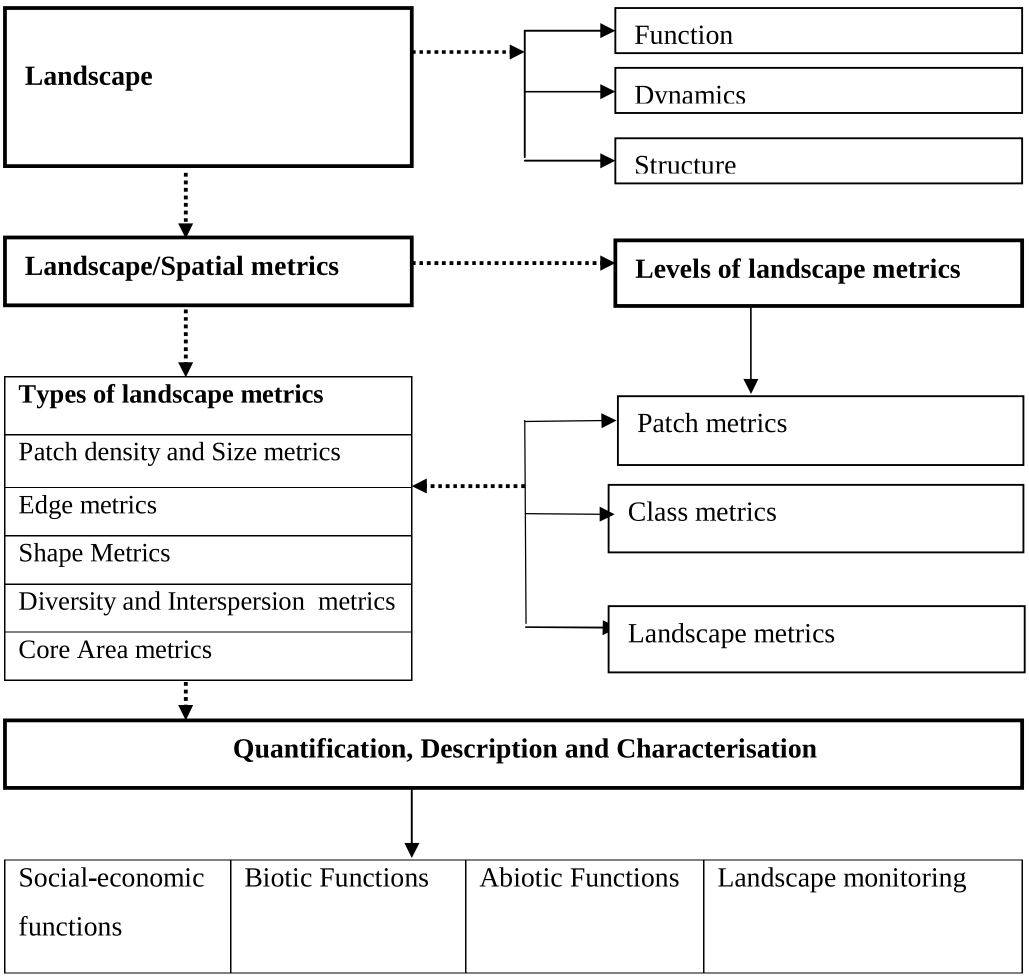


Figure 2.1 The conceptual framework of landscape metrics (Source:Lausch and Herzog 2002)

Table 2. I. Description of the spatial metrics(source: McGarigal et al. 2002 and Herold et. al 2003).

Landscape metrics (unit)	**Description**	**Units**
CA (Class area ;)	sum of areas of all patches belonging to a given class, in map units	(ha)
NP	Number of patches	
MPS	Mean patch size; the average patch size within a particular land cover class	(ha)
PERCLAND (per cent)	Per cent of landscape PLAND equals the sum of the areas (m2) of a specific land cover class divided by total landscape area, multiplied by 100.	Percent
LPI (per cent) Largest patch index	LPI equals the area (m2) of the largest patch of the corresponding class divided by total area covered by that class (m2), multiplied by 100 (to convert to a percentage	Percent
PD Patch density;	PD equals the number of patches of a specific land cover class divided by total landscape area	Numbers per 100 ha
PSCV (per cent)	Patch size coefficient of variation	
AWMSI	Area-weighted mean shape index, the average perimeter-to-area ratio for a class, weighted by the size of its patches	
AREA_SD - Area standard deviation	AREA_SD equals the standard deviation in size of the patches of a land cover class.	Hectares
ED - Edge density	ED equals the sum of the lengths (m) of all edge segments involving a specific class, divided by the total landscape area (m2) multiplied by 10000 (to convert to hectares).	Meters per hectare
ENN_MN - Euclidian mean nearest neighbour distance	ENN_MN equals the distance (m) mean value over all patches of a class to the nearest neighbouring patch based on shortest edge-to-edge distance from cell center to cell center	Meters
ENN_SD - Euclidian nearest neighbour distance standard deviation	ENN_SD equals the standard deviation in Euclidian mean nearest neighbour distance of land cover class	Meters
FRAC-AM - Area weighted mean patch fractal dimension	Area weighted mean value of the fractal dimension values of all patches of a land cover class, the fractal dimension of a patch equals 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m2); the perimeter is adjusted to correct for the raster bias in perimeter.	None
FRAC-SD - Fractal dimension standard deviation	FRAC_SD equals the standard deviation in fractal dimension of land cover class.	None
COHESION	Cohesion is proportional to the area-weighted mean	Percent

	perimeter area ratio divided by the area-weighted mean patch shape Index (i.e., standardized perimeter-area ratio).	
CONTAG - Contagion	CONTAG measures the overall probability that a cell of a patch type is adjacent to cells of the same type	Percent

2.7. Use of spatial metrics for urban land cover analysis

Since landscape or spatial metrics describe various properties of the spatial heterogeneity and configuration of land cover in a given area (Turner et al. 1989 ; Turner et al. 2001), they provide a quantitative approach for studying urban land cover change through the measurement of spatial and temporal variations in these metrics (Herold et al. 2002).While they were originally developed for landscape ecological research, recent studies have indicated their potential for the analysis of urban environments in understanding and inferring the processes involved in the spatial distribution of urban land cover and the patterns created (Herzog and Lausch 2001; Herold et al. 2005).

Spatial metrics have been used in the urban environment for modelling urban structure and related dynamics of spatial and temporal change and growth processes (Alberti and Waddell 2000; Barnsley and Barr 2000; Bauer and Steinnocher 2000; Herold et al. 2002). This is because spatial or landscape metrics can measure the various aspects of the land cover and land use pattern, including composition (e.g. diversity, dominance etc.), spatial configuration (e.g. density, size, shape, edge, connectivity, fractal dimension) and spatial neighbourhood (e.g. heterogeneity and contagion) of the landscape. The area-weighted mean patch fractal dimension index (AWMPFDI) and contagion index (CI) were used by Torrens (2006) to measure urban sprawl. Patch size and patch shape indices have been widely used to convey meaningful information on biophysically changed phenomena associated with patch fragmentation at a large scale (Herold et al. 2002).These configuration indices usually correlate with the basic parameter of individual patch, such as the area, perimeter, or perimeter–area ratio (Gustafson and Parker 1992).

Heterogeneity-based spatial metrics indices were also developed to quantify the spatial structures and organization within the landscape (Turner 1987; Forman 1995). The dominance and contagion indices were first developed on the basis of the information theory to capture major features of spatial pattern throughout the eastern United States (O'Neill 1988). The proximity index quantifies the spatial context of patches in relation to their neighbours (Gustafson and Parker 1992). For example, the nearest-neighbour distance index distinguishes isolated distributions of small patches from the complex cluster configuration of larger patches (Turner 1987). These measures can be used to discern the extent to which the landscape is becoming more or less fragmented over time. In addition they offer much promise as practical tools for quantifying the spatial heterogeneity of the urban landscape and help predict the ecological effects of urban sprawl. Such an analysis can aid in informing public officials and the public about the nature and consequences of land cover or landscape change over time. For instance the extent to which urban sprawl has evolved in a particular region (Alberti and Waddell 2000).

Studies by Seto and Fragkias (2005) have shown that landscape metrics helps to improve understanding of the shape and trajectories of urban expansion. This study used landscape metrics like area, number, edge density, mean size, patch fractal dimension, and patch variation to analyze spatio-temporal patterns of urban land use change associated with four cities in the Pearl River Delta in China. Although the choice of indices relies on the emphasis of a specific research, it is preferred to adopt groups of indices when modelling a spatial pattern because landscape pattern possesses both homogeneous and heterogeneous attributes (Barnsley and Barr 1997; Turner and Gardner, 1991; Forman 1995; Farina 2000; 2006; Turner et al. 2001).

2.8. Usability testing procedure of a method

Usability testing is the capability of the method to be understood learned, used and attractive to the user, when used under specified conditions (ISO 1993). The phrase "when used under specified conditions" (equivalent to "context of use" in ISO 9241-11) was added to make it clear that a product has no intrinsic usability, only a capability to be used in a particular context for instance urban planning and management. There are several ways to measure the usability of a method.

Shackel (1990) refers to four aspects of interest in usability testing: learnability (easy of learn), throughout, flexibility, and attitude. Rubin (1994) accepts that usability includes one or more of the four factors outlined by Booth (1989): usefulness, effectiveness (ease of use), learnability, and attitude (likeability). Smith and Mayes (1996) notes that usability focuses on three aspects: easy to learn, easy to use and user satisfaction in using the system. International Organization for Standardization (ISO9241-11) identified three usability measures, which include effectiveness, efficiency and satisfaction (ISO 1993). Usability testing methods involve assessing the method’s ability to meet user’s performance (effectiveness and efficiency) and satisfaction objectives.

Table 2.2. Usability measures from literature (ISO 1993)

Effectiveness	Measures the ability of the system in meeting the intended goal by looking at how the system assists the user to accurate and correctly complete the tasks
Efficiency	Observes time and effort required to accomplish particular task by the user
Satisfaction	Relates directly to users attitude when using the system. Looks on how the system is acceptable by the user with regard to comfortability felt in using it.

2.8.1. Usability evaluation and test methods

Preece (1993) discusses common usability evaluation methods like observational evaluation and survey evaluation. These different methods imply different types of evaluators, different number of users, and different types of data to be collected.

2.8.1.1. Observational evaluation

This method implies collecting data that provide information about what users do when interacting with a method, software or prototype. It involves visiting one or more users in their work place. Several data collection techniques may be used. According to Preece (1993) two broad categories of data may be obtained: how users tackled the tasks given, where the major difficulties lie and what can be done; and performance measures like frequency of correct task completion, task timing, and frequency of participant errors.

2.8.1.2. Surveys

Surveys are employed to know users' opinions or to understand their preferences about an existing or potential method or product through the use of interviews or questionnaires. The interview is one way of collecting data in a survey. Interviews can be structured (sequence of predetermined questions with no exploration of individual attitudes) or flexible (it has some topics and develops in response to the interviewees' replies).

The other way to collect data in a survey is through questionnaires. There are two types of questionnaires: open ended questionnaire (the respondent provides his/her own answer) and closed questionnaire (the respondent selects the answer from a choice of alternative replies). Questionnaires, which are a more common approach for usability testing, are useful for studying how end users use the system and their preferred features, but need some experience to design (Holzinger 2005). Questionnaires are considered an indirect method, since they do not study the actual user interface; rather it only collects the opinions of the users about the interface.

Chapter Three: Research Methods

This chapter presents a general research methodology of how the remotely sensed image data acquired were pre-processed and how the image classification processing were carried out to derive land cover maps from Landsat TM of 2002 and 2009. It is then followed by a discussion of post image classification refinement and accuracy assessment procedures performed on the derived land cover maps. Spatial Analysis methods used to measure and quantify land cover and vegetation cover change is then discussed. It is then followed by a discussion on how landscape metrics were selected to quantify landscape composition and configuration of the study area. The last section of this chapter presents a methodology used to measure usability of spatial metrics method during the fieldwork for urban planning purposes.

3.1. General approach and research design

The general approach of the research can be divided into three parts that is the pre-fieldwork, fieldwork and post work phase. The pre-fieldwork involved designing a research objectives and questions to answers the research problem conceived in the study area. To answer the specific objectives of the study, various kinds of data were required. Land cover and vegetation cover change detection required multi-temporal satellite data of different years. Ancillary data like air photographs and Google image were needed for accuracy assessment of classified images.

Landscape configuration and composition change in urban growth form, land cover fragmentation and spatial heterogeneity required classified land cover maps. Usability assessment of spatial metrics including carrying out interviews needed to be conducted in the fieldwork to collect relevant information in the study area. All the data collections were done during the fieldwork phase. Data analysis was a post fieldwork phase that was carried out in image processing and GIS software. Conclusion and recommendations about the findings then concludes the research design. Figure 3.1 gives a general conceptual framework of the research design of the research thesis.

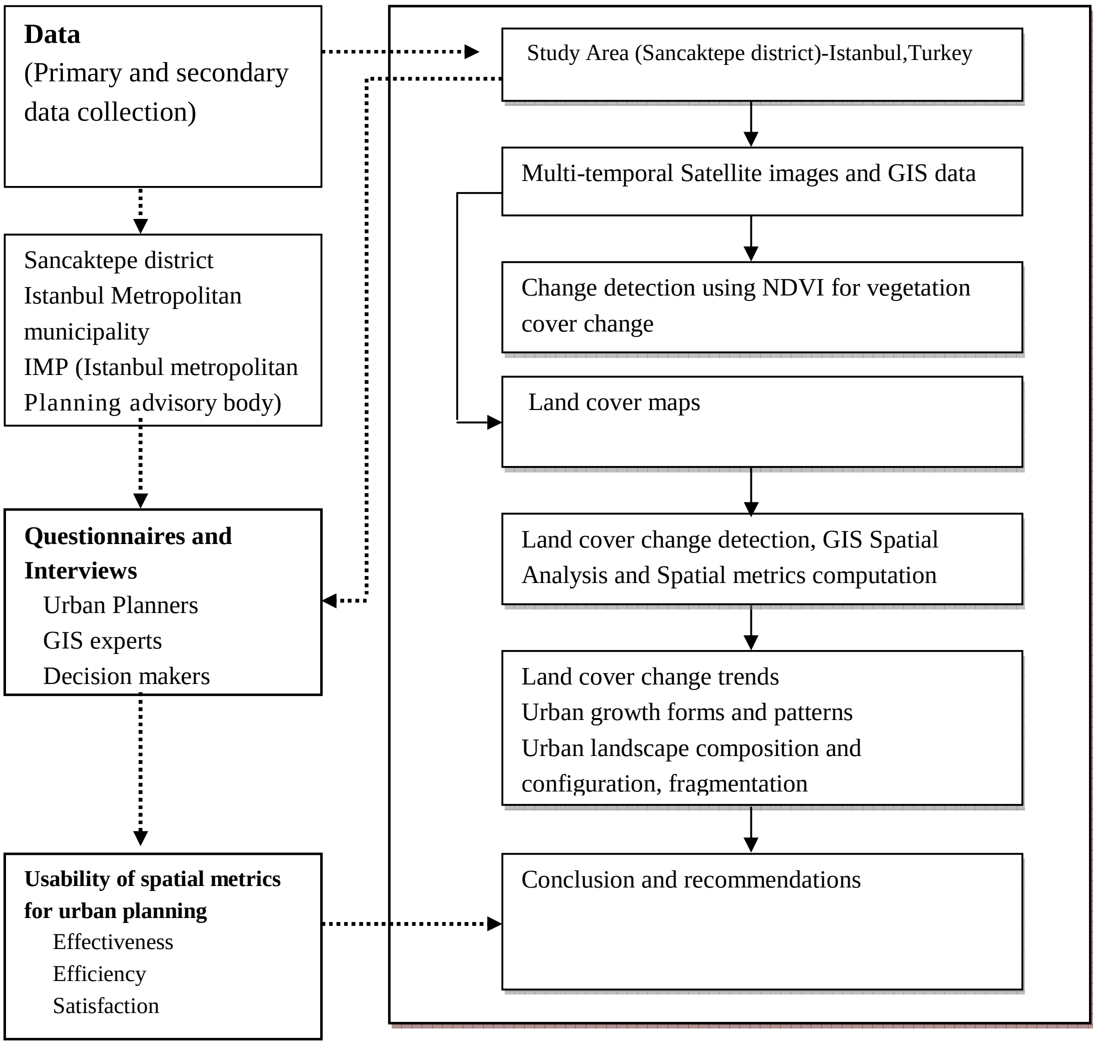


Figure 3.1. The general conceptual framework of the research

3.2. Remote sensing data acquistion

The Landsat Thematic Mapper (TM) images of 2002 and 2009 were downloaded from USGS's Earth Resources Observation and Science (EROS) Center (**http://glovis.usgs.gov/).** The IKONOS remotely sensed images of June 2008 were acquired from Istanbul Metropolitan Planning and Urban Design Centre (IMP) during the field work campaign between 12 September 2009 to 3 October 2009. The characteristics of the of satellite image data acquired are shown on table 3.1.The IKONOS 2008 data was used to determine the effects of changing spatial resolution on landscape metrics. For the urban land cover change detection analysis in Sancaktepe district, Landsat TM images were used and the month of June was selected as this is a dry season in the study area in all the remotely sensed data acquired to ensure that detected changes are not due to seasonal and phenological differences. In addition, it is easier to distinguish different land cover types for instance forest, grassland from bareland or fallow croplands in the dry season than the wet season. Furthermore change detection methods like NDVI performs better in accurately estimating biomass abundance in the dry season since high NDVI values are expected for natural vegetation and lower NDVI values are expected for bareland.

Table 3. 1. Characteristics of satellite image data

Satellite Data Type	Spatial resolution	Acquisition date	Path/row
Landsat TM	30 meters	2002/6/14	181/31
Landsat TM	30 meters	2009/6/17	181/31
IKONOS	Im (pan sharpened)	June 2008	181/31

As shown on Table 3.1 and Table 3.2, the Landsat Thematic Mapper data have a spatial resolution of 30 meters, and seven spectral bands that simultaneously record reflected or emitted radiation from the Earth's surface in the blue-green (band 1), green (band 2), red (band 3), near-infrared (band 4), Middle Infrared (band 5), and the thermal or far-infrared (band 6) and Short-wave infrared (band7) portions of the electromagnetic spectrum. Therefore, urban land cover change detection can be generated using the Landsat TM data at different scales of regional and local level due to high information content of its multispectral bands of the electromagnetic spectrum. However, the 30 meter spatial resolution of the Landsat TM data allows only general land cover change detection but not detailed as compared to high resolution images like, IKONOS with 4 meter spatial resolution and 3 to 5 days off-nadir and 144 days for true-nadir revisit rate.

However, data from these commercial sensors like IKONOS and Quick bird are costly compared to government-operated sensors (Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper) since they are limited in both spatial and temporal coverage and also spectral coverage is also limited to the visible and near infrared wavelengths (Jensen 2005). Data from the USGS's Earth Resources Observation and Science center (EROS) satellite-based instruments offers an opportunity to collect high spectral and temporal resolution relevant information for urban environments and applications. For instance the 16 days revisit time of Landsat TM make it easier also to find multi-temporal Landsat TM data for change detection analysis between different years and or seasons to analyse land cover and vegetation cover changes for urban landscapes which requires consistent monitoring and measurement.

Table 3.2. Satellite image spectral bands characteristics

Satellite Data Type	**Spectral Range**	**Band name**
Landsat Thematic Mapper		
Band 1	0.45-0.52 micrometers	blue
Band 2	0.52-0.60 micrometers	green
Band 3	0.63-0.69 micrometers	red
Band 4	0.77-0.90 micrometers	Near Infrared
Band 5	1.55-1.75 micrometers	Middle Infrared
Band 6	10.40-12.50 micrometers	Thermal Infrared
Band 7	2.09-2.35 micrometers	Short-wave Infrared
IKONOS satellite		
Panchromatic	450 - 900 nanometers	(Pan) **Black and white**
Band 1	445 - 516 nanometers	(Blue)
Band 2	506 – 595 nanometers	(Green)
Band 3	632 - 698 nanometers	(Red)
Band 4-	757 - 853 nanometers	(Near Infrared)

3.2. Satellite image data processing procedures

Satellite image pre-processing commonly comprises a series of sequential operations, including geometric registration, atmospheric correction or normalization. Accuracy assessment and filtering of the classified images are post classification methods procedures done after image classification. Pre-processing of satellite images prior to image classification is essential for change detection. The following procedures were undertaken in the image processing software of Erdas Imagine to derive land cover data.

3.2.1. Geometric Registration

The satellite images were orthorectified to the UTM coordinate system using nearest–neighbour resampling method and projected to the World Geodetic System 1984 (WGS84). Geometric rectification of the imagery resamples or changes the pixel grid to fit that of a map projection. This becomes especially important when scene to scene comparisons of individual pixels in applications such as change detection are being sought. The images acquired were then digitally processed in Erdas Imagine software to get land cover maps. Figure 3.2 shows the procedures undertaken to derive the land cover maps.

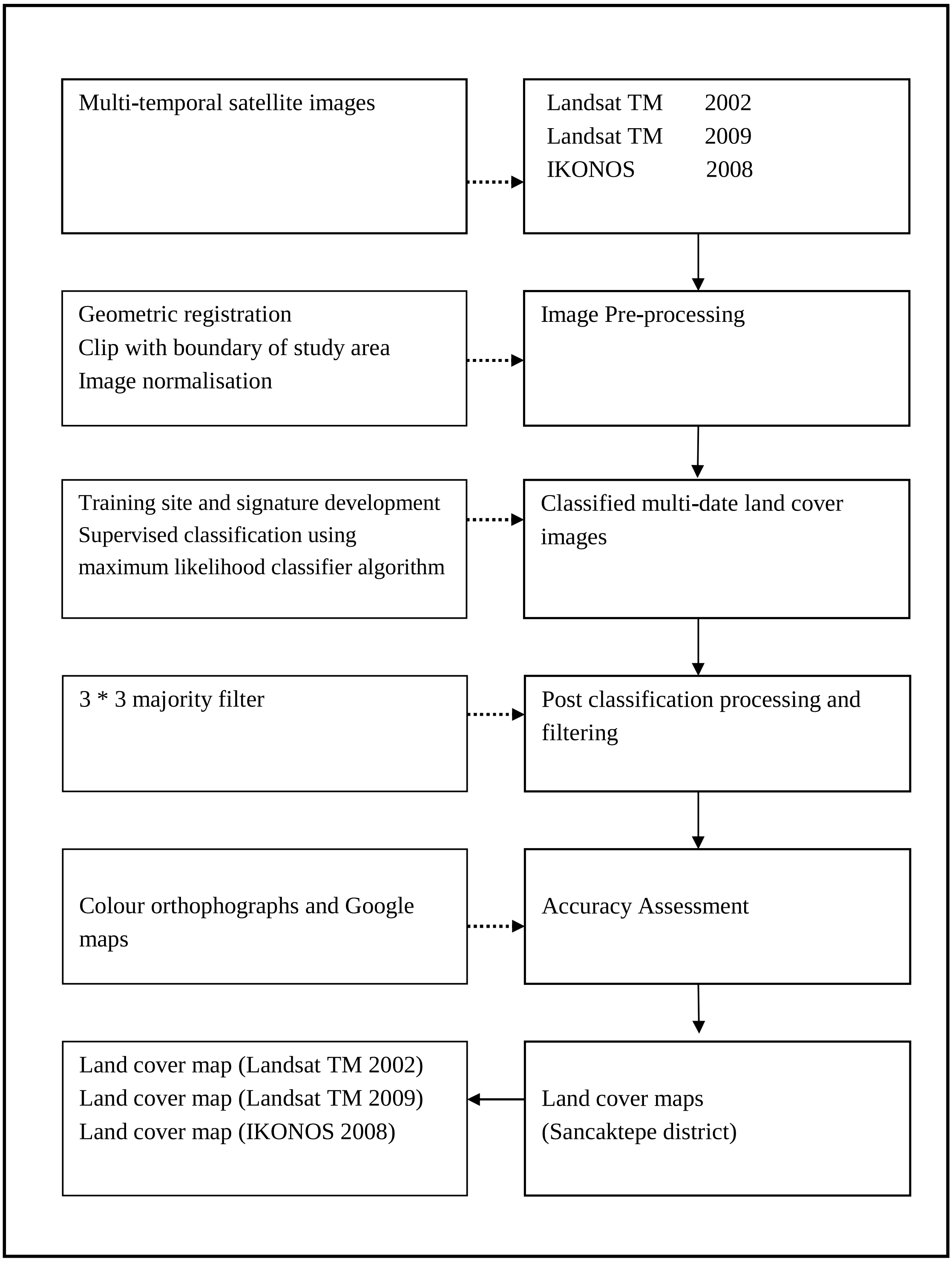


Figure 3.2. Flow chart showing the steps undertaken in the satellite image processing to derive to derive land cover maps.

3.2.2. Image normalization using regression

The satellite data were rescaled to the range of 0–255 in order to facilitate data handing in the image processing software. The image normalization was performed to minimize pixel Digital Number (DN) variation caused by non-surface factors so that variations in pixel brightness value between dates could be related to actual changes in surface conditions (Jensen 2005). It was assumed that the multiple dates of remotely sensed data were acquired with varying sun angle, atmospheric, and soil moisture conditions. Relative radiometric correction of the two images was done using the regression method based on pseudo invariant objects (features with stable reflectances) such as water bodies, airstrips and roads identifiable in the images.

A set of theses pixel samples of features with stable reflectances (pseudo invariant objects) were then used to develop a linear fit equation for normalizing the Landsat TM spectral radiances of 17 June 2009 relative to Landsat TM spectral radiances for 14 June 2002 as shown on figure 3.3. Then the coefficients and intercept of the equation were used to compute a normalized image with the reference image (17 June 2009). The method is widely used to improve the fidelity of the brightness value magnitudes by reducing the influence of errors or inconsistencies in image brightness values for change detection in digital remotely sensed images (Jensen 2005). This also ensures that changes in spectral radiances for corresponding pixels of a multi-temporal image sequence are proportional to actual changes in spectral reflectance of the surface.

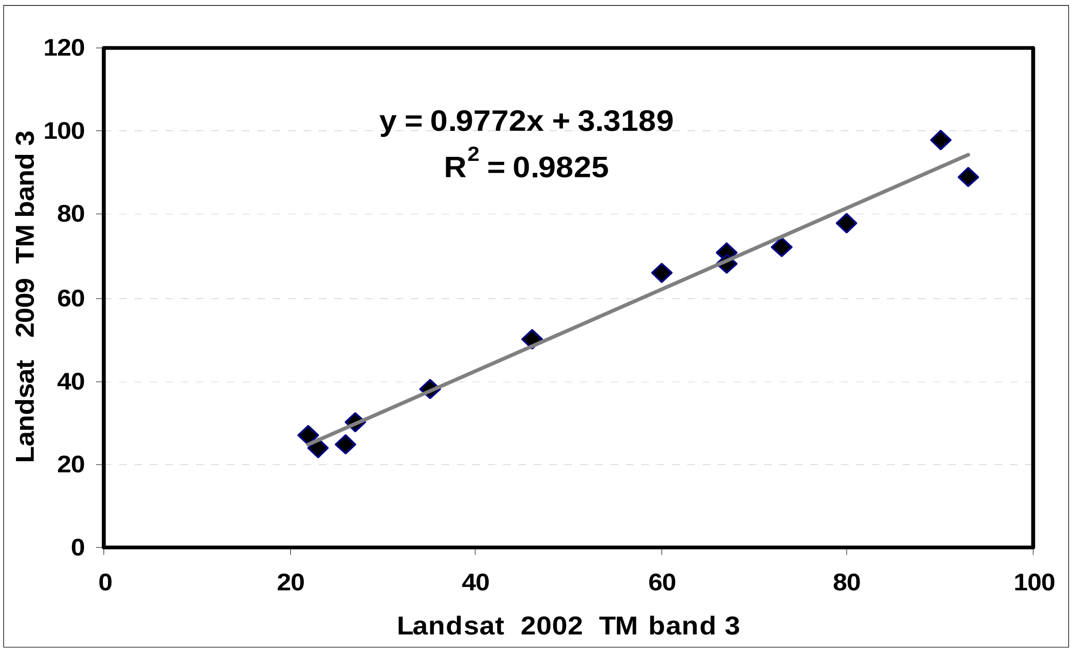


Figure 3.3 Relationship between the DN values of sampled pseudo invariant objects between the Landsat TM bands 3 of 14 June 2002 and 17 June 2009.

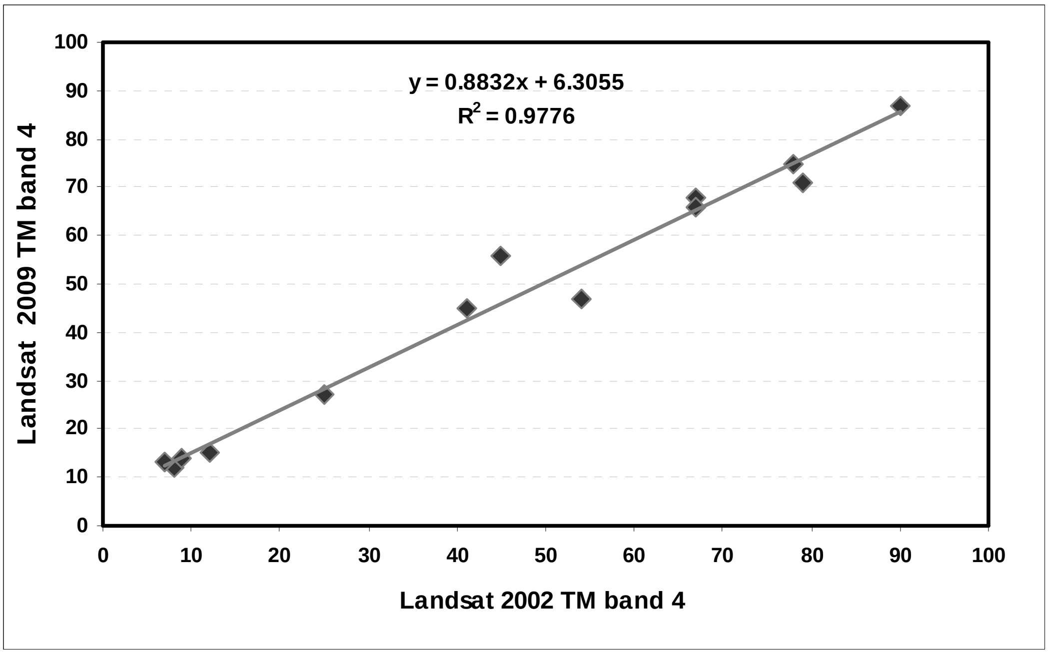


Figure 3.4. Relationship between the DN values of sampled pseudo invariant objects between the Landsat TM bands 4 of 14 June 2002 and 17 June 2009.

3.3. Image classification

To enhance accurate image classification, each training site was evaluated graphically to determine their spectral response patterns in Erdas imagine as shown on figure 3.2. This was done to ensure that sufficient signature separation and the signature generated of different spectral classes from each training site has a high probability of being correctly classified (Lillesand & Kiefer 2000). As depicted on both graphs of 14 June 2002 and 17 June 2009 Landsat TM images, forest and grassland showed high spectral reflectance in near infra red but low spectral reflectance in the visible bands, the reflectance of built and bareland increases with increasing wavelength from visible to near infrared, while for water the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases from the blue to red bands (channels).

Also the two graphs reveals that the spectral signatures of some land cover classes like built areas and bareland appeared similar at some spectral bands (Landsat band 1 and 2) though they were separable at some spectral bands (Landsat band 4). The Landsat thermal band (band 6) was not used in generating spectral reflectance of different land covert types and subsequently in supervised image classification due to its different spatial resolution as compared with other bands. The Landsat thermal band (band 6) has spatial resolution 120 m compared to others six Landsat TM bands with a spatial resolution of 30 m.

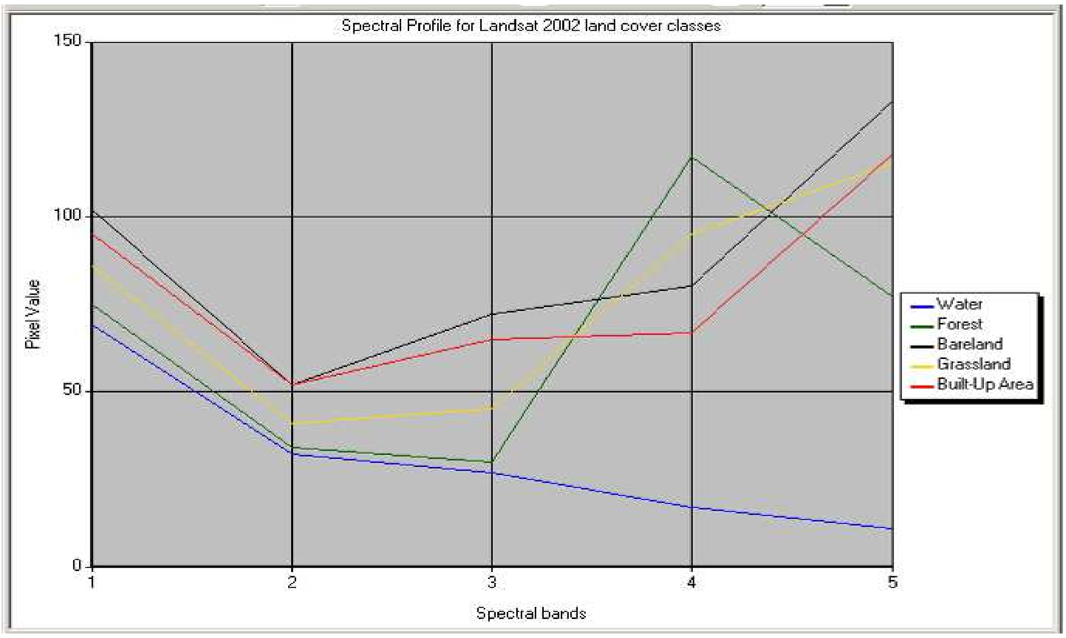


Figure 3.5. Spectral profile for 14 June Landsat 2002 Thematic Mapper land cover classes

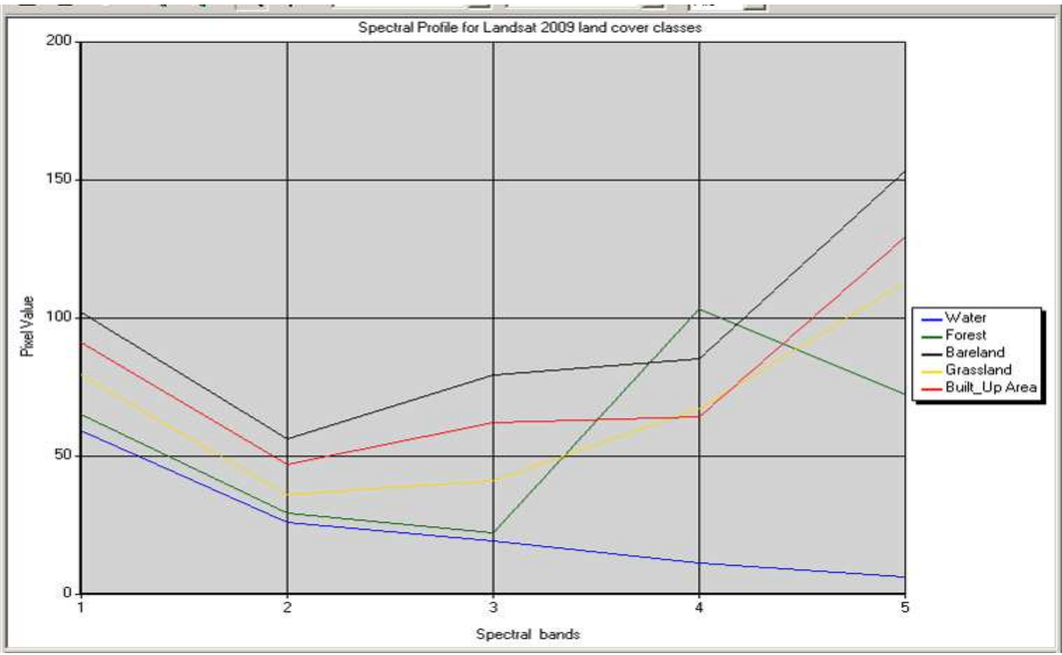


Figure 3.6. Spectral profile for 17 June Landsat 2009 Thematic Mapper land cover classes

In additional false colour composites were used in order to distinguish thematic land cover of interest on the images. For instance the false colour composite scheme using bands 4(near infrared), 3(red), 2 (green) on Landsat TM allowed distinction of different land cover types as vegetation appeared in different shades of red, water appears dark-bluish, bare soils buildings appeared in a cyan colour on the image as shown on Figure 3.7 (a) and (b).

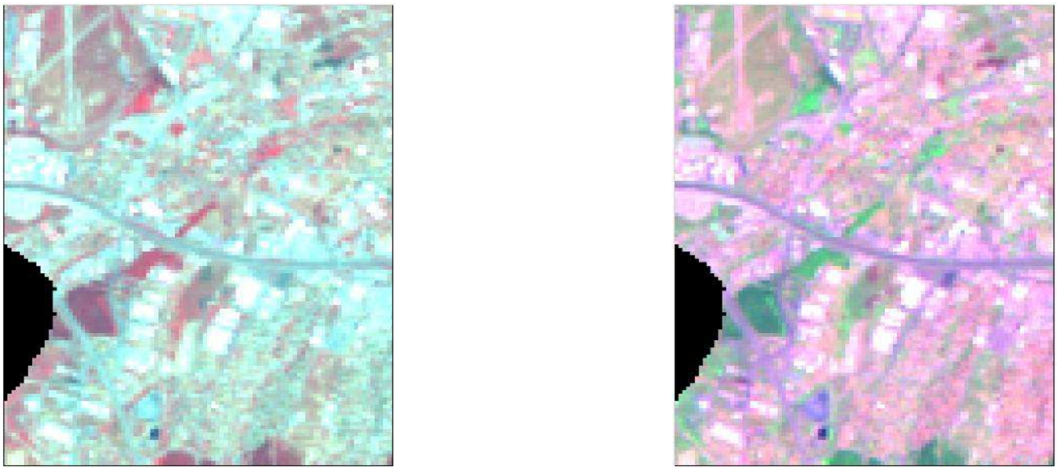


Figure 3.7. (a) Landsat band 4, 3, 2 colour composite (b) Landsat band 7, 4, 2 colour composite

During signature development a two-dimensional scatter plots, in the form of feature class ellipses, were also calculated from the means and standard deviations derived from the range of pixel values in each training site in two different image data (e.g Landsat TM Band 2 and 4) combinations. Sample locations were then selected on each acquired image to seed polygons as signatures of land cover classes on-screen in Erdas Imagine 9.3 software. Each sample location was grown into an area of relatively spectrally homogeneous values using Erdas Imagine's Area Of Interest function. The satellite images were then classified in Erdas Imagine 9.3 software using the maximum likelihood algorithm to derive land covers thematic classes of interest that is forest, built-up area, water, and bareland and grassland (see description of land cover classification scheme in appendix 2). A majority filter with 3 x 3 window size was applied to remove the noise in the classified images.

3.4. Accuracy assessment

The classified images were compared to the reference data to asses the accuracy of classification process. Colour orthophotographs and the Google earth maps were used as ground reference data for accuracy assessment of the image classification process. Test sites across the five land cover classes were selected randomly as ground reference data from current high resolution imagery (4m) in Google earth for accuracy assessment of the classified images 17 June 2009 and June IKONOS 2008 while colour orthophotographs of 2003 were used for 14 June 2002. The overall accuracy, producer's accuracy (error of omissions), user's accuracy (error of commissions), and kappa coefficient were calculated for each classified image as shown in table in appendix 3. The overall classification accuracy for June 2008 IKONOS was 91.92% with Overall Kappa Statistics of 89.71%. The high accuracy reached on the IKONOS image can be explained by high detailed resolution of data which accurately discriminate or separate different land categories. However, the overall classification accuracy for 17 June 2002 Landsat TM image was 80% with Overall Kappa Statistics = 0.75%. For

14 June 2009 Landsat TM image, the overall classification accuracy was 86.7% with the Overall Kappa Statistics of 82% (see appendix 3). Low producer's accuracy and user's accuracy of certain land cover types was attributed to spectrally mixed pixels indicating limitations in detailed urban mapping and change detection with data at a coarse spatial resolution. For instance grassland in both years had low producer's accuracy which was attributed to the larger variability and overlapping with some land cover types like bareland and forest due to their spectral similarity at certain reflectance channels or bands.

3. 5. Land cover changes and rates analyses

A cross tabulation technique was used to identify land cover conversions between 2002 and 2009 in Integrated Land and Water Information System (ILWIS) software. This was after the 2002 and 2009 classified images were exported to ILWIS GIS as **IMG** file format from Erdas image software. This allowed contingency matrices to be generated which showed the transitions and conversion of one land cover class to another in terms of number of pixels which were then converted into hectares. A spatial analyst method in ArcGIS and also image difference helped to detect the type of change whether it was decrease, increase or no change in the land cover between 2002 and 2009.

3.6. Vegetation cover change detection

Vegetation cover was estimated from a remotely sensed Normalized Difference Vegetation Index (NDVI) from each date of image acquisition (14 June 2002 Landsat TM and 17 June 2009 Landsat TM) of the study area. The **NDVI** was calculated from these Landsat TM images by using the combinations of bands 3 (0.63-0.69 micrometer) and 4 (0.76-0.90 micrometer).

$$\mathbf{NDVI} = \frac{\mathbf{NIR - RED}}{\mathbf{NIR + RED}} = \frac{\mathbf{[(B4-B3)]}}{\mathbf{[(B4+B3)]}}$$

Where NIR is the reflectance or radiance in a near infrared channel (0.78–0.90 micrometer) and RED is the reflectance or radiance in a red visible channel (0.63–0.69 micrometer) on a Landsat TM.

In order to identify areas in Sancaktepe district that experienced a decrease, increase or no change in vegetation cover from 2002 to 2009, an NDVI image difference method was performed for each year of analysis, that is subtracting the remotely sensed NDVI of 17 June 2009 from the remotely sensed NDVI of 14 June 2002. The NDVI image differencing method was performed in Erdas Imagine and resulted in maps which showed areas of decrease, increase, some decrease, some increase and no change of NDVI observed between 2002 to 2009. To better correlate NDVI values with individual land cover classes, an intersection (cross) method in Integrated Land and Water Information System (ILWIS) was performed by crossing the NDVI images with the classified land cover maps of the same year. This method distinguished the vegetated (forest and grassland) and non-vegetated surfaces (bareland, water and built-up) in the district whether they had low or high NDVI values.

3.7. Statistical Analysis

The Statistical Package for Social Scientist (SPSS) was used in the exploratory data analysis to test the normality of NDVI data of 2002 and 2009 and in the confirmatory data analysis to test the statistical significance of independent samples of the mean NDVI values of 2002 and 2009.

3.8. Change in urban growth and land cover fragmentation patterns

Landscape metrics computations were performed on the classified land cover maps of 2002 and 2009 using Patch Analyst, an extension to the ArcView GIS 3.3 software that accepts vector polygon GIS data or raster-based image data as input. The selection of the metrics was based on their value in measuring and quantifying landscape characteristics to get meaningful insight into urban spatial structure changes of the evolving urban growth dynamics, land cover spatial heterogeneity and fragmentation between 2002 and 2009. Literature from McGarigal et al. (2002) and Herold et al. (2002) were the major basis and guidance used for selection of certain metrics used in this study. Moreover few metrics were selected since many of these indices are highly inter-correlated (Riitters et al. 1995). Two groups of metrics were computed in this study: (1) class-level metrics (each patch type (class) in the given mosaic) and (2) landscape-level metrics(the landscape mosaic as a whole).The class and landscape level metrics used in this study captures both landscape composition and configuration (structure). As for landscape structure, metrics on the number, shape and size of patches were investigated and quantified as described below.

3.8.1. Quantifying change in landscape configuration

(1) Number of Patches

Number of Patches metric was used to measure of the extent fragmentation of patch type or each land class. NP is the total number of patches of the same type. A land cover or landscape with a high number of patches is considered more fragmented while land cover or landscape with a low number of patches is considered less fragmented.

(2) Mean Patch Size (MPS)

Mean Patch Size (MPS) can serve as a fragmentation index and was used to measure the land fragmentation that could have taken place between 2002 and 2009 in Sancaktepe district. It is often calculated separately for each cover type as follows:

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10000}\right)$$

Thus, MPS equals the sum of the areas 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) (McGarigal and Marks 1995). A land cover or landscape with a smaller mean patch size for the target patch type than another land cover or landscape might be considered more fragmented. Similarly, within a single landscape, a patch type with a smaller mean patch size might be considered more fragmented.

(3) Total Edge

Total edge (TE) was used to measure the land cover fragmentation that could have taken place between 2002 and 2009.It is an absolute measure of total edge length of a particular patch type (class level) or of all patch types (landscape level). Increase in total edge indicates more fragmentation.

(4) Perimeter-to-area ratio (m/ha)

Perimeter-area ratio was used for measuring the complexity of the shapes of patches between 2002 and 2009 at class level. It is also closely related with concepts of aggregation or contagion. Thus it is an expression of the spatial heterogeneity of a landscape mosaic. It is calculated as follows;

$$\frac{P}{2\sqrt{(A\,\Pi)}}$$

Where P = perimeter and A = area. Holding the area constant, as shape complexity increases, the perimeter-area ratio increases, the patch, class, or entire patch mosaic (landscape) becomes increasingly disaggregated (i.e., less contagious). Hence this statistic is also a good measure of fragmentation among patch type.

(5) Area-weighted mean shape index

Area-weighted mean shape index (AWMSI) was used to measure the urban morphology of the district in terms of the irregularity in patch shape between 2002 and 2009. The area-weighted mean shape index is the sum, across all patches, of each patch perimeter divided by the square root of patch area, adjusted by a constant for a square standard, multiplied by the patch area and divided by the total landscape area. To formulate, for $i = 1\ldots$ **fc** patch types (land cover categories) and **j** $= 1\ldots$ **ni** patches within type i, let pij and aij equal the perimeter and area, respectively, for the j^{th} patch of the i^{th} type. Then,

$$\text{AWMSI} = \sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(\frac{0.25p_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{A}\right)$$

The AWMSI provides an average shape index of patches, weighted by patch area so that large patches are weighted higher than smaller ones. The patch shapes become more irregular as AWMSI increases above 1. Because larger patches tend to be more complex than smaller patches, this has the effect of determining patch complexity independent of its size.

(6) Area-weighted mean patch fractal dimension

Area-weighted mean patch fractal dimension (**AWMPFD**) was another metric used to analyze the built-up compactness and land cover fragmentation changes that occurred between 2002 and 2009. Since the AWMPFD averages the fractal dimensions of all patches by weighting larger land cover patches, this metric is also good measure of class patch fragmentation because the structure of smaller patches is often determined more by image pixel size than by characteristics of natural or manmade features found in the landscape. AWMPFD is formulated as follows:

$$\mathrm{AWMPFD} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} \left(\frac{2\log(0.25 p_{ij})}{\log a_{ij}} \right) \left(\frac{a_{ij}}{A} \right)$$

m = Number of patch types (classes)
n = Number of patches of a class
p(ij) = Perimeter of patch **ij**,
a(ij) = Area of patch
ij, A = Total landscape area.

Fractal dimensions varies from 1, which indicates relatively simple shapes such as squares, to , 2 which indicates more complex and convoluted shapes. Low values are derived when a patch has a compact rectangular form with a relatively small perimeter relative to the area. If the patches are more complex and fragmented, the perimeter increases and yields a higher fractal dimension. Fractal dimensions measure the degree of shape complexity.

3.8.2. Quantifying change in landscape composition

To measure landscape composition, the Shannon Diversity Index and the Shannon Evenness Index were used. Shannon Diversity Index and the Shannon Evenness index are robust measures of landscape composition since they measure the presence and amount of different patch types within the landscape, without explicitly describing its spatial features and they are not affected by the spatial configuration of patches.

(1) Shannon evenness Index

Shannon evenness was chosen to characterize the land cover distribution of area among patch types, and is simply the Shannon entropy of the land cover proportions divided by the maximum attainable entropy. Therefore, for **i** = 1… **A**; land cover types and ***Pi*** equals the proportion of data pixels in the landscape that are categorized as type **i**,

$$\mathrm{SHEI} = \frac{-\sum_{i=1}^{k} P_i \log P_i}{\log(k)}$$

and as SHEI approaches 0 from above, the landscape is increasingly dominated by particular land cover types, whereas as SHEI approaches 1 from below, the distribution of land cover types becomes increasingly more even.

(2) Shannon diversity Index

The Shannon Diversity Index was used to measure the degree of diversity of the landscape.

It is calculated as follows:

$$SHDI = -\sum_{i=1}^{m} \left(P_i \ln P_i\right)$$

m = number of classes,
Pi **=** percentage of the landscape occupied by class **i**

It is zero when there is only one patch in the landscape and increases with the number of patch types and as the proportional distribution of patch types increases.

3.8.3. The response of changing grain size (spatial resolution) on landscape metrics

The spatial resolution of Im panshapened IKONOS 2008 classified image of five classes of bareland, built, water, forest and grassland was resampled beginning with 5m, 10m, 20m to 30m using resample tool in ArcGIS. The class metrics of number of patches, mean patch size, area weighted mean shape index, area weighted fractal dimension, total edge were then calculated using the Patch Analyst extension in Arc View to detect their response for each changing grain size of 5m, 10m, 20m to 30m.

3.9. The Usability assessment of the spatial metrics

This section presents a research methodology used to explore the usability and the potential role of spatial or landscape metrics in assisting urban planners who are involved in urban planning in Istanbul. The basic tentative assumption was that, spatial or landscape metrics can be a potential useful tool in urban planning activities to current urban planners and practitioners if they became aware of its functionality and relevance, which can eventually increase usability will, in turn, increase its applicability in urban planning practice. To test the hypothesis various techniques of data collection were designed and a fieldwork was conducted between 12 September to 2 October 2009 in Istanbul to get the perspectives of urban planner about the subject.

3.9.1. Data collection techniques used to determine usability

1. Focus group discussions were conducted with urban planners at the department of Urban Planning at the Istanbul Metropolitan Planning and Urban Design Centre (IMP), which is the main urban planning advisory body of Istanbul metropolitan city. One of the reason of using focus group discussion is that is relatively easy, affordable and can be quickly assessed and some issues and misconceptions can be clarified during the group discussions. Information was solicited from the 8 participants who were drawn from department of urban planning of IMP's views on the knowledge and awareness of the subject being investigated, their understanding of the pitfalls and capabilities of methods they are currently using and to what extent have these methods been successful in achieving their planning goals with satisfaction, efficiency and effectiveness desired.

2. **Interviews** with key informants. Relevant key informants were the head of urban planning at Istanbul Metropolitan Planning and Urban Design Centre (IMP), head of urban planning department and decision makers like the deputy mayor and mayor of the Sancaktepe district (see Figure 3.8.) During the meetings with these key informants the aim of the research was presented and a dialogue established. This provided valuable information on whether policy makers involved in urban planning are concerned with methods like landscape metrics. Using examples of printed articles of application of landscape metrics from literature from authors like Herold et al. (2005) on how spatial metrics can refine urban planning efforts, various application roles of landscape metrics in urban planning could be further appreciated by the key informants.

3. **Questionnaire survey** was a quantitative data collection method and the advantages of using questionnaires include the easy identification of subjective user preferences, satisfaction and the ability to use them for compiling statistics (Holzinger 2005). During the fieldwork conducted in Istanbul, questionnaires were sent mainly to urban planners and some GIS experts involved in the urban planning process. These were urban planners and some GIS experts drawn from Department of Remote sensing and GIS department, Department of Urban Planning at the Istanbul Metropolitan Planning and Urban Design Centre (IMP), the urban planning department of Istanbul metropolitan authority and at the Sancaktepe municipality district in Istanbul as shown on table 3.3.

17 people responded to the open ended and closed questionnaire (Appendix 4) by filling answers and expressing their opinions. Out of many usability elements, efficiency, effectiveness, and user satisfaction were selected to be used in this research. Since it was assumed before fieldwork that urban planners in Istanbul were using different methods, respondents were required to rate their overall satisfaction, efficiency and effectiveness when using their existing quantitative methods on a scale of 1 to 5 with 1 being the lowest and 5 being the highest score. Respondents would look at different questions listed on the questionnaire and indicate their degree of agreement with each item. Secondly the respondents were also asked whether they had knowledge in the application of landscape or spatial metrics in urban planning in one of the open ended question in the questionnaire.

Table 3.3. The respondents who were drawn from different departments in Istanbul

Name of the Department	**The main Organisation**	**Target group**	**Number of Respondents**
Department of Urban Planning	Istanbul metropolitan authority (Asian and European side)	Urban Planners	6
Department of Urban Planning	Istanbul Metropolitan Planning and Urban Design Centre (IMP)	Urban Planners	7
Department of GIS and Remote Sensing	Istanbul Metropolitan Planning and Urban Design Centre (IMP)	GIS and Remote sensing experts	2
Department of Urban Planning	Sancaktepe district (Municipality district)	Urban planners	2
Mayor’s Office	Sancaktepe district (Municipality district)	The Mayor and Deputy mayor of Sancaktepe district	2

Figure 3.8. Photographs showing some of people contacted during the fieldwork interviews and in Istanbul

Chapter Four: Findings and Discussions

The first part of this chapter presents results and discussion of spatial and temporal change of land cover that occurred between 2002 and 2009 in Sancaktepe district, which are visually illustrated with maps, graphs and table of statistics. It is then followed by discussion of results of vegetation cover change using NDVI method. Change in spatial pattern of urban growth form, Patch shape complexity, land cover fragmentation, landscape composition then complete the change detection of urban landscape change which was quantified by using different combination of selected landscape metrics.

4.1. Results of land cover change between 2002 and 2009

Table 4.1 and figure 4.1 and 4.2, shows that Sancaktepe district experienced urban expansion from 2002 to 2009 since there was about 50% increase in the built–up areas at the expense of bareland which decreased by almost 24% (2893 hectares in 2002 to 2204 hectares in 2009).

Table 4.1 land cover change between 2002 and 2009

Year	Classified Landsat TM image 2002	Classified Landsat TM image 2009		
Land cover class	**Total area (hectares)**	**Total area (hectares)**	**Amount of change (ha)**	**Percentage change**
Built-up	1601	2395	794	50
Bareland	2893	2204	689	-24
Forest	1554	1518	36	-2.3
Grassland	110	47	63	-57
Water	7	10	3	43

The land cover maps on figure 4.2 (a) and (b) can illustrate that by 2009, Sancaktepe district was now dominated by built-up area (38.8% of the total of the study area), followed by bareland areas (35.7 of the total of the study area) which are adjacent to and sandwiched between built areas and forest areas (24.6% of the total of the study area). The urban expansion in Sancaktepe district has increased the pressure on the natural environment as they are occurring in vacant and undeveloped land like bareland areas. Figure 4.2 aslo illustrates that by 2009 most of the bareland areas of 2002 were converted into built-up areas.

In addition, the rapid urban expansion phenomenon experienced caused also the decline of forest and grassland areas, as grassland declined from 110 hectares in 2002 to 47 hectares in 2009 while forest declined from 1554 hectares in 2002 to 1518 hectares in 2009. However, some forest areas destroyed appeared to be located where they converged with settlements such as in the north part of Sancaktepe district. Figure 4.1 shows a photograph taken during the fieldwork in the north part of Sancaktepe district near the Omerli basin that illustrates human settlements and urban developments within the forest dominated area.

Figure 4.1. A photograph taken during the fieldwork that illustrates human settlements and urban developments within the forest dominated area.

Rapid population growth, existing high cost and shortage of land in the district may be responsible for the increase in urban expansion through densification of building structures and settlements and with the likely result of conversion of undeveloped land like barelands, forests and grassland to accommodate high population pressure increase in the district. These land cover changes, especially the increase in urban growth in the district, reflects the rapid urbanization that took place between 2002 and 2009. Most municipal districts in Istanbul have been the preferred destinations of large scale movement of rural migrants every year from different parts of the country in order to find jobs and a better life (TÜ˙IK 2008b). For instance the population in the whole of Istanbul city increased by over 400 000 from 1995 to 2000 due to immigration alone and its rate is still growing (TÜ˙IK 2008b).

Given the scale of this population and urban growth neither the local or the central government are capable of controlling the large influx of rural migrants to urban centres, most end up settling illegally on vacant public lands creating low cost housing (Karaburun et.al 2009). Karaburun et.al (2009) also highlighted that urban expansion associated with rapid population growth in Istanbul has increased the formation of slum populations and encouraged “gecekondus,” the term used in Turkey for illegal one- or two-story houses built very fast in poor quality. These gecekondu neighborhoods constitute the nuclei of many municipal districts of Istanbul in general and Sancaktepe in particular and today.

However, transport networks and accessibility could aslo have been responsible for facilitating the increase in the urban expansion experienced in the district. Torrens et al. (2000) noted that urban growth has been high and rapid in most municipal districts of Istanbul in the recent years mainly after highways were constructed towards the end of 1980s and also after the construction of the Trans European Motorway (TEM) and the second Bosporus Bridge by supplying accessibility.

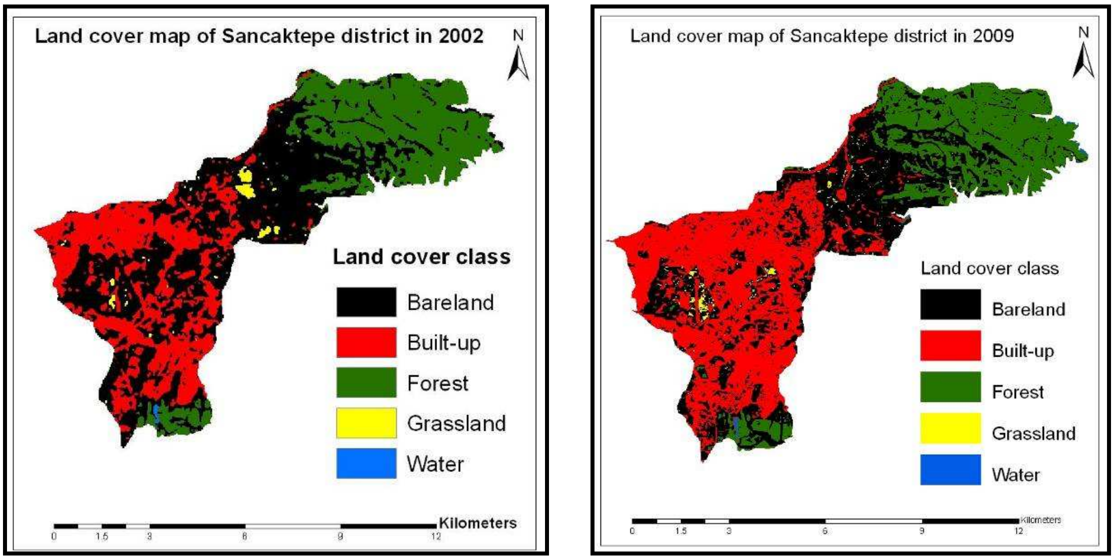


Figure 4.2 Land Cover map of (a) 14 June 2002 and (b) 17 June 2009 derived from Landsat Thematic Mapper data.

4.2. Vegetation cover change using NDVI

This section presents results and analysis of NDVI calculation to monitor temporal and spatial variability of vegetation cover between 2002 and 2009 using the Landsat TM remotely sensed data. To visually aid easy interpretation of results of NDVI calculation, results are shown in tables, graphs and maps. The objective was to test, the hypotheses that the increase in urban growth led to decline of vegetation cover.

4.2.1. Temporal variability of vegetation cover change

Table 4.2 Descriptive statistics of NDVI images

Date of satellite data	**Mean**	**Median**	**Standard deviation**	**Min**	**Max**
14 June 2002 Landsat TM	0.286	0.293	0.142	-0.101	0.670
17 June 2009 Landsat TM	0.235	0.166	0.189	-0.126	0.702

There was significant difference (assuming unequal variance) between the mean NDVI values of 14 June 2002 image and of 17 June 2009 image at the 95% ($p<0.05$) confidence interval as revealed by independent t-test carried in Statistical Package for the Social Sciences (SPSS) as shown on table

4.3. This was arrived after it was hypothesized that the differences between NDVI means of 2002 image and 2009 image are statistically significant.

Table 4.3. Independent sample test of mean NDVI values of 2002 and 2009

NDVI (2002 and 2009)	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	3269.787	.000	33.529	48438	.000	.051152	.001526	.048162	.054143
Equal variances not assumed			33.529	44912.243	.000	.051152	.001526	.048162	.054143

The NDVI mean and median on 2009 image are significantly lower than NDVI mean and median on 2002 image as can be shown on Table 4.2 and by the box plots on figure 4.3. This therefore indicates a decline in the vegetation cover or biomass in the whole area during the period under study. The effects of residual sensor degradation and sensor inter-calibration differences, effects of changing solar zenith and viewing angles, atmospheric water vapour and cloud cover between the image acquisitions dates can reduce the overall NDVI values. Since the remotely sensed data acquired were of the same period of June and were radiometically corrected, these have minimal effects and influence on overall result of NDVI series between 2002 and 2009.

Generally in natural areas, the decline of vegetation cover coincide with the patterns of climatic conditions like below-normal rainfall, deforestation, variations in agricultural land production and primary biological productivity of the ecosystem. However, in this context urban growth and development to some extent has also been responsible for vegetation cover loss since there was an increase in built areas on previously forested areas. This is expected when urban areas expand onto non-urban areas and eventually more biomass will be lost. As more biomass is lost to built-up areas and other impermeable artificial surfaces due to urban expansion it reduces biodiversity, increase the urban heat island and even increasing run off and flooding during precipitation events.

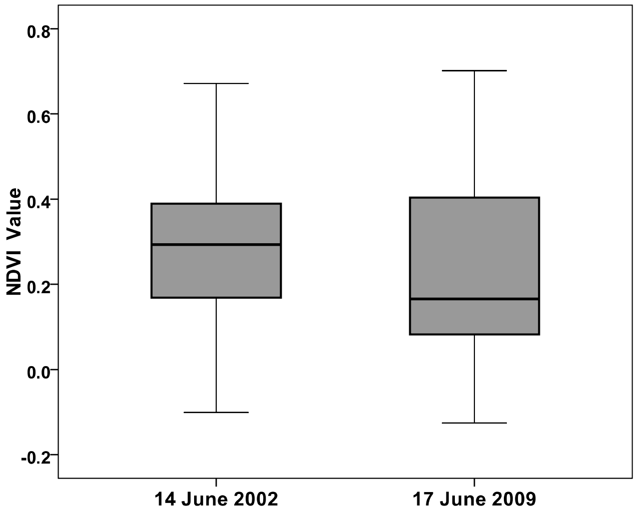


Figure 4.3. Box plots showing variations of NDVI on 14 June 2009 and 17 June 2002 Landsat TM image

The temporal variability of vegetation cover was further and clearly illustrated by different shapes of the histograms for the observed NDVI data and their corresponding theoretical normal distribution for the 14 June 2002 image and 17 June 2009 image which showed significant variations. By 17 June 2009 the NDVI histogram exhibited a slight bimodal distribution NDVI profile rather than the normal Gaussian distribution profile observed on 14 June 2002 image as shown on figure 4.4 and 4.5. The increasing existence of lower NDVI values attributed to the increase in built-up areas land cover from 2002 to 2009 could have ultimately caused a slight bimodal distribution of observed NDVI of 17 June 2009 rather than the normal Gaussian distribution trend in the 14 June 2002.

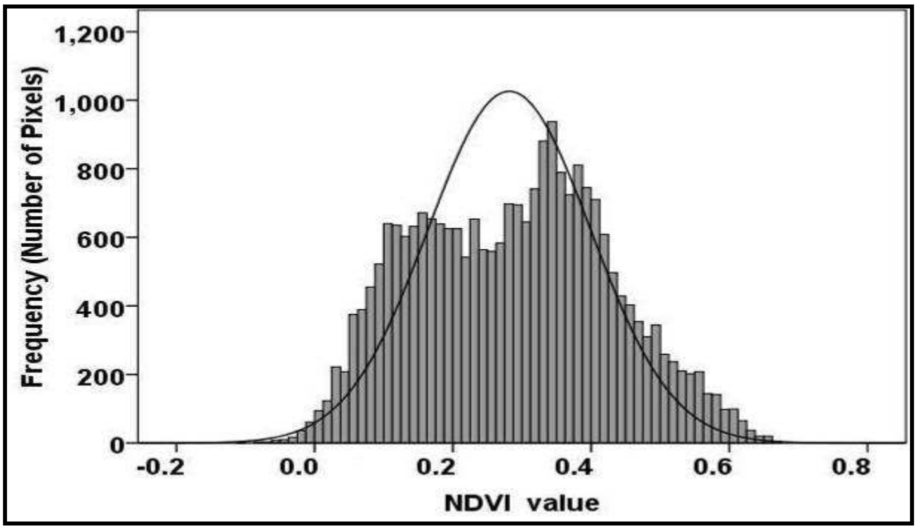


Figure 4.4. The NDVI Histogram of Landsat TM image of 14 June 2002 showing theoretical normal Gaussian distribution

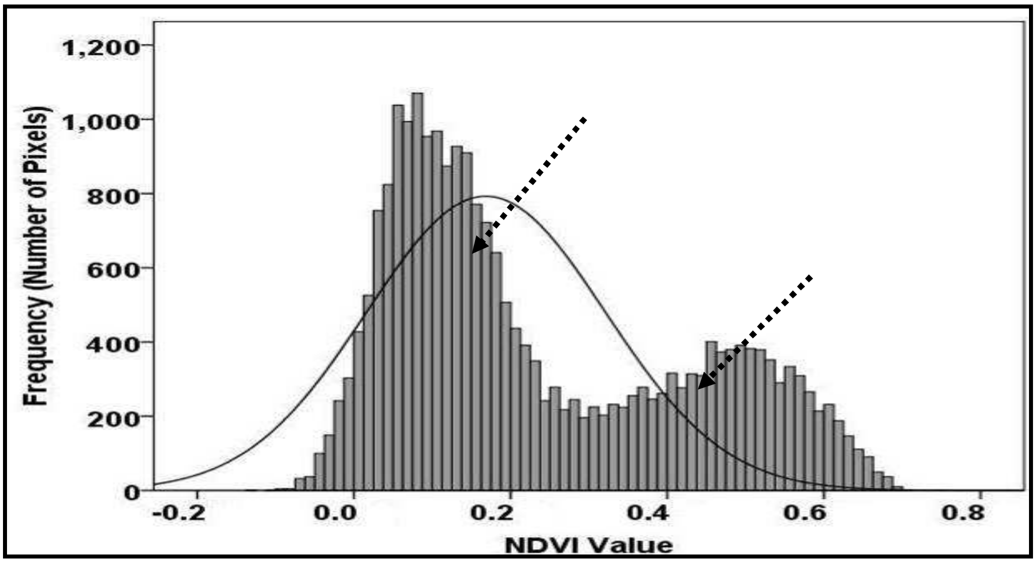


Figure 4.5. The NDVI Histogram of Landsat TM image of 17 June 2009 showing a bimodal distribution.

As shown by figure 4.5, there are two distribution trends of NDVI data on 17 June 2009 histogram, one appearing on lower NDVI values from -0.2 -02 and another on higher values from 0.2-0.7, thus implying that increasing existence of lower NDVI values attributed to the increase in built areas land cover categories by 2009 could have been responsible for the observed bimodal distribution found on NDVI histogram of 17 June 2009. Furthermore descriptive statistics like standard deviation also illustrated the increasing variability of NDVI trend as the 17 June 2009 image had a standard deviation of 0.189 which was higher than the 14 June 2002 image which had a standard deviation of 0.142 (see Table 4.2). The standard deviation can be envisaged as robust measure of variability and dispersion of a probability distribution from the mean. The observed trends are indicative of changing nature and structure of the landscape with both low and highly vegetated areas.

4.2.2. Spatial variability of vegetation cover change

A spatial variability trend in vegetation cover was also observed in study area between 2002 and 2009 using the results of NDVI image differencing method which showed that areas with no vegetation cover, occurred primarily in areas experiencing urban growth expansion and to smaller extent on bareland as shown on figure 4.6. These areas can also be detected with their low NDVI values (-0.3 to 0.2) appearing on blue, green and orange colours on the NDVI images of 2002 and 2009 on figure 4.7 (a) and (b) and also on Table 4.4 and 4.5 (variation of NDVI on different land cover classes).

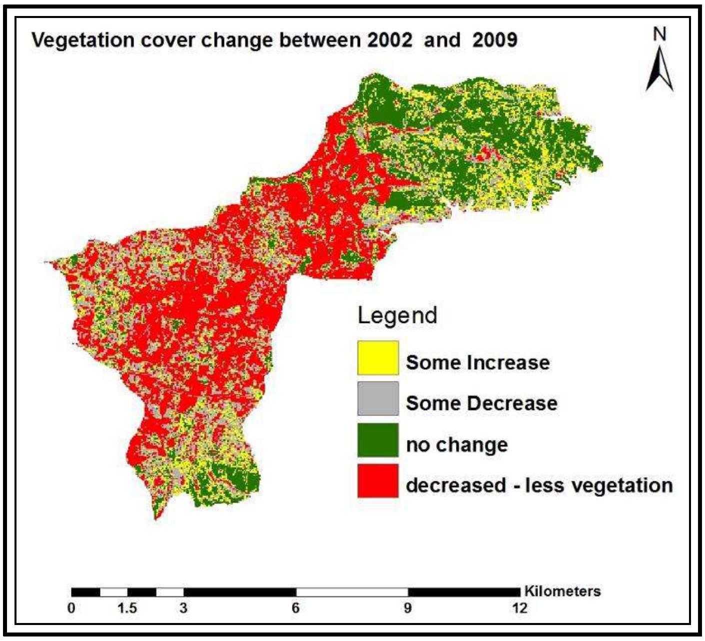
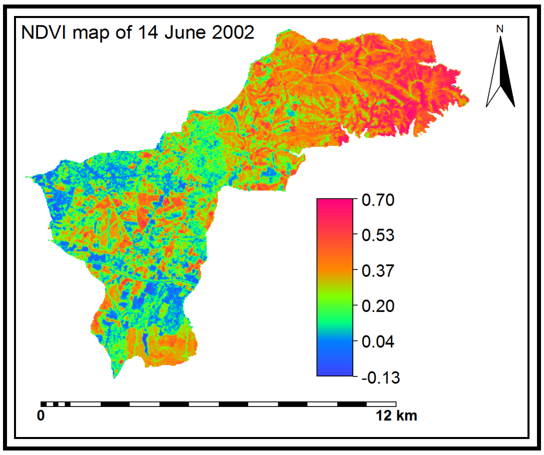


Figure 4.6. Map of vegetation cover change between 2002 and 2009

Areas in the north of Sancaktepe district remained relatively constant without significant vegetation cover and they are mostly forest areas as shown on figure 4.5. In fact some areas in the north experienced some increase in vegetation cover between 2002 and 2009. On the NDVI images of 2002 and 2009 as shown on figure 4.6(a) and (b), these areas have high NDVI positive values (0.3-0.7) with shades of red colours. In addition, the distribution of the vegetation cover in Sancaktepe district tend to vary by each land cover class. In other words NDVI trend between 2002 and 2009 showed significant spatial variation corresponding to distribution in land cover types of the study area. This was observed after the land cover class map were cross tabulated with NDVI data of 14 June 2002 and NDVI data of 17 June 2009.



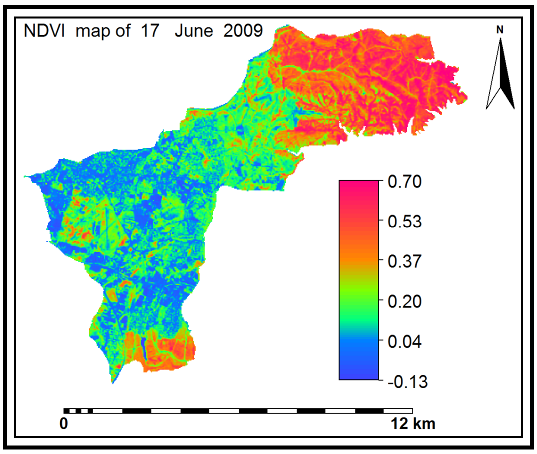


Figure 4.7. NDVI maps of (a) 14 June 2002 and (b) 17 June 2009 derived from Landsat Thematic Mapper data

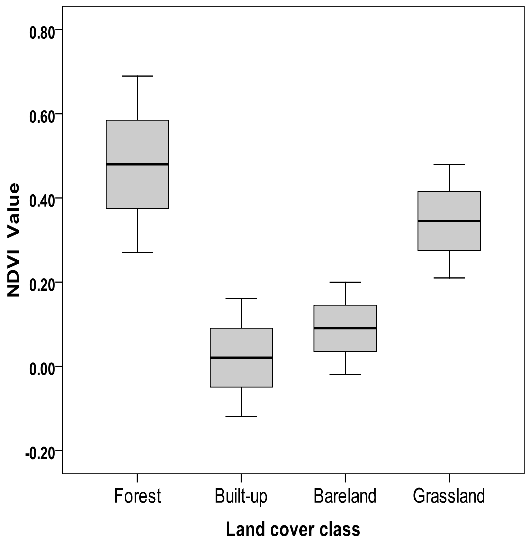
More vegetation cover measured by NDVI are found in the northern and southern part depicted by high positive NDVI values of forest and grassland as can be shown on the figures 4.7(a) and (b) and figure 4.8 (a) and (b) and Table 4.4 and 4.5 ccompared with low or no vegetation cover with low an negative NDVI values (bareland and built-up area) mainly concentrated on the western side of Sancaktepe district.

Table 4.4. Descriptive statistics of NDVI data of 14 June 2002 in different of land cover types

Land cover type	Mean	Minimum	Maximum	Std. Deviation
Forest	0.4800	0.27	0.69	0.12557
Built-up	0.0200	-0.12	0.16	0.08515
Bareland	0.0900	-0.02	0.20	0.06782
Grassland	0.3450	0.21	0.48	0.08226

Table 4.5. Descriptive statistics of NDVI data of 17 June 2009 in different of land cover types

Land cover type	Mean	Minimum	Maximum	Std. Deviation
Forest	0.5150	0.30	0.73	0.12845
Built-up	0-.0222	-0.18	0.11	0.08331
Bareland	0.0800	0.00	0.17	0.05627
Grassland	0.2550	0.11	0.40	0.08803



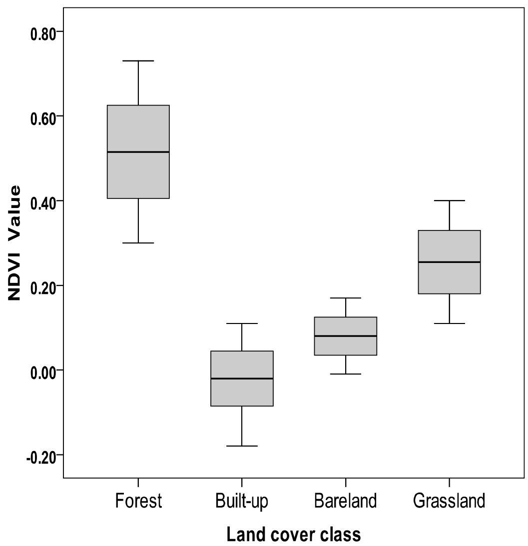


Figure 4.8. (a) NDVI data of 14 June 2002 (b) NDVI data of 17 June 2009 showing its variation with land cover type using box plots

Table 4.4 and 4.5 and graphs on 4.8(a) and (b) shows that forest land cover had high variability on NDVI data than any land cover type and it was high in 2009 than in 2002. Its standard deviation in 2009 was 0.128 and in 2002 it was 0.125. The built-up land cover class was expected to show higher variability due to different stages and phases of urban development when it gradually expanded to vegetated and green areas (grassland lost 63 hectares of land and forest lost 36 hectares of land) of the study area. However, because the urban expansion in these areas occurred mainly at the expense of bareland (lost 689 hectares), which shared similar characteristics with built-up NDVI values, variability remained low. Thus, the NDVI values of bareland had overlaps with NDVI values of built-up as shown on Table 4.4 and 4.5 an also 4.8(a) and (b) in both years while forest it tended to overlap with grassland in both years.

4.3. Characterising and quantifying change in the urban growth form or morphological patterns, spatial heterogeneity and land fragmentation patterns

The characterization of change in landscape composition and configuration (landscape structure) patterns of Sancaktepe district between 2002 and 2009 was based on the computation of landscape metrics. Landscape metrics, describing the number, size, shape, and edge, diversity and evenness of land cover patches (where patch is a contiguous set of pixels assigned to the same land cover type), were generated from the land cover data derived from Landsat TM of 2002 and 2009. By applying such indices, it was possible to analyze process of agglomeration, coalescence and fragmentation level of the involved land cover covers. Fragmentation processes, are the subdivision of continuous patches cover into smaller patches while agglomeration are the opposite.

4.3.1. Change in spatial pattern of urban growth form

Table 4.6 illustrates results at class level of number of patches, mean perimeter area ratio (m/ha), mean patch size and total edge landscape metrics which were used to measure change in spatial pattern of urban growth form between 2002 and 2009 for Sancaktepe district. The largest percentage increase (135.6%) of mean patch size was in a built-up land cover class (urban areas) as it increased from 3 hectares in 2002 to 7.1 hectares in 2009 reflecting the increasing agglomeration and concentrated urban growth pattern of Sancaktepe district as can be seen on the maps on figure Fig 4.9. This is in contrast to a fragmented landscape that overtime would experience a decrease in mean patch size patches, increase in number of patches and its perimeter area ratio (m/ha) and total edge.

Table 4.6. Results of the mean patch size, number of patches and mean perimeter area ratio results between 2002 and 2009

	Total edge(Km)		**Number of patches (Hectares)**		**Mean patch size (hectares)**			**Mean Perimeter Area Ratio (m/ha)**	
	Year		Year		Year			Year	
Land cover class	**2002**	**2009**	**2002**	**2009**	**2002**	**2009**	**Percentage change**	**2002**	**2009**
Bareland	125.4	602.7	1113	1442	2.6	1.5	-41.18	0.13	0.13
Forest	503.0	223.4	329	218	4.7	7.0	47.46	0.14	0.13
Built-up	399.1	372.6	534	339	3.0	7.1	135.60	0.13	0.13
water	2.2	6.8	16	31	0.4	0.3	-26.88	0.13	0.12
Grassland	120.2	41.9	407	246	0.3	0.2	-29.34	0.15	0.15

In areas with shortage of land for urban expansion, new urban buildings and developments generally occur in the voids of the core or adjacent to existent built-up patches resulting in a concentrated way. In addition, results of mean perimeter- area ratio and number of patches at class level also confirmed the analysis from mean patches size which suggested that spatial pattern of built-area of Sancaktepe district has become concentrated than fragmented from 2002 to 2009 as mean perimeter area ratio remained stagnant at 0.13 meters per hectare.

The result of the number of patches computed at a class level also revealed that built-up spatial pattern of Sancaktepe district had by 2009 become less scattered as new development tended to infill around existing development forming large contagious patches than small scattered patches. The number of patches class metric for built-up declined from 534 in 2002 to 339 in 2009. As shown by figure 4.9(a) and (b) of the built-up maps of 2002 and 2009, by 2009 that built-up land cover had large contiguous patches than 2002 reflecting increasing aggregation and agglomeration spatial pattern of urban growth of Sancaktepe district.

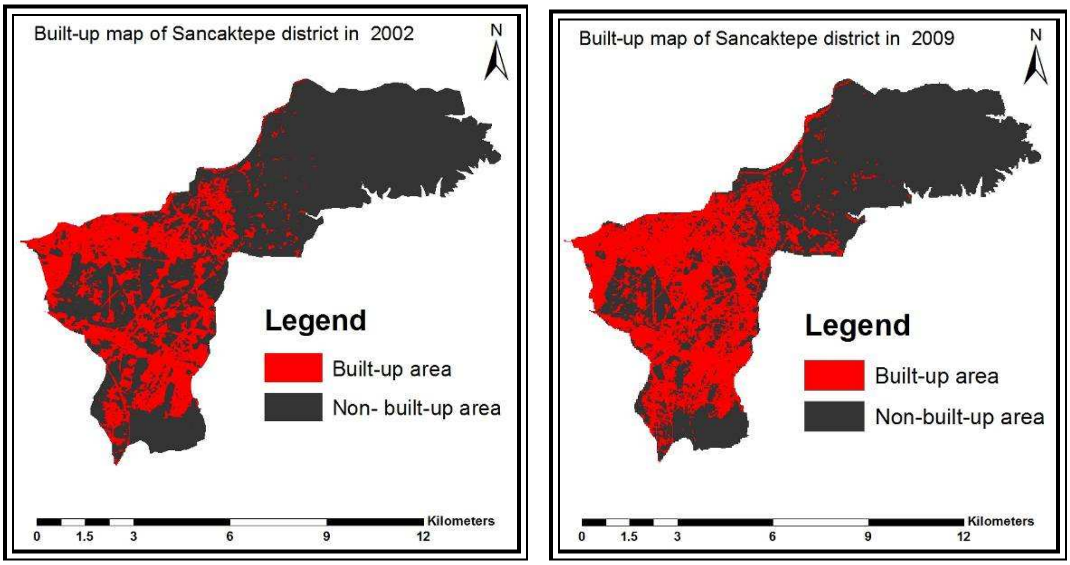


Fig 4.9. The built- up map (a) 14 June 2002 and (b) 17 June 2009 derived from Landsat Thematic Mapper data.

While the growth of the economy strictly connected with high urbanisation and industrialisation currently being experienced in Istanbul in general and Sancaktepe district in particular could be responsible for a large number of patches mainly belonging to built-up, the shortage of land in the district for urban development causes the densification of buildings resulting in the infilling of patches. In addition, various Master plans in Istanbul since 1995 (IMP 2008) have encouraged linear and polycentric development than monocentric to reduce high population density in city centres by creating what are called primary and secondary subcentres in peripheral areas in all district municipalities of Istanbul. This have had effects of increasing densities of neighbourhoods which are close to these primary and secondary subcentres and that in turn tends to infill around existing development forming an agglomeration pattern such as observed in Sancaktepe district. DiBari (2007) also observed that the changes in distribution and dispersion of urban areas is enhanced by the agglomeration of new urban areas within existing urban zones.

4.3.2. Land cover Fragmentation

Land cover fragmentation varied with each land cover type as results of number of patches, mean patch size, and total edge sum on table 4.6 shows. A more fragmented land cover pattern is associated with an increase overtime of the number of patches, a decrease of mean patch size, and increase in total edge sum. Bareland are fragmented as its number of patches increased from 1113 hectares in 2002 to 1442 hectares in 2009, the mean patch size declined from 2.6 in 2002 to 1.5 hectares in 2009 and its total edge also increased from 125.4km in 2002 to 602.7 km in 2009. However other land cover categories like forest, built-p area and grassland are not fragmented as they experienced a decrease in the number of patches, an increase of mean patch size, and decrease in total edge sum indicating that these land cover types have become increasingly clustered over time. For instance number of patches of forest declined from 329 hectares in 2002 to 218 in 209 while mean patch size of a forest increased from 4.7 hectares in 2002 to 7 hectares in 2009 suggesting that forest are not fragmented, thus avoiding the breakup of patches areas into smaller and more isolated units.

4.3.3. Change in Patch shape complexity

Table 4.7 illustrates Area weighted mean shape index (AWMSI) and Area weighted mean patch fractal dimension (AWMPFDI) landscape metric results at class level which were used to quantify landscape configuration in terms of the complexity of patch shape at the class level between 2002 and 2009 for Sancaktepe district.. The largest percentage increase in Area weighted mean shape index (AWMSI) was in a built-up land cover class, which increased by 38 % from 9.1 to 12.5 between 2002 and 2009. Patches shapes of land covers are irregular when AWMSI is above 1. This reflects an increasing complexity in irregularity in the spatial pattern of urban growth of Sancaktepe district. The reasons for the observed pattern can be linked to rapid urban expansion associated with the growth of unplanned, informal housing and settlement patterns in the study area. This results in more complex and irregular in shape of the built-up area due to the different types of blocks and housing sizes than the urban development which is generally planned and highly regular.

Table 4.7. Results of Area weighted mean shape index (AWMSI) , Area weighted mean patch fractal dimension (AWMPFD) landscape metric at class level

	Area weighted mean shape index (AWMSI)			Area weighted mean patch fractal dimension (AWMPFD)		
	Year			Year		
Land cover class	**2002**	**2009**	**Percentage change%**	**2002**	**2009**	**Percentage change**
Bareland	9.0	5.5	-39	1.292	1.291	-0.1
Forest	8.8	7.9	-9	1.207	1.244	3.0
Built-up	9.1	12.5	38	1.060	1.195	12.7
water	1.6	1.2	-25	1.104	1.065	-3.6
Grassland	1.5	1.4	-6	1.099	1.042	-5.2

In fact, results of fractal dimensions presented on Table 4.5, which were calculated as the area weighted mean patch fractal dimension (AWMPFDI), also confirmed the results of AWMSI in quantifying and measuring the degree of irregularity in spatial patterns of land cover change. There was a 12.7 % increase of the AWMPFDI value for built-up from 2002 to 2009 suggesting that new irregularity patterns of urban developments have resulted in a increase in the complex built-up patch shapes. McGarigal et al. (1994) noted that the value of the fractal dimension is dependent upon the patch size and the units used. Therefore, slightly complex shapes of the built-up is a function of the large, continuous areas and aggregated patches that infilled disorderly around existing built-up areas in the study area.

Although other land cover types like bareland and forest and are irregular there they became less complex in irregularity as their AWMSI declined between 2002 and 2009. AWMSI value for bareland declined by 39% from 9 in 2002 to 5.5 in 2009 which resulted in the intermediate shapes since it had the AWMPFD value of 1.2 which almost remained stagnant between 2002 and 2009.The forest patches are irregular despite the fact that their AWMSI value declined by 9% from 8.8 to 7.9 and the slight increase of 3% in its AWMPFDI value indicates that they still have slightly complex shapes probably due to human modification influence. Grassland patches, some of which are located in open fields and agricultural activities had its AWMSI value declined by 6% from 1.5 to 1.4 resulting in relatively simple circular shapes as indicated by the 5% decrease in its AWMPFDI.

4.3.4. Change in landscape composition

The Shannon's diversity (SHDI) and Shannon Evenness Index (SHEI) indices both became lower as shown on Table 4.8, indicating that the landscape heterogeneity and evenness slightly decreased between 2002 and 2009.This was contrary to what was expected, that with the increase in urban expansion it would cause an increase in landscape diversity.

Table 4.8. Results of Shannon Diversity Index and Shannon Evenness Index

Year	Shannon Diversity Index	Shannon Evenness Index
Land cover map of 2002	1.190	0.740
Land cover map of 2009	1.163	0.723

The Shannon Diversity Index was 1.19 in 2002 and it was 1.63 in 2009 while the Shannon Evenness Index was 0.74 in 2002 and 0.723 in 2009. This is because the Shannon diversity index takes into account the abundance of classes and it increases as the number of classes increases or the equitability of the distribution of land amongst the various classes increases, ranging from 0 to infinity. On the other hand, Shannon Evenness Index did not change much between the time period of 2002 and 2009 with had a lower evenness index. This indicates that the classes of map units are not uniformly distributed in the study area reflecting the differences in sizes of certain land cover on the landscape ascertain land cover categories tends to dominate others on the landscape. Evenness is the complement of dominance and diversity only approaches perfect evenness when the Shannon's evenness index approaches 1. Thus it can be argued that while it is possible for the spatial configuration (structure) to change as evidenced by change in number of patches and mean patch size, total edge, and the relative abundance of land cover types can remain relatively stable through time.

4..4. The effect of changing grain size (spatial resolution) on landscape metrics using IKONOS image

This section discusses results of the effect and types of behaviour of change in grain size (spatial resolution) on selected landscape pattern metrics on a classified high resolution remotely sensed June IKONOS 2008 image (Im panshapened) which was resampled to 5m, 10, 20m and 30m. The spatial resolution resampling (5m, 10, 20m and 30m) method attempted to approximate data gathered with varying spatial resolutions sensors since remotely sensed fine, medium and coarse resolution data are unavailable for the same place and time. Landscape metrics are presumed to respond to scale issues (Turner 2005a) and therefore the effects of changing scale have significant implications on some landscape attributes and elements of land cover spatial heterogeneity and processes, for instance fragmentation of urban landscape and therefore are critical aspect to investigate. Due to increasingly availability of high resolution data and the urgent need for detailed urban planning and management, the response or behaviour of landscape metrics measurements for resolution data of below 30m is critical to be investigated for future temporal analysis. Also, the information of the variations of landscape indices over multiple scales is very important for the identification of the scale of heterogeneity (patchiness) of the landscape, in order to carry out analyses at an appropriate scale (Gustafson 1998).

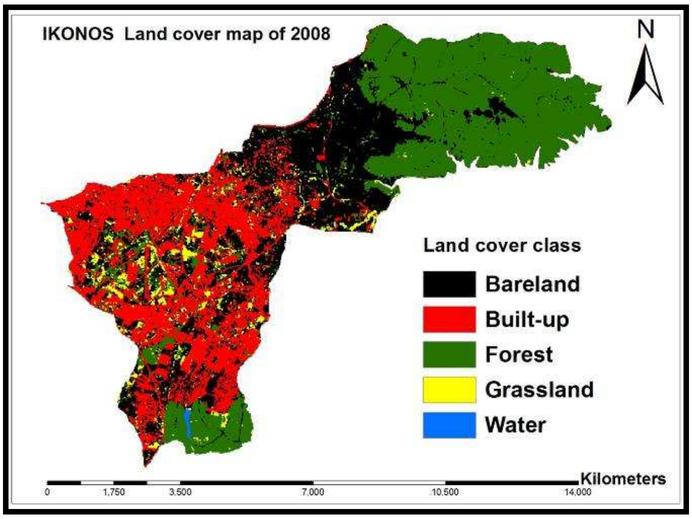


Figure 4.10 Land Cover map of June 2008 which was resampled to 5m, 10, 20m and 30m

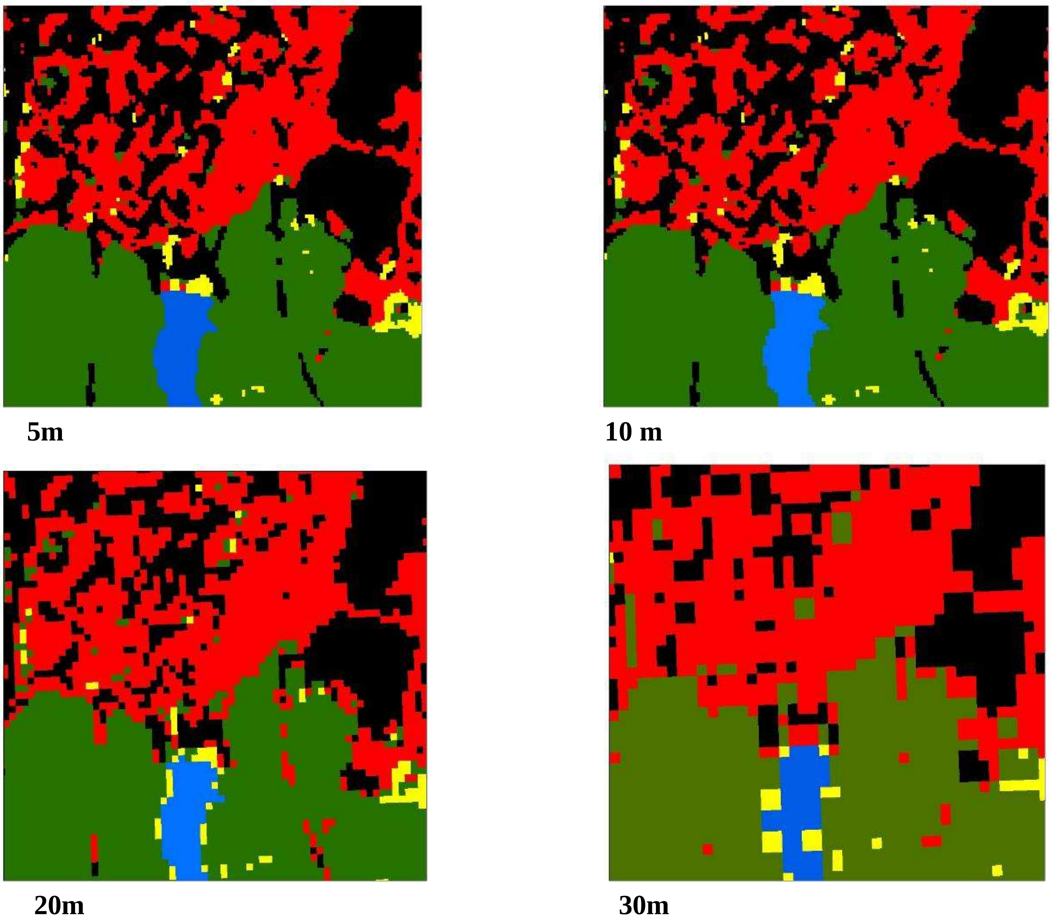
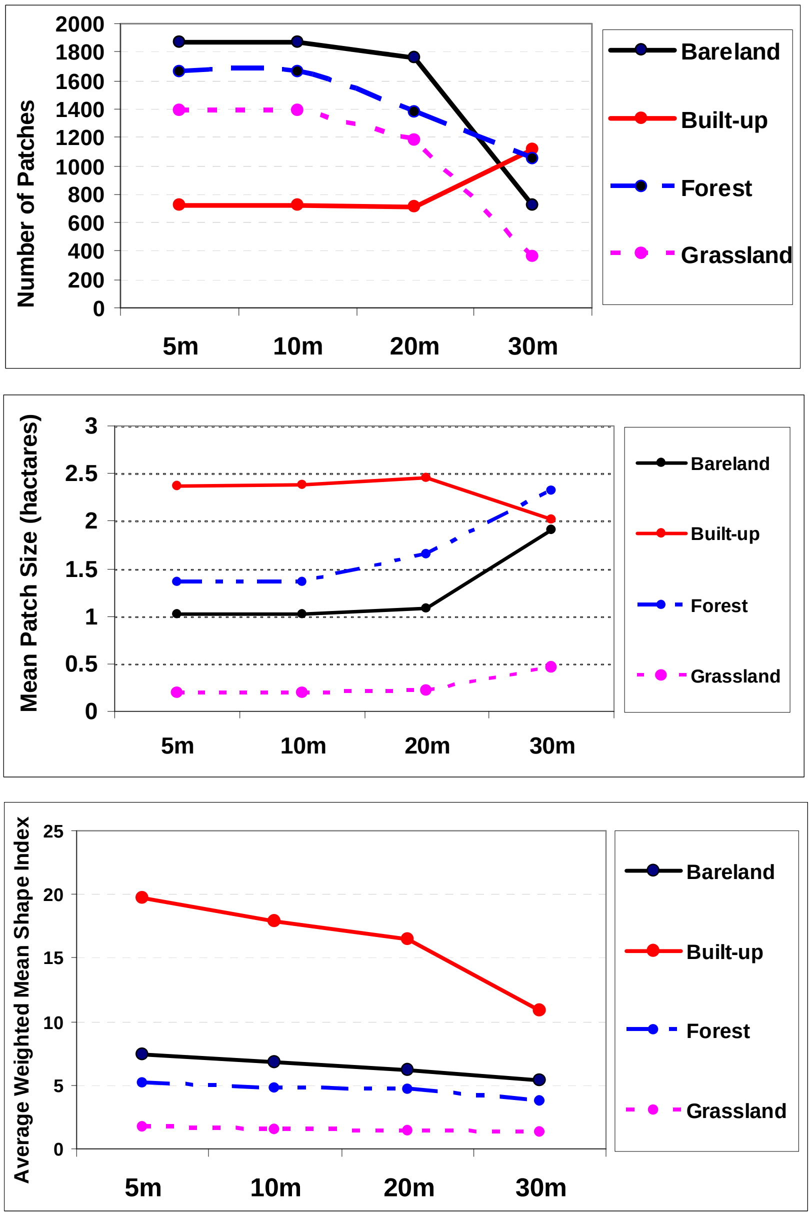


Fig 4.11. Effects of changing grain size (spatial resolution) on June 2008 derived from IKONOS data successively resampled to 5m, 10m, 20m and 30m.

Table 4.9. Results of total area of land cover categories with changing spatial resolution of classified June IKONOS 2008 image

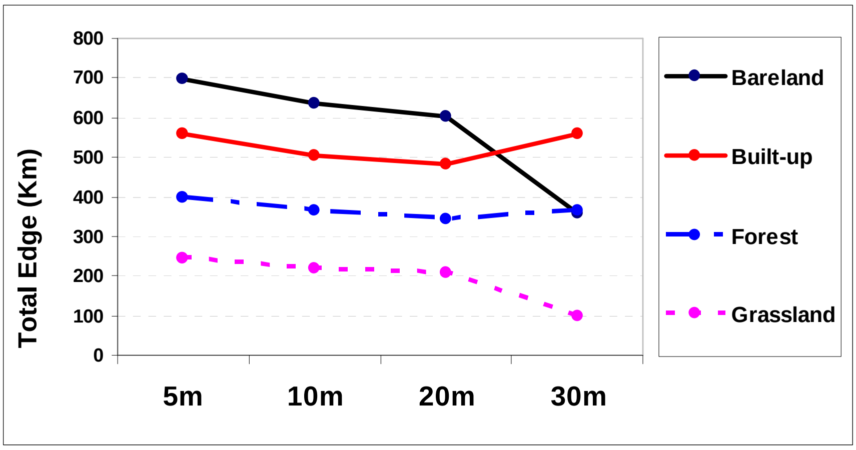
Land cover class	IKONOS 5m (ha)	IKONOS 10m (ha)	IKONOS 20m (ha)	IKONOS 30m (ha)
Bareland	1914	1911	1901	1387
Built-up	1712	1721	1736	2256
Forest	2262	2258	2262	2441
Grassland	266	263	255	167
Water	8	8	8	7



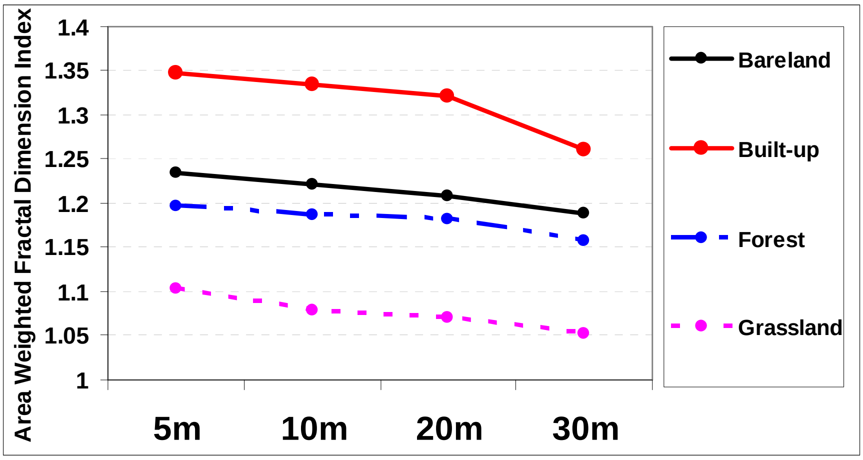
(a)

(b)

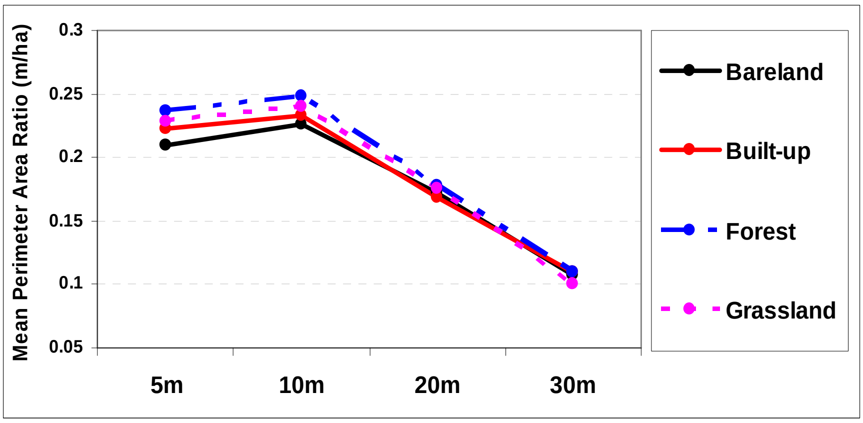
(c)



(d)



(e)



(f)

Fig 4.12. The effects of changing grain size (spatial resolution) on landscape metrics values (a) number of patches (b) Mean patch size (c) Area weighted mean shape index (d)Total edge (e) Area Weighted Fractal Dimension (f) Mean Perimeter Area Ratio

The results on figure 4.12 (a)-(f) suggest that landscape metrics measurements are sensitive to and affected by changes in scale (spatial resolution). Since scale refers to various concepts, including spatial resolution and extent (total area), spatial resolution is much more addressed than changing extent as extent is fixed when the study area is determined (Wu 2004). It was observed that landscape metrics values of Area weighted mean shape index, Area weighted fractal dimension and mean perimeter area ratio are sensitive to change in spatial resolution, at most showing a linear decrease as spatial resolution decreases that is from a fine resolution (5m-10m) to a relatively coarser resolution (20m-30m) for each different land cover type of forest, grassland and bareland and built-up. However the values of the mean perimeter area ratio showed an increase from 5m -10m before monotonically decreasing from 10m to 30m spatial resolutions for each land cover type. Water however was not used for the analysis due to its minimal representation.

It was also observed that, as the spatial resolution decreases from 5 m to 30 m, number of patches values were monotonically decreasing for all land cover types of forest, grassland and bareland except built-up which had a linear increase from 5m, 10m, 20m to 30m spatial resolution. This is because unlike other land cover categories, built-up's total area increased with changing spatial resolution (5m, 10m and 20m to 30m) as shown on table 4.9. On the other hand, the mean patch size values of forest, grassland and bareland showed a linear increase from 5m to 30m spatial resolution expect for built-up land cover class. The mean patch size of built-up was relatively stable at 5m-20m spatial resolutions but started to decline monotonically from 20m-30m spatial resolution. The total edge values of bareland and grassland monotonically declined from 5m to 30m spatial resolutions. While monotonically decreasing from 5m to 20m spatial resolution, the total edge values of built-up and forest started to increase from 20 to 30m spatial resolution. All the values of mean perimeter area for all land cover categories ratio increased from 5m -10m but started monotonically decrease from 10m - 30m spatial resolutions.

Thus it can be observed from these results that some metrics or indices like number of patches showed a robust response with each changing spatial resolution for each land cover type. This is also true with some metrics like Area weighted mean shape index, Area weighted fractal dimension and mean perimeter area ratio values as they changed consistently with changing spatial resolution (grain size). It was either showing a linear increase or decrease with changing spatial resolution from fine to coarse resolutions. However, The responses for some indices like mean patch size and total edge showed variability in the way the respond to spatial resolution. Significant change in variability for the mean patch size and total edge is noted between 5m-10m spatial resolutions and also between 20m-30m spatial resolutions showing either an increase or decrease in values of certain each land cover categories.

These results thus indicate that comparing landscape metrics at different spatial resolution may be affected by different types of responses to changes in spatial resolution (grain size). It can be argued that depending on the metric used, it seems therefore that there is no optimal scale whether at fine, medium or coarse resolution in the applicability of some these landscape metrics tools for the measurement of landscape change. It is suggested that before applying landscape metrics from different resolution data (fine, medium to coarse), researchers should explore the effects of scale (in this case spatial resolution) for landscape change studies. Since some studies (Wu 2004) have aslo noted that there is no 'optimal' scale for characterizing spatial structure and heterogeneity it is important therefore that spatial resolution or grain size must be kept the same when using landscape metrics. This becomes essential in urban planning and decision making because of the need of consistent results for efficient characterization of the urban land cover change.

4.5. Usability of landscape or spatial metrics findings

This section explores the usability and the potential role of spatial or landscape metrics in assisting urban planners who are involved in urban planning. The basic assumption was that, spatial or landscape metrics can be a potential useful tool in urban planning activities to current urban planners and practitioners if they became aware of its functionality and relevance, which can eventually increase usability will, in turn, increase its applicability in urban planning practice. After analysing some selected landscape metrics results in this study, the general possible application and relevance of landscape metrics in urban planning is explored. This is discussed by making reference to the findings obtained from interviews, questionnaires conducted in the fieldwork in Istanbul.

It was found from the interviews and focus group discussions that remote sensing in combination with GIS are currently being used in monitoring urban land cover change in Istanbul especially at the metropolitan level and to a smaller extent at district level. While spatial metrics in combination with remote sensing have been reported (Herold et al,2002) and already pointed out in this study as potential tools useful for improving the thematic mapping of urban land cover change and providing useful information about urban morphological structures, they are not being used in Istanbul. This was established from the 17 respondents who answered a prepared questionnaire and some urban planners who were involved in the focus group discussion and key informants interviewed at IMP, Istanbul metropolitan authority (European and Asian part) and in Sancaktepe district in Istanbul who indicated they were not aware of the method, its function or role in urban planning.

In general, urban planning departments are mandated to use different monitoring tools in various aspects of urban planning for supporting and conducting environmental review of projects, analysis and compliance planning and developing local and master plans. Some of the existing tools like Netcad software are widely being used for developing local and master plans in most districts of Istanbul including Sancaktepe. This could be complemented by using spatial metrics for improving the thematic mapping of urban land cover change. But landscape or spatial metrics could be a more potential useful tool only when practitioners in the study area became aware of the functions, contents and suitability in the relevant urban planning applications. This was established from interviews with key informants, focus group discussions and questionnaires answered by urban planners during the fieldwork campaign in Istanbul who indicated they were not aware of the spatial metrics methods, especially their functions or role in urban planning.

It was also discovered in the fieldwork that, the challenge involved in the potential use of spatial metrics for urban planning purposes lies in the uncertainty in what a landscape metric index really measures. Since all the urban planners involved in the study did not have the knowledge of spatial metrics, some pointed out during the focus group discussions that they need more thorough knowledge as well as a more detailed understanding of what the spatial or landscape indices mean. Specifically on the information of what a change in spatial or landscape index value conveys. Lack of understanding of spatial or landscape metrics value could affect its ability to communicate and inform policy makers, managers in urban planning. Much information may be ignored by the decision makers, regardless of scientific relevance due to lack of understanding their interpretation.

However, from the results of computing some landscape metrics in this study for Sancatktepe district, it was noted that landscape metrics could play a significant role in urban planning in the study area for example by providing some guidance for urban planners and managers about the preferred composition and configuration of landscape change for instance in urban growth form or pattern. These landscape change for instance in urban growth form or pattern are conceived by urban planners and managers in various local plans and master plans of Sancaktepe district in particular and the whole Istanbul metropolitan city in general. Urban planners and managers including those involved in land use planning can develop and implement plans or take other actions that change the landscape for instance retarding bareland fragmentation using the knowledge of spatial or landscape metrics metric or indices for instance the mean patch size, number of patches, and total edge used in this study.

Landscape metrics indices like AWMSI and AWMPFDI, perimeter area ratio, are hardly used to widely compare, measure and analyze changes in urban form or patterns over time in the study area. Various Master plans in Istanbul since 1995 (IMP 2008) have encouraged a compact and linear spatial development and thus the decision whether to approve a specific development, for example, could be based in part on some measures of urban growth form or pattern as illustrated by use of AWMSI and AWMPFDI in this study area. Irregular shapes of unplanned and rapid growth of haphazard informal settlements developments can be observed by AMWSI and AWMPFDI. It quite often difficult to provide efficient public infrastructure services like water supply, health service facilities and disposal system in these areas with scattered, haphazard development patterns. Such information is critical in helping urban planners in informing them about consequences of such spatial development trends and also in developing efficient plans control and manage these trends.

The approach of using landscape metrics can also improve communication between land use and urban planners with the decision-makers. For instance, information on the changes on landscape structure and composition allows land use planners to model and predict the impacts of planned activities on ecological systems, and then to provide results or alternatives in terms of quantitative data. Outputs of this approach can fit into broader decisions tools such as Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) and strategies such as city region development strategies, where landscape structure and composition in Istanbul metropolitan city in general and Sancaktepe district in particular, is one of a broad range of environmental issues under consideration in urban planning purposes.

The approach of using spatial or landscape metrics in urban land cover change could make a valuable contribution to the formulation of urban planning policies related to the preferred composition (either using Shannon Diversity or Evenness) and configuration (using for instance total edge and mean patch size) of landscape change. This knowledge could be used for the enhancement and conservation of landscape character in Sancaktepe district in particular and other municipality districts in Istanbul. It is also envisaged that rapid urban growth and urbanization will create significant environmental and landscape changes in the study area. These environmental changes area related to continual loss of undeveloped land categories (like bareland lost 689 hectares, grassland 63 lost hectares and forest lost 36 hectares between 2002 and 2009) at the landscape level. Therefore the use and knowledge of spatial metrics or landscape metrics for changes in the mosaic of landscape elements like fragmentation are essential to measure processes, functions and integrity of ecosystems.

Monitoring and assessing the effects of urban expansion on landscape change provides important information and knowledge that support urban planning to establish local and regional development policy for a district like Sancaketepe. Using the knowledge and results of spatial metrics, significant effects and threats of urban expansion on the landscape can be reduced by establishing a scheme of planning and zoning within the study area that would better govern the local environment and landscape composition or structure. The planning and zoning of principal functions including zones of optimal development, key development, restricted development, and prohibited development, can provide a useful measure of landscape ecosystem integrity, and can lead to a cost-effective, long-term management system.

Chapter Five: Summary, Conclusions and Recommendations

5.1. Summary

5.1.1. Summary of land cover change findings

The study focused on the application and analysis of Landsat TM satellite images to detect the land cover changes between the years of 2002 and 2009 in the municipal district of Sancaktepe, Istanbul. It was discovered that there was rapid urban expansion of Sancaktepe district as built-up area had by 2009 dominated the landscape of Sancaketepe district (38.8% of the total of the study area) as from 2002 it increased by about 50%. The rapid urban expansion in district has increased the pressure on the natural environment and undeveloped land categories of bareland (lost 689 hectares) and grassland (63 hectares) and forest (lost 36 hectares). Given the rising land prices, the shortage of land and the increasing population pressure found in this district, more undeveloped land especially the remaining bareland (35.7 % of the total of the study area) is likely to be converted into built-up or urban area. Monitoring land cover change will enable better management of the problems associated with urban expansion like degradation of forest, grassland and bareland areas for the district.

5.1.2. Summary of vegetation change using NDVI findings

Use of NDVI index in change detection present a very robust behavior for the quantification of spatial and temporal patterns of vegetation cover change. The ability of NDVI to quantify the location or concentration of vegetation cover is important especially its loss or decline over time. The NDVI method showed that the total amount of vegetation cover in Sancaktepe district declined over the years (NDVI mean=0.28 in 2002, NDVI mean =0.23 in 2009). Some of the temporal variability perhaps could be attributed to general changes in the patterns of below-normal to rainfall, deforestation, agricultural land production, and primary biological productivity occurring in the area. However there was strong evidence that urban growth experienced between 2002 and 2009 was responsible for some vegetation cover decline. In additional, the spatial distribution of the vegetation cover change tended to vary by each land cover type with forest and grassland showing high NDVI values while bareland, built areas showed low values of NDVI. Particularly this information would allow urban planners to indentify current green space areas to protect from urban development or to target vacant land to convert them in new green space areas like city parks.

5.1.3. Summary of landscape configuration and composition change findings

The results of landscape metrics computation shows distinctive differences between the land cover categories concerning landscape configuration and composition change in Sancaketepe district between 2002 and 2009. Combination of metrics of landscape indices like mean patch size, number of patches, total edge and mean perimeter area ratio calculated at class level are useful and robust measures in charactering urban landscapes to discern landscape structure change especially dynamic processes of coalescing, disintegrating and fragmentation of land cover patches attributable to the urban expansion, densification and other human and natural landscape modifications through time. Bareland was found to have been fragmented while land cover categories of forest, built-p area and grassland were not fragmented during this period.

There was an increase in agglomeration process of built-up patches in the Sancaktepe district between 2002 and 2009 as indicated by the in increases in mean patch size, decrease in total edge and number of patches, indicating the nature and pattern of at urban expansion being experienced. Thus, the urban expansion pattern experienced was not scattered (fragmented) but concentrated due to infilling around existing patches. Changes in AWMSI and AWMPFDI indicate that the physical shapes within built-up areas are relatively complex and irregular. This indicated that the urban expansion of Sancaktepe between 2002 and 2009 was not uniform or regular, a possible reflection of unplanned developments in the district. This information is vital to decision makers in informing them about containing human modifications on the landscape particularly in this case controlling some unauthorised development and constructions, which are possible explanations for the irregular urban growth pattern observed by AWMSI and AWMPFDI.

While it is possible for the spatial configuration to change as evidenced by change in number of patches and mean patch size, total edge, the diversity (relative abundance of land cover types) can remain relatively stable through time. This is because the landscape heterogeneity and evenness slightly decreased between 2002 and 2009 as measured by Shannon’s diversity (SHDI) and Shannon Evenness Index (SHEI) in the study area. The Shannon's diversity index is not particularly meaningful as a relative index for comparing the same landscape at different times (McGarigal and Marks 1995; 2002). Its output was contrary to what was expected, that with the increase in urban expansion it would cause an increase in landscape diversity.

It was evident that landscape metrics are sensitive to changes in grain size for different land cover type, after examining responses to grain size (spatial resolution) change using a IKONOS 2008 classified image resampled to 5m, 10m, 20m and 30m. The results thus indicate that comparing landscape metrics at different spatial resolution may be affected by different types of responses to changes in spatial resolution (grain size). Depending on the metric used, it seems therefore that there is no optimal scale whether at fine, medium or coarse resolution in the applicability of some these landscape metrics tools for the measurement of landscape change. It is suggested that before applying landscape metrics from different resolution data (fine, medium to coarse), researchers should explore the effects of scale (in this case spatial resolution) for landscape change. Since some studies (Wu 2004) have noted that there is no 'optimal' scale for characterizing spatial heterogeneity it is important that, spatial resolution or grain size must be kept the same when using landscape metrics. This becomes essential in urban planning and decision making because of the need of consistent results for efficient characterization of the urban land cover change.

5.1.4. Summary of usability of landscape or spatial metrics findings

Landscapes metrics offer much promise as practical tools for quantifying the spatial landscape structure and composition of the urban landscapes and help refine some urban planning efforts especially in the monitoring stage especially to urban planners targeted in the fieldwork who do not have the knowledge of spatial metrics. Some landscape metrics like AWMSI and AWMPFDI are important in informing about the change in urban growth patterns in terms of uniformity and irregularity and change in shape complexity. Since various Master and local plans in Istanbul since 1995 (IMP, 2008) and Sancaktepe district have encouraged a compact and linear spatial development and thus the decision whether to approve a specific development, for example, could be based in part on some measures of urban growth form or pattern as illustrated by use of AWMSI and AWMPFDI in this study area. The approach of using landscape metrics can also improve communication between land use and urban planners with the decision-makers. For instance, information on the changes on landscape structure and composition allows land use planners to model and predict the impacts of planned activities on ecological systems, and then to provide results or alternatives in terms of quantitative data. However, challenges related to the use of quantitative measures of spatial metrics relate to the concerns regarding the understanding of their interpretation. Some urban planners in the fieldwork pointed to the fact that they need more thorough knowledge as well as a more detailed understanding of what the landscape metrics indices mean and how they change. Thus there is still a need for guidelines on how to apply, interpret and communicate them, establish links between the ecological patterns and processes of urban planning purposes. Once this translation is achieved successfully, it seems a widespread use and understanding of spatial metrics as quantitative measures of urban land cover change will increase its usability for decision making in urban planning purposes.

5.2. Conclusion

Given the increasing population pressure, the pace of urban growth and current and future impacts associated with urban growth or expansion, the need to study urban land cover change will continue in the foreseeable future. Consistent and future monitoring of urban land cover change will enable better management of the problems associated with urban expansion like degradation of forest, grassland and bareland areas for the district. In this regard the integration and combination of remote sensing and quantitative measures of spatial metrics will play an important role towards better understanding of urban land cover change. This is because the combination of remote sensing and spatial metrics provides a robust approach as it provide insights to urban planners, policy makers researchers, and managers for linking information about the consequences of landscape structure elements (agglomeration, compactness, complexity and irregularity) and composition (diversity) changes. This becomes essential and useful for decision making in urban planning purposes for managing change in rapidly growing area to current urban planners who need to use various methods and tools to understand the complex dynamics of urban landscape. Further research using high resolution data, exploring other landscape metrics may provide other interesting insights regarding the complex nature of the urban land cover change in a rapidly growing district like Sancaktepe.

5.3. Recommendations

In a rapidly changing landscape of Sancaktepe's district, adequate urban planning becomes increasingly important for overcoming the problems of urban sprawl. Adverse environmental effects resulting from urban sprawl, such as the conversion of forest, loss of grassland land, and fragmentation of barelands must be minimized to maintain the ecological functioning of a landscape. However findings from this study however still needs further investigations that replicate and improve upon this kind of research by addressing the following considerations.

Appropriateness of aggregated versus disaggregated land cover classification used

While the research studied the landscape of Sancaktepe district using some aggregated classes for instance forest comprised of deciduous and evergreen forests, we argue that use of disaggregated classes probably would produce different results for measuring processes of coalescing and fragmentation on a dynamic landscape. So there still are these unanswered questions

(1) What is the appropriate land cover classification hierarchy, aggregated versus disaggregated to measure some landscape elements and process?

(2) Is the extent of this study sufficiently large and diverse to understand the landscape character?

Appropriateness of coarse spatial resolution data versus fine resolution data

The research had two time steps of 2002 and 2009, it recommended to have more than two time steps in order to observe certain urban land changes which occur faster than others for instance urban expansion. Moreover, the data used here for land cover and landscape change had a resolution of 30 m (Landsat TM data), which is considered coarse and therefore may simplify the spatial and temporal complexity of urban development patterns, spatial heterogeneity in landscape pattern and process like coalescing and fragmentation. The following research question should be investigated.

(1) Would a multi-temporal finer resolution data better capture important elements of landscape configuration and composition change?

The results of investigating the effect of grain size (spatial resolution) in study on selected landscape pattern metrics on high resolution remotely sensed Im panshapened June IKONOS 2008 image which was resampled to 5m, 10, 20m and 30m , however suggests that most landscape metrics are sensitive to change in grain size (spatial resolution**).** However this study could not clearly establish whether this may limit the applicability of spatial metrics indices for the measurement of landscape change over time if landscapes are represented by differently spatial resolution data of finer-resolutions to coarser-resolution data and how inferences from this can affect and inform urban planning and management practice.

Further research on other municipal districts of Istanbul

More studies of urban land cover change should also be done in other municipal districts of Istanbul as they would be able to establish whether they are similar or different trends in the magnitude, and direction of urban land cover change.

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Appendices

Appendix 1

Istanbul districts and their population (source IMP, 2008)

	District	Population		District	Population
1	Adalar (Islands)	10.460	**21**	Gaziosmanpasa	1.013.048
2	Arnavutkoy	141.634	**22**	Gungoren	318.545
3	Atasehir	345.588	**23**	Kadiköy	744.670
4	Avcilar	323.596	**24**	Kagithane -	418.229,
5	Bagcilar	719.267	**25**	Kartal	541.209
6	Bahcelievler	571.711	**26**	Kucukcekmece	785.392
7	Bakirkoy	214.821	**27**	Maltepe	415.117
8	Basaksehir	193.750	**28**	Pendik	520.486
9	Bayrampasa	272.196	**29**	Sancaktepe	223.755
10	Besiktas	191.513	**30**	Sariyer	276.407
11	Beylikduzu	186.789	**31**	Silivri	125.364
12	Beykoz	241.833	**32**	Sultanbeyli -	272.758
13	Beyoglu	247.256	**33**	Sultangazi	436.935
14	Buyukcekmece	688.774	**34**	Sile	25.169
15	Catalca	89.158	**35**	Sisli	314.684
16	Cekmekoy	135.603	**36**	Tuzla	165.239
17	Esenler	517.235	**37**	Umraniye	897.260
18	Esenyurt	335.316	**38**	Üsküdar	582.666
19	Eyüp	325.532	**39**	Zeytinburnu	288.743
20	Fatih	422.941	40		

Appendix 2

Description of the land cover classification scheme

1. Built-up areas-High, medium and low –density buildings, urban Central business districts, multi-family dwellings, commercial, and industrial facilities, high impervious surface areas of institutional facilities, large transportation facilities (e.g. airports, multilane interstate/state highways), roads
2. Bareland- Areas with sparse vegetation , fallow cropland, quarries, strip mines, rock outcrops, sand beaches along rivers and lakes
3. **Grassland** ,row crop agriculture, orchids, vineyards, horticultural businesses, pastures, non-tilled grasses, golf courses
4. Forest- Evergreen, deciduous, and mixed forests
5. **Wate**r -Rivers, streams, lakes, and reservoirs

Appendix 3

CLASSIFICATION ACCURACY ASSESSMENT REPORT OF 14 JUNE 2002 LANDSAT IMAGE

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	4	0	---
Water	12	12	12	100.00%	100.00%
Bareland	18	17	15	83.33%	88.24%
Forest	18	18	15	83.33%	83.33%
Built-up	17	16	12	70.59%	75.00%
Grassland	16	12	10	62.50%	83.33%
Totals	**80**	**80**	**64**		

Overall Classification Accuracy = 80.00%

KAPPA (K^) STATISTICS =Overall Kappa Statistics = 0.7520

CLASSIFICATION ACCURACY ASSESSMENT REPORT OF 17 JUNE 2009 LANDSAT IMAGE

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	1	0	---
Water	11	11	11	100.00%	100.00%
Forest	19	17	17	89.47%	100.00%
Bareland	27	23	21	77.78%	91.30%
Grassland	15	10	10	66.67%	100.00%
Built-up	28	34	26	92.86%	76.47%
Totals	**98**	**98**	**85**		

Overall Classification Accuracy = 86.73%

KAPPA (K^) STATISTICS =Overall Kappa Statistics = 0.8287

CLASSIFICATION ACCURACY ASSESSMENT REPORT JUNE IKONOS 2008

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	26	25	25	96.15%	100.00%
Forest	43	42	39	90.70%	92.86%
Built-up	41	40	36	87.80%	90.00%
Bareland	58	57	53	91.38%	92.98%
Grassland	32	32	29	90.63%	90.63%
Totals	198	198	182		

Overall Classification Accuracy = 91.92%

KAPPA (K^) STATISTICS=Overall Kappa Statistics = 0.8971

Appendix 4

<u>Spatial and temporal urban land cover and land use change analysis in the Istanbul Metropolitan Area</u>.

The purpose of this questionnaire is to assist with the information necessary to analyze urban land cover and land use change detection. The research seeks to determine how spatial metrics, derived from remotely sensed imagery and GIS data can provide objective information and useful descriptions of urban landscape and land use change. In order to determine this, part of this questionnaire is concerned with usability of current quantitative methods and techniques being used by your department/organisation in spatial-temporal urban land cover and land use change detection.

(1) As part of a urban planning and management organisation, what kind of spatial data (eg. Satellite images) do you collect?

List 1……………………………………………………………………………………………….

List 2……………………………………………………………………………………………….

List 2……………………………………………………………………………………………….

(2) Do you also collect land cover data?

Yes ☐ No ☐

....

(3) What about land use data?

Yes ☐ No ☐

……………………………………………………………………………………………….

Spatial data collection

Land cover data	**Land use data**	**Spatial scale/resolution**	**Year of collection**

(4) Which methods do you use for the collection of this data?

☐ Point Measurements

☐ Transects
☐ Quadrant/Plots
☐ Complete Coverage
☐ Survey/Questionnaire
☐ Other ………………………………………………………………………………

(6) What is the purpose of the collection of this land cover and land use data?

…………………………………………………………………………………………………

(8) How is the data being analyzed?

…………………………………………………………………………………………………

(9) What quantitative methods and techniques do you use for urban change detection?

……………………………………………………………………………………………………

(10) How do these quantitative methods and techniques contribute to your urban planning purposes?

…………………………………………………………………………………………………

……………………………………………………………………………………………………

(11) Do you find them relevant for urban planning purposes?

Yes ☐ No ☐

(12) If relevant, how would you rank the relevance of these methods for urban planning purposes?
(1-very weak, 2-weak, 3=not weak/ not strong, 4=strong, 5=very strong) (Please tick)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

(13) Do you find them effective for your urban planning purposes?

Yes ☐ No ☐

(14) If yes, how would you rank the effectiveness of these methods for urban planning purposes?
(1-very weak, 2-weak, 3=not weak/ not strong, 4=strong, 5=very strong) (Please tick)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

(15) Do you find them efficient for your urban planning process?

Yes ☐ No ☐

If yes, how would you rank the efficiency of these methods for urban planning purposes?
(1-very weak, 2-weak, 3=not weak/ not strong, 4=strong, 5=very strong) (Please tick)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

(16) Do you find them satisfactory for your urban planning purposes?

Yes ☐ No ☐

(17) If yes, how would you rank the satisfaction of users in the application of these methods for urban planning purposes?
(1-very strong, 2-weak, 3=not weak/ not strong, 4=strong, 5=very strong) (Please tick)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

(18) Do you have any knowledge of spatial metrics methods?

Yes ☐ No ☐

……………………………………………………………………………………………………

If yes, for what purpose are they being used in urban planning efforts?

……………………………………………………………………………………………………

Additional comments?

……………………………………………………………………………………………………