DIRECT IMPACTS OF URBAN DEVELOPMENT IN İSTANBUL

ON NATURAL HABITATS: 2000-2015

A Thesis

by

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ABSTRACT

İstanbul is the largest city in Turkey with a total administrative area over 5400 km^2 and a population over 15 million as of 2018. Among the ambitions of the rapidly growing megacity is becoming a major transportation hub in global air travel. The culmination of this ambition, İstanbul New Airport is planned to be the largest airport in the world once completed. However, its chosen location, in the middle of one of the last remaining natural habitats at the outskirts of the city, has drawn great attention due to potential direct and indirect impacts of its construction on these habitats, especially over the forest and coastal areas.

This study analyzes the land cover changes due to rapid growth of the city between 2000 and 2015 and specifically focuses on the extent of land change and fragmentation caused by the construction of İstanbul New Airport. The construction of the airport serves as a case study of the impacts of big infrastructure projects on natural habitats in the context of a rapidly growing metropolitan area. To this end, the changes are quantified through land change analysis using Landsat satellite imagery. Furthermore, the changes in the spatial configuration of six land cover types –forest, bare soil, grassland/pasture, barren, built-up and water– are quantitatively analyzed using a representative set of landscape metrics.

The results indicate that the construction of the airport and the related road networks did lead to large-scale land cover changes in the study area. Forest cover and grassland/pasture decreased, respectively, by 4% to 2413 km^2 and by 16% to 443 km^2

while built-up land increased by 45% to 955 km^2. Most of the land changes happened either in the core area of the construction around the new airport or along the area where road networks developed originated from the new airport. In addition, the analysis reveals substantial fragmentation of forest, grassland/pasture and barren lands (of which most is cropland) in the study area. Mean patch size of built-up patches increased drastically, which is a reflection of the rapid growth of the urban areas. Forest and grassland/pasture patches, in contrast, became smaller and more fragmented with increased number of patches and smaller mean patch size. On the European part of the study area where the new airport is located, the number of patches of forest and grassland/pasture increased, respectively, by 2% to 3837 and by 90% to 8078 respectively. On the other hand, mean patch size for forest and grassland/pasture decreased from 0.114 km^2 and 0.032 km^2 to 0.102 km^2 and 0.015 km^2. Overall, the study provides a comprehensive understanding of direct impacts on landscape of urban development during a period of particularly rapid growth in İstanbul.

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Contributors

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NOMENCLATURE

IsoData   Iterative Self-Organizing Data Analysis Technique

USGS   United States Geological Survey

NBI   New Built-up Index

PCA   Principal Component Analysis

MSI   Mean Patch Shape Index

LSI   Landscape Shape Index

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

1.1.1 Urbanization in İstanbul

İstanbul is Turkey's historical, cultural and commercial center, as well as an important center of tourism. İstanbul has always been an important international port due to its strategic location as the only city connecting continents of Europe and Asia (Ozus et al., 2011). Modern industries began to develop in İstanbul by mid-nineteenth century as İstanbul became an important node for European commercial network (Enlil, 2011). With industrialization in the mid-twentieth century, the demand for working class population increased, bringing migration from rural to urban areas (Dogan and Stupar, 2017). At the same time, the need for labor force in farming decreased and the need for urban housing increased. As various industries gathered in and around the city the population of the city continued to grow fueled by massive rural-urban migration across the country; in the meantime, insufficient housing supply led to sprawling informal and illegal settlements (Enlil, 2011). Nowadays, İstanbul is a metropolis with a population of more than 15 million (Turkish Statistical Institute, 2018). Continuing rapid urbanization process brought opportunities but also challenges of growing population, accelerating land change and decreasing of natural habitats. City infrastructure is also under great strain to serve the growing needs of the city's burgeoning population.

In order to fulfill the increasing air traffic flow and to realize the city as a major transportation hub in global air travel, the plan for a third airport is purposed. Currently, the main airport in İstanbul is Atatürk Airport on the European side which is also the main base for the national flag carrier, Turkish Airlines. The airport is the important connection to the world with more than 180 international flight to over 100 countries. The second airport, Sabiha Gökçen Airport on the Asian side, mainly serves domestic flights. Atatürk Airport now has 3 runways, 2 terminal buildings and a cargo terminal (Saldıraner, 2012). However, increasing air traffic load puts strain on the airport which lacks sufficient capacity to meet the demand. Furthermore, it is surrounded by several residential neighborhoods in three directions and by the Marmara Sea to its south. Therefore, a few years ago, plans for a new airport with much larger capacity were laid out, one that can accommodate further increases in air traffic and larger aircrafts. The selection of the site for the new airport, however, proved controversial as its construction would mean destruction of habitats critical for local biodiversity as well as detrimental to ecosystem services such as freshwater provision to the growing megacity.

Land change has been regarded as one of the key drivers of biodiversity loss (Sharma et al., 2018). The major causes of land degradation in Turkey are urbanization, transportation, agriculture, industry and tourism (Yilmaz, 2010). A lot of land were converted from natural land cover such as forests to agriculture and urban land to fulfill as humans' demands on land resources increased. Growing tourism sector is also another powerful driver disturbing local ecosystems. The forests and coastal habitats in the administrative boundaries of İstanbul provide significant ecosystem services. These

natural habitats lie on migration paths of birds, provide clean the air, supply water and serve as urban life support systems (Baz et al., 2009). Habitat protection is vital and urgent especially for those species that are already under pressure due to habitat loss.

1.1.2 Large Infrastructure Projects

Large infrastructure projects have long been regarded to have significant impacts on the environment, mostly negative. There are numerous studies analyzing the impacts of infrastructure, especially critical transportation infrastructure, on the local habitats. Roads, bridges, and railways are considered to be efficient and economic ways for transportation and trading. Van Bohemen (1998) and Sharma et al. (2018) indicate that linear infrastructure such as roads and rail can have negative impacts like habitat loss and landscape fragmentation by reshaping the habitats and landscapes into smaller and more isolated units. Van Bohemen (1998) overviews the Second Dutch Transportation Structure Plan to raise people's awareness of conserving ecosystems and reducing negative effects of urban infrastructure when planning road construction.

Several studies also document the land change caused by large infrastructure projects such as dam construction and mining activities. Bulleri and Chapman (2010) state that common coastal urban infrastructure like breakwaters, jetties and seawalls can be a driver converting marine environment by influencing intertidal and shallow subtidal habitats, thus inducing more severe global changes such as sea-level rise. Ritter et al. (2017) illustrate the Environment Impact Assessment over Belo Monte Dam in Brazil indicating that this large hydroelectric dam can result in an increase in deforestation, lead to changes in flood cycle and even contribute to global warming. Laurance et al.

(2015) also mention that large hydroelectric dams in the Amazon basin and a number of major hydroelectric projects in Southeast Asia can have severe impacts on local ecosystems and species. Kaiser (2009) examines the environmental impact of the East Port Said harbor in Egypt, which helps maintain fueling stations and serves as a summer resort. It turns out that it may have influenced the surrounding landscapes like creation of salt crust and reduction of marshes and wetlands with industrial activities and increasing cultivated lands and fish farms.

There are several other studies on the impacts of large urban infrastructure including but not limited to power plants, oil and gas extraction projects, aerospace projects (Flyvbjerg, 2007). However, studies evaluating potential impacts of large infrastructure with scale as large as an airport are still rare, especially in an area that has a number of natural habitats like İstanbul. In addition, as airports rely on other ground transportations like roads and railways, the impacts would be amplified to a broader scale. The lands in proximity to these new transportation infrastructure typically undergo subsequent development, which creates new urban centers with commercial and industrial facilities to support the airport operation as well as residential development, hence, extend the immediate direct impacts of the construction of the airport on landscape. Moreover, many studies analyze the impacts of large infrastructure based on economic benefit or policy implication. This study explores the specific direct impacts of the infrastructure project on land cover.

İstanbul New Airport in Turkey, which is planned to be the largest airport in the world once completed that covers a total area of 76.5 km^2 with an annual passenger

capacity of 150 million, has drawn particular attention both nationally and internationally (Dogan and Stupar, 2017). The major concern is that the construction of this new airport and its related road networks will destroy the ecological balance of the surrounding forests and coastal habitats which can also reflect the potential impacts of urban development towards the nearby environment.

1.1.3 Remote Sensing and GIS Techniques

Remote sensing and GIS are the two fundamental and most widely used techniques for studying land use and land cover classification and land change. Remote sensing provides a cost-effective way to obtain spatial data covering large areas and over long time periods (Canaz et al., 2017). Integrated with GIS techniques, urban dynamics can be detected and analyzed by monitoring land change. Land change analysis is one of the major applications of remote sensing data and can be detected with multi-spectral remote sensing imagery of repetitive acquisition based on per-pixel or object-oriented classifications (Jensen, 1996, Sunar, 1998). But there are also challenges for satellite images including obtaining data of uninterrupted time series and detecting subtle changes (Turner Ii et al., 2007)

There are numerous remote sensing data sources available with varying spatial resolution. There are existing land cover data like Coordination of Information on the Environment (CORINE) and Global Land Cover Facility (GLCF) land cover that include land cover type as grassland/pasture, agriculture, built-up etc. There are high and very high spatial resolution data, such as IKONOS, QuickBird, AVHRR and WorldView. These data sources can provide very ideal structure, texture and other land cover

information, but the cost and data availability over time should be considered (Zhou et al., 2014). Low spatial resolution data can only provide coarse information which are insufficient for monitoring land change accurately. Moderate resolution data, such as Landsat data, have more advantages over other data sources for my research purpose specifically.

Landsat can provide moderate resolution data with longer time period which is more capable for temporal dynamics analysis and is more suitable for spatial pattern modeling and large-area mapping in consideration of its availability and data coverage (Cohen and Goward, 2004). However, limited resolution of Landsat data would result to classification confusion for land types with a relatively small scale due to the unclear object information. Moreover, using spectral response alone for classification may not be sufficient for land cover with similar spectral characteristics. However, in account of the wide temporal and spatial range of data availability, Landsat is still proved to be sufficient for land use and land cover analysis, especially for timely monitoring of large areas (Karaburun et al., 2010, Sanli, 2011, Kowe et al., 2015).

1.1.4 Land-Use and Land-Cover Change

Land-use and land-cover change (or, land change) has become an important and major part of global change. Two main drivers for land changes are natural processes and human activities. Land changes to meet human's immediate needs often lead to degradation of natural resources (Foley et al., 2005). Therefore, land change detection analysis has important meaning for detecting and analyzing the influence of human activities on the ecosystems.

In land-change analysis, the first step is to get land-use and land-cover map to classify the land types. Land-use and land-cover maps are essential to understand the land use and land cover dynamic over a period in the region. The accuracy of the classification results is vital to land change analysis as the result of land use and land cover type classification can directly influence the analysis of land change. There are several techniques for automatically obtaining land use and land cover classification. These methods can be categorized to supervised and unsupervised methods. Supervised classification needs knowledge of the ground-truths as prior knowledge which may need field work over the study area (Al-Ahmadi and Hames, 2009). Iterative Self-Organizing Data Analysis Technique (IsoData) algorithm is an unsupervised classification method that clusters pixels into a number of groups according to pixels' spectral characteristics (Sunar, 1998). IsoData is proved to be able to provide better results in a very heterogeneous areas (Rozenstein and Karnieli, 2011).

Pre-classification and post-classification are the two basic techniques for land use and land cover classification and change detection. Pre-classification can help improve the accuracy of the classification results by emphasizing the significance of land change detection (Peiman, 2011, Sanli et al., 2008). Techniques like principle component analysis, band combination or image differencing can help reduce data redundancy of satellite imagery and therefore highlight the significance of land cover. Post-classification provides change information of "from-to" by comparison of classification images with time series (Peiman, 2011, Sanli, 2011). Post-classification results can show

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the scale, rate, and extent of land changes the study area experienced over the time period of interest.

1.1.5 Landscape Spatial Patterns

Urban areas consist of various types of built-up structures, water bodies, bare soil, and different types of grassland/pasture (Herold et al., 2002). In addition, urbanization is a complex dynamical process and a major driving force of land change that has greatly changed natural landscapes and results to transformation in landscape structures (Akın et al., 2015). These effects should be considered at a large-scale and these significant land changes need to be detected, monitored and analyzed (Green et al., 1994, Luck and Wu, 2002). Landscape metrics can quantify landscape structure and spatial pattern of landscape function and changes (McGarigal and Marks, 1995, Luck and Wu, 2002). Landscape metrics can be used to measure landscape structure and complexity to better understand landscape characteristics (Gökyer, 2014).

This study uses the case of the recent growth of İstanbul including a large infrastructure project to study urbanization's direct impacts on natural habitats. Remote sensing, GIS and landscape metrics are integrated in the study to analyze the extent of changes in landscapes, habitat loss and fragmentation to provide an understanding of those significant potential impacts of land changes caused by urban development. With Landsat data collected, land change of the entire İstanbul province over a time period of 15 years is analyzed.

The findings of the direct impacts of urbanization on the surrounding habitats can be used to raise public attention to protect the environment, and for governments and

agencies to reduce those negative impacts when planning and processing urban constructions.

1.2 Research Objectives

This study asks the following questions in the context of extensive changes İstanbul underwent over the past two decades:

1) How did the landscape change and fragment in İstanbul since 2000?

2) How did the recent construction of the new airport and supporting transport infrastructure contribute to these changes in the landscape?

To address the above questions, the study has the following three major objectives:

1) Analyze the land cover and land change in İstanbul from 2000 to 2015.

2) Quantitatively analyze landscape fragmentation between 2000 and 2015 to evaluate the impacts of urban development and the airport construction on the surrounding natural habitats.

CHAPTER II

LAND-CHANGE ANALYSIS OF İSTANBUL

2.1 Introduction

Large infrastructure projects can have significant impacts on the surrounding environment. The third airport of İstanbul in Turkey, planned to be the largest airport in the world once completed, has drawn particular attention both nationally and internationally. The airport is currently under construction in the north-west of İstanbul along the Black Sea coast in the Arnavutköy district on the European side (Figure 1). The forests and coastal habitats in the area are rich in biodiversity and provide significant ecosystem services but have already been under threat from illegal and unplanned development (Güneralp et al., 2013). The construction area of the new airport includes state-owned forest lands. In order to construct the airport, many trees are cut or moved to new places. In the study, the direct impacts of the new airport and its related road networks on the surrounding forests and coastal habitats specifically are analyzed.

2.2 Objectives

The objective of this chapter is to get a comprehensive understanding of land change in İstanbul province during the 15 years period. There are 4 major tasks in this chapter, which are to:

1) Classify the pre-processsed Landsat images for year 2000 and 2015 of the study area separately to achieve the land cover classification maps with pre-classification techniques and unsupervised IsoData algorithm.

2) Conduct an accuracy assessment of the two classified maps for 2000 and 2015 with Google Earth as ground true value in order to estimate the sufficiency of the classification results.

3) Describe the land cover of the study area in 2000 and 2015 quantitatively and spatially.

4) Map and analyze the land cover change of the study area from 2000 to 2015, especially for the forest and coastal areas around the construction to analyze the land change over the period.

2.3 Materials and Methodology

2.3.1 Study Area

The study area is the administrative region of İstanbul province, Turkey, covering a total area of over 5400 km^2 (Figure 1). İstanbul is the most populated city in Turkey with a population of more than 15 million (Turkish Statistical Institute, 2018). It is the economic and cultural center of the country. İstanbul is a crucial crossroad that connects the European continental landmass and the Asiatic continental landmass, and two large water bodies as well, the Black Sea and the Marmara Sea. The rich biodiversity of the city is partly due to this unique location and topographic characteristics (Güneralp et al., 2013). The majority part of İstanbul has a climate type of Mediterranean and also has temperate continental climate. All these natural and anthropogenic factors contribute to the rich biophysical diversity in the city (Güneralp et al., 2013).

Rapid urban expansion in İstanbul started in early 1950s with increasing

population and rapid industrialization, leading to a number of negative impacts on the

environment (Ozus et al., 2011, Güneralp et al., 2013). With the construction of bridges

on Bosphorus and peripheral highways, suburbanization started during 1970s and 1980s

(Ozus et al., 2011). Also, globalization since the 1980s has been a major force changing

national spatial, social and economic structure (Kocabaş, 2006).

Figure 1. The location of İstanbul New Airport (Base map: Landsat 7 image on 09.04.2000)

Most of the urban areas in İstanbul is concentrated at the southern part of the

city, both on the European side and Asian side. These urban covers include residential

areas, commercial areas, institutional areas and more. While the northern part of the city

has a giant scale of forests and coastal habitat covered. The forest in the north can be a

natural barrier to force the urban to develop along the coast of Marmara but the city

continued to grow northwards because of the irrational factors of urban planning

(Karaburun et al., 2010, Geymen and Baz, 2008). The new airport is also located at the northern part of the city which is surrounded by forests. As a result, the site selection has led to huge controversy as the construction could bring to negative impacts on the vulnerable forest and coastal ecosystems surrounded.

2.3.2 Data

The study is supported by a verity of data collected. Altogether 4 Landsat remote sensing imagery sourced from United States Geological Survey (USGS) are used for land type classification and land change analysis, including 2 Landsat 7 images for 2000 and 2 Landsat 8 images for 2015 (Table 1). All collected Landsat images are Landsat Collection 1 Level-1 products. Landsat data keep a good balance between spatial resolution and availability compared with data of other sensors, which enables us to obtain sufficient images that could cover the study area for conducting the land change analysis.

Table 1. Information on Landsat Imagery

Date	Sensor	Path	Row	Spatial Resolution	Land Cloud Cover	Source
September 04, 2000	ETM+	180	31	30 meters	0	USGS
September 04, 2000	ETM+	180	32	30 meters	0	USGS
September 06, 2015	OLI/TIRS	180	31	30 meters	.02	USGS
September 06, 2015	OLI/TIRS	180	32	30 meters	.01	USGS

With the Landsat Enhanced Thematic Mapper Plus (ETM+) sensor, Landsat 7 imagery have a ground spatial resolution of 30 meters for the three visible bands, one near-infrared band and two shortwave-infrared bands, 60 meters for the thermal band. In addition, Landsat 7 has an extra panchromatic band with a resolution of 15 meters (USGS). Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) is carried on Landsat 8 with a spatial resolution of 30 meters for ultra blue band, the three visible bands, one near-infrared band and two shortwave-infrared bands, 100 meters for the two thermal bands. Landsat 8 also has a panchromatic band with a resolution of 15 meters and a cirrus band with a resolution of 30 meters (USGS).

2.3.3 Pre-Processing

ENVI is introduced as the primary satellite image processing software in the study. All the Landsat images are first calibrated and the 2015 images are processed by FLAASH Atmospheric Correction Model. For 2000 and 2015 respectively, each 2 Landsat images are mosaicked to completely cover the land of İstanbul and then clipped by the shapefile of the administrative boundary with a buffer of 0.7 kilometers. The buffer is processed to cover all the land as the actual land boundary can be different from the shapefile. New Built-up Index (Chen et al., 2010) is added as an additional supporting band for the 2000 image to help separating built-up and bare soil by enhancing the spectral characteristic of concrete and some of the clay roofs. The equation for the index is:

$$NBI = \frac{TM3*TM5}{TM4} \tag{1}$$

NBI is used to automatically extract built-up area and has better performance on distinguishing residential areas and bare areas compared with other index such as Normalized Difference Built-up Index (NDBI) (Chen et al., 2010). Followed by NBI index calculation, forward Principal Component Analysis (PCA) with covariance matrix is processed for the two clipped images of both years. PCA can help reduce the linear correlation between bands, thus enhance the spectral characteristic of certain kinds of land cover. Three visible bands, one near-infrared band and two short-infrared bands are processed and among the six PCA resulted bands, 3 bands, which are Band 2 enhancing forests, Band 3 enhancing concrete and band 5 enhancing residential areas are selected for further land cover classification.

2.3.4 Land Cover Classification

IsoData is applied in the study to process the land cover classification. IsoData algorithm is an unsupervised classification approach where all pixels are classified to the nearest class without providing sample classes. It is used to create a number of clusters and classes that are defined in one image and needed to be later labeled and combined in order to create a land cover classified map. With IsoData, there is no need to determine the class number before processing classification, which is an advantage of the method. Three input parameters are needed to be defined, which are the maximum number of classes, maximum iteration and change threshold. The parameters determine the precision of the classification results. The larger the maximum number of classes and maximum iteration are and lower change threshold is, the more detailed results will turn

out. However, too many clusters in the results can also be time consuming for processing and gathering.

In the study, both pre-processed images are classified by IsoData independently with the maximum number of classes as 500, maximum iteration as 500 and change threshold as 1%. The pixels classified by the process are then clustered into 6 land types: water, forests, grassland/pasture, built-up, bare soil and barren based on the Anderson (1976) Level 1 classification scheme. Water includes all open water, including seas, lakes, rivers and ponds. Forests includes natural forests and plantation. Grassland/pasture includes small areas of artificial planted green grassland/pasture. Built-up includes residential, commercial, industrial and transportation infrastructure. Bare soil refers to agricultural land with artificial cultivated cropland. Barren includes construction areas, sand beaches, mine field and other land with no cover on the surface. After getting preliminary results for land cover classification, Majority Analysis, which is a focal statistics, is calculated with a 3 by 3 window to minimize scattered isolated points. Some pixels are also manually edited to improve the accuracy of the classification results.

2.3.5 Accuracy Assessment

Random points samples are generated from classification results to assess the accuracy of the results and historical images from Google Earth of the same years are introduced as ground true reference data. Stratified Random Proportionate sampling with a proportion of 0.05% are applied for the six land types for both years. At least 50 points for each land type are ensured. Each sample point is then compared with Google Earth based on expert knowledge to determine whether the land type assigned in the final

classification results is correct. Confusion matrices are computed to calculate user's accuracy, producer's accuracy and overall accuracy in order to quantitatively evaluate the accuracy of land cover classification results. The Standard Kappa index is also introduced in accuracy assessment. The Standard Kappa index has been a traditional accuracy assessment technique for remote sensing classification. Kappa values greater than 0.75 indicate strong agreement beyond chance, values between 0.40 and 0.75 indicate fair to good, and values below 0.40 indicate poor agreement (Congalton, 1991). In addition, quantity disagreement and allocation disagreement are applied as Pontius (2000) stated that the Standard Kappa can be not accurate for both quantity and location (Pontius Jr and Millones, 2011). Quantity disagreement and allocation disagreement were later introduced by Pontius Jr and Millones (2011) to take place of the standard Kappa in order to evaluate classification accuracy more precisely.

2.3.6 Land-Change Analysis

First, area and the percentage of total area are calculated to show the areal cover of each land type for both 2000 and 2015. Areal change is calculated to provide an overall view of the loss and gain of each land type quantitatively. In order to further figure out the explicit process of land change, a change matrix is computed using Tabulate Area in ArcGIS. The change matrix can provide more detailed information of land change patterns quantitatively. The gains and loss each kind of land cover are illustrated with the change matrix. Finally, land changes are presented graphically with bi-temporal overlay to spatially and qualitatively show land changes. The most significant land change processes are discussed according to the maps.

2.4 Results and Discussion

2.4.1 Accuracy Assessment

Confusion matrices are computed with the random sample points generated from land cover classified images for each year (Table 2). Water and forest land types have the highest producer's accuracy and user's accuracy for both years over 90%. Water and forest land cover types both have significant spectral signatures that lead to high agreement between classified images and reference data. While barren and bare soil land types have relatively low user's accuracies lower than 80%. This can be due to the limited Landsat resolution that makes it hard to separate the classes when assigning classes in the procedure of IsoData classification. However, bare soil land type has a high producer's accuracy. This is mainly because bare soil can be confused with built-up, grassland/pasture and also barren as they share similarity in spectral characteristic. Some of the roof tops in built-up areas in the study area are made of clay which has high similarity of spectral signature with bare soil. The confusion between bare soil and grassland/pasture is mainly because of the distribution of bare soil in grassland/pasture area when the plants are not flourish enough to cover the soil. Nevertheless, these can also lead to low user's accuracy for bare soil. Grassland/pasture land type has fair producer's accuracy and user's accuracy majorly between 75% and 80%. Built-up land type has more balanced producer's accuracy and user's accuracy both of over 85% which can meet the requirement for the study.

The 2000 classified image has an overall accuracy of 90.842% and the 2015 classified image has an overall accuracy of 91.084%. Overall accuracies, however, can

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be biased by forest land type as forest has a quite large distribution in İstanbul. This large proportion of random point samples with high accuracy can have a dominated role in the calculation of overall accuracy. Kappa value for year 2000 is 0.871 and 0.869 for year 2015, indicating both values have strong agreement between the classification results and reference data beyond the chance agreement. Quantity disagreement and allocation disagreement are also introduced to better estimate the classification accuracy (Table 3). Quantity disagreement is the amount of difference between the reference map and a comparison map that is due to the less than perfect match in the proportions of the categories while allocation disagreement is the amount of difference between the reference map and a comparison map that is due to the less than optimal match in the spatial allocation of the categories, given the proportions of the categories in the reference and comparison maps (Pontius Jr and Millones, 2011). For 2000 and 2015 respectively, the quantity disagreement and allocation disagreement are 3% and 6% and 5% and 4%, which show that the classification results are accurate enough to conduct the land-change analysis.

Table 2. Confusion matrices for (A) 2000 and (B) 2015 land cover classified results using stratified random proportionate sample points.

Classified Data	Reference Data						Overall	Producer Accuracy
	Bare Soil	Forest	Built-Up	Barren	Grassland /pasture	Water		
Bare Soil	380	0	21	6	7	0	414	91.787%
Forest	45	1315	9	12	12	1	1394	94.333%
Built-Up	28	0	322	16	0	0	366	87.978%
Barren	18	4	17	111	4	2	156	71.154%
Grassland/ pasture	19	17	4	20	233	0	293	79.522%
Water	0	0	0	0	0	238	238	100.000%
Overall	490	1336	373	165	256	241	2861	
User Accuracy	77.551%	98.428%	86.327%	67.273%	91.016%	98.755%		90.842%
Standard Kappa	0.871							

(A)

Table 2. Continued

| Classified Data | Reference Data | | | | | | | |
	Bare Soil	Forest	Built-Up	Barren	Grassland /pasture	Water	Overall	Producer Accuracy
Bare Soil	352	0	7	7	15	0	381	92.388%
Forest	65	1378	9	3	18	1	1474	93.487%
Built-Up	52	4	460	15	9	2	542	84.871%
Barren	1	3	2	42	2	2	52	80.769%
Grassland/ pasture	7	14	1	14	142	0	178	79.775%
Water	0	2	0	0	0	231	233	99.142%
Overall	477	1401	479	81	186	236	2860	
User Accuracy	73.795%	98.358%	96.033%	51.852%	76.344%	97.881%		91.084%
Standard Kappa	0.869							

(B)

**Table 3. Quantity disagreement and allocation disagreement for 2000 and 2015 land cover classified results using stratified random proportionate sample points.**

|	Sample		Population	
	Quantity Disagreement (%)	*Allocation Disagreement (%)*	*Quantity Disagreement (%)*	*Allocation Disagreement (%)*
2000 Classified Image	3	6	3	6
2015 Classified Image	5	4	5	4

2.4.2 Land Cover Classification

The classification results for 2000 and 2015 are presented (Figure 2). Generally, İstanbul has a large cover of forest at the northwest and northeast parts on the European side and the majority of north and middle parts on the Asian side. Built-up areas are highly centralized on the south along the common border of European and Asian continents and the coastal area of the Marmara Sea. Agriculture is mainly concentrated at the southwest part of the European side. Distribution of barren and grassland/pasture are more scattered.

In the 2015 classification map, there is an apparent small area of barren land appearing at mid-north on the European side where used to be forest and grassland/pasture in 2000. This is the location of the construction of the new airport. There is also linear distribution of barren origins from the new airport which is the road networks developed from the airport. But in both results, there is still confusion between built-up, bare soil and barren as there are barren land mixed up with built-up land in the 2000 classification map and urban land confused with agriculture that is classified as land type bare soil in this study.
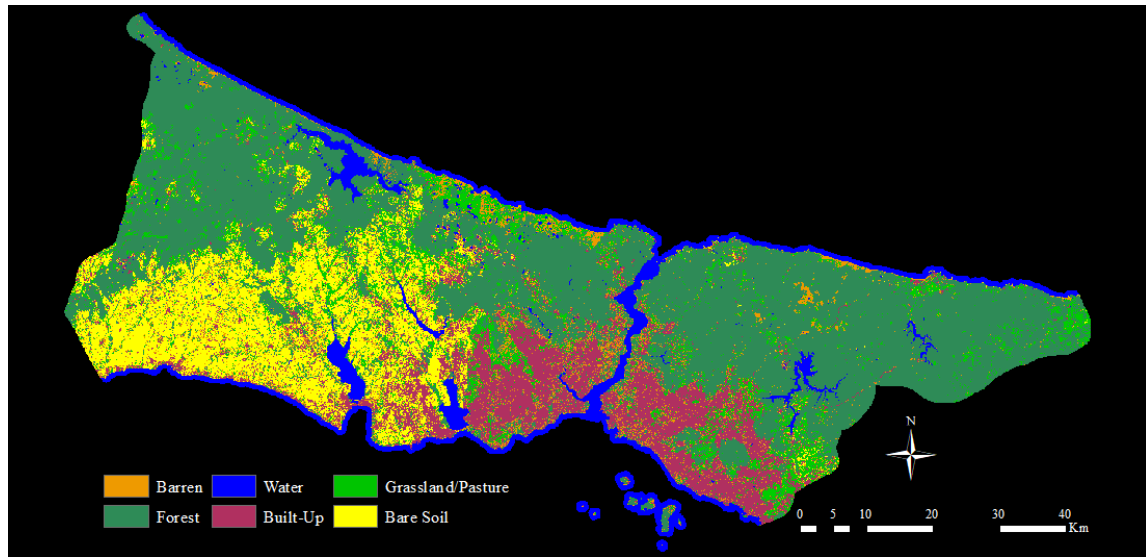
(A)
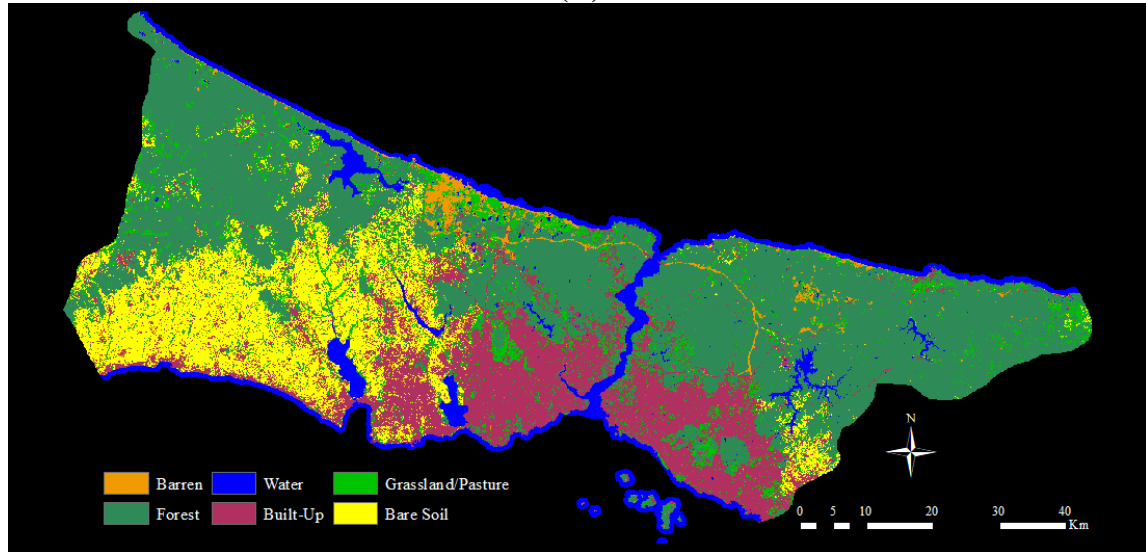
(B)

Figure 2. Classified maps for (A) 2000 and (B) 2015

2.4.3 Land-Change Analysis

Total areas and proportion for each type of land cover for both 2000 and 2015 can provide a preliminary and general idea of land change pattern during the period (Table 4). From the data of land change areas and proportion, built-up land type has the

most increase by 45.06%, which is within expectation. However, barren has the most

decrease by 65.26% which is unexpected. In the area of the new airport's construction at

mid-northern part of the European part of İstanbul, there are large areas that transform

from forest, bare soil and grassland/pasture to barren and built-up. That area is the

biggest contribution for built-up and barren gains. But barren has a great loss at the

central part of the city where built-up is concentrated. Urbanization in the area that

turned construction to urban can explain the result, but classification errors and

confusions can also be blamed as barren has a relatively low distribution of only 5.44%

of the total area in 2000 and 1.89% in 2015. The small sample size of barren for

classification can lead to relatively low classification accuracy that is not satisfying as

discussed. Forest land has a loss of 3.88%. Although the proportion is not big, but

considering of total area, the absolute area lost is 97.3 km^2 which is noticeable. Water

has the lowest rate of change with 2.09% loss of total area with few transformations.

There are some new sandy beaches, but urban development doesn't bring to significant

direct influence on water bodies.

Table 4. Area and percentage of total area for each cover type and land cover change from 2000 to 2015 for İstanbul.

	2000		2015		LULC Change	
	Area (km^2)	% of Total Area	Area (km^2)	% of Total Area	Area (km^2)	% of Change
Bare Soil	745.88	14.48%	820.28	15.93%	74.39	9.97%
Forest	2509.89	48.73%	2412.59	46.86%	-97.30	-3.88%
Built-Up	658.62	12.79%	955.41	18.56%	296.79	45.06%
Barren	279.99	5.44%	97.28	1.89%	-182.71	-65.26%
Grassland/pasture	527.02	10.23%	443.36	8.61%	-83.66	-15.87%
Water	428.68	8.32%	419.71	8.15%	-8.97	-2.09%

Table 5. Change matrix of land change from 2000 to 2015 for İstanbul.

		2015 Land Cover (km²)					
		Bare Soil	**Forest**	**Built-Up**	**Barren**	**Grassland/pasture**	**Water**
2000 Land Cover (km²)	**Bare Soil**	639.22	0.00	96.41	7.18	2.50	0.57
	Forest	31.24	2365.93	57.11	37.50	11.69	6.42
	Built-Up	0.00	0.00	658.62	0.00	0.00	0.00
	Barren	47.69	0.00	78.91	25.21	121.42	6.76
	Grassland/pasture	92.11	41.00	75.92	20.77	294.43	2.77
	Water	0.29	0.00	6.91	5.43	11.47	402.99

Together with land change matrix (Table 5), a more specific analysis of the land change pattern can be presented. Most of the built-up areas in 2015 are transformed from bare soil, barren, grassland/pasture, and forests as well. These areas are clusters around the construction area and the central part of the city alone the common border of the European side and Asian side, which is the traditional downtown area of İstanbul. Forest areas has a slight decrease of 3.88% of the total area. Forest area has a loss of 57.11 km^2 that transformed to built-up, 37.5 km^2 to barren and 31.24 km^2 to bare soil. But forests also have a lot gain from grassland/pasture of 41 km^2 which can be because of human forest plantation. Bare soil areas, which are mostly agriculture areas, transformed a tremendous 96.41 km^2 to built-up. However, bare soil also got a great gain of 92.11 km^2 from grassland/pasture. Although there is land that has experienced the transformation from grassland/pasture to bare soil, the growth situation of the plants can also have significant influence on the classification of the two land types. Barren gains a lot from forest of 37.5 km^2 and grassland/pasture of 20.77 km^2, these gains are mostly due to urban constructions. Barren experienced loss mainly to bare soil of 46.69 km^2 and built-up of 78.91 km^2. Transformation from barren to built-up is due to the built-up of the construction areas and barren to bare soil may due to land reclamation. Water basically remain the same as water bodies are relatively stable and not disturbed.

For those land types that have tremendous change rates, there is more detailed analysis on why these transformations happened with the bi-temporal overlay maps for these changes.
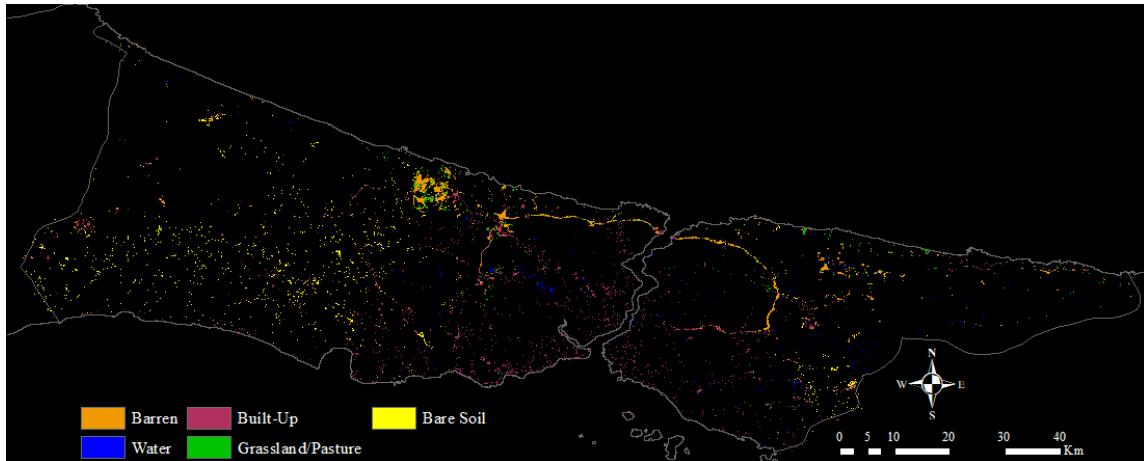
Figure 3. Forest loss from 2000 to 2015

Forest areas have apparent loss (Figure 3) around the construction area of the new airport and its related road networks. These areas are transformed mostly to barren and grassland/pasture indicating the development of urban, and some built-up. In the central urban areas, there is also forest loss that transformed to built-up. There is urban development in these traditional urban areas that causes the loss of green grassland/pasture but this transformation can also partly due to the difference of grassland/pasture growth of the two years. This problem can also be reflected in the bare soil and barren changes. In the mid-north part of the Asian side, there is also land changed to barren from forest. This area is developed as an industrial area with several mining companies, electrician companies, and garbage collection service. In addition, in the north-east part of Asian side, there is an area not far from the coast that turned to barren and built-up.
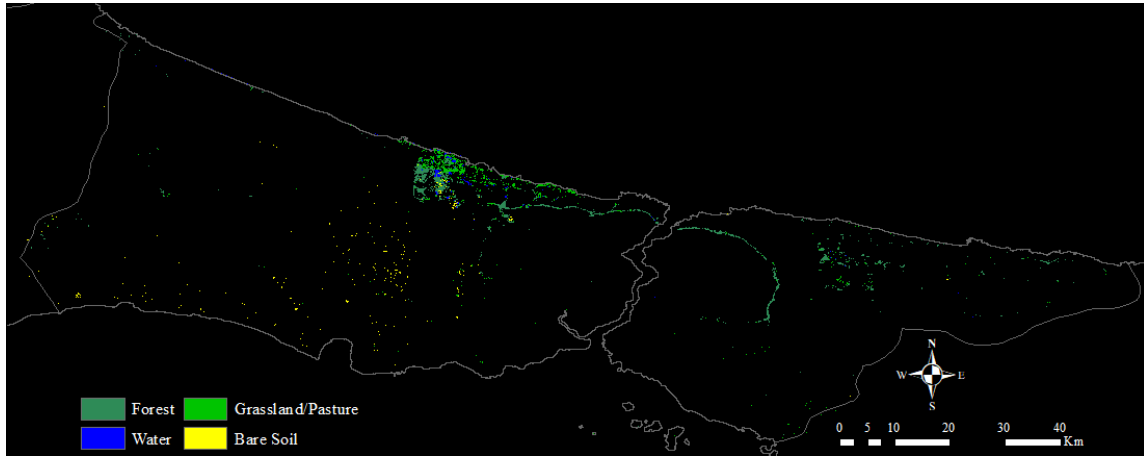
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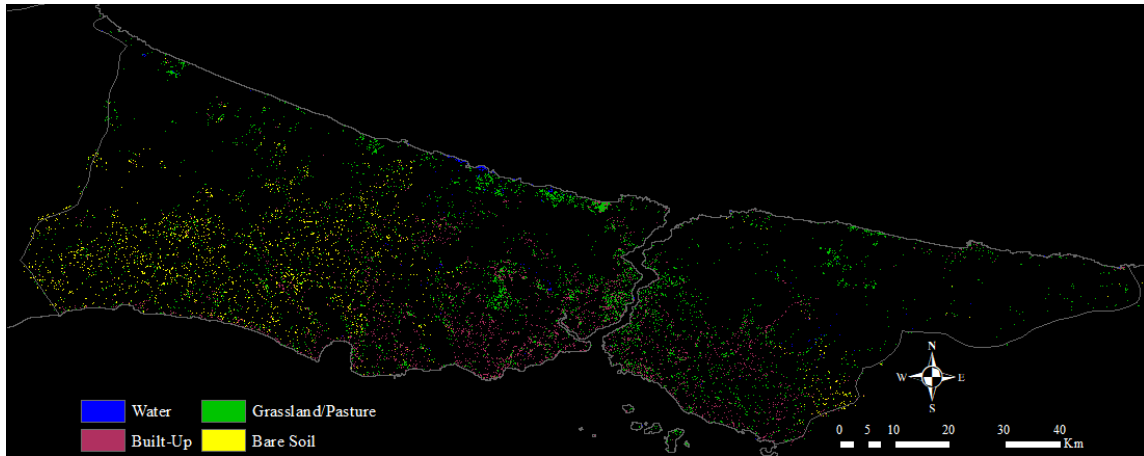**Figure 4. Barren gain from 2000 to 2015**

Figure 5. Barren loss from 2000 to 2015

Barren gains a lot land from forest, grassland/pasture and some water around the

new airport and its related road networks (Figure 4). These transformations are mainly

construction areas of the new airport and the related constructions. The most important

road network is highway O-6 that connects the European side and Asian side by Yavuz

Sultan Selim Bridge which is very clear in the map that has transformed from forest to

barren. Barren loss (Figure 5) is rather scattered. Most of the barren that converted to

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built-up in the central area of the city is because of the completion of constructions. Some of the loss can be due to different growth of vegetation that causes the land cover classified as grassland/pasture or bare soil.
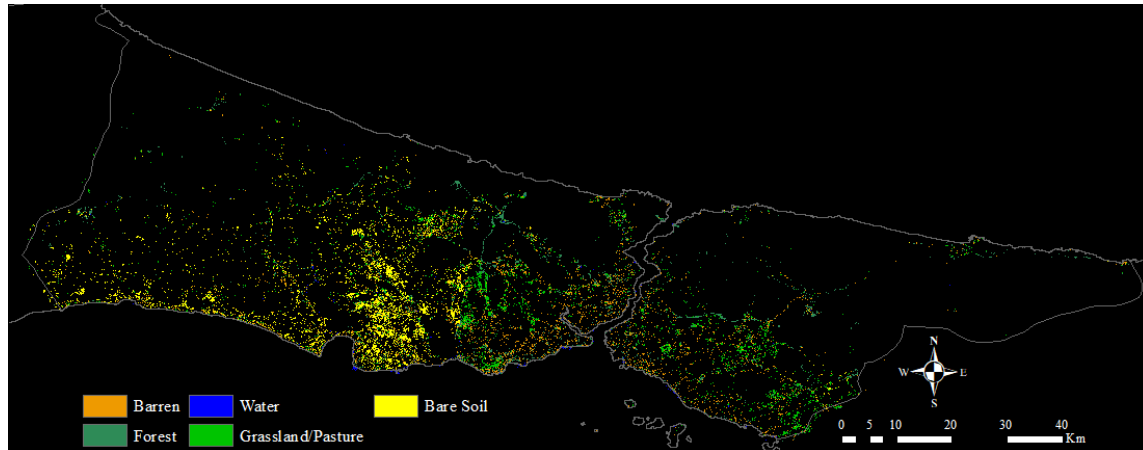

Figure 6. Built-up gain from 2000 to 2015

Built-up gains (Figure 6) are distributed all around the city including the airport area, central urban areas and the agriculture area at mid-south of European part. These linear land transformations from forest, grassland/pasture and bare soil to built-up can indicate the dramatically developed road networks around the new airport. However, there is not much land changed to built-up in the core area of the new airport as the area is still under construction and is classified to barren as a construction area as explained in the barren gain. Coastal areas along the south coast also have lots of urban developed from water. These areas are mostly developed to harbor, shipyards, hotels, public beaches, and other public services like museums by sea reclamation.

2.5 Conclusion

In the classification, there are confusions between bare soil and built-up as the two land types share similarity in spectral characteristic. Most of the roof tops in the urban areas of İstanbul are made of clay that has very similar spectral response as bare soil. This result is mostly within expectation and acceptable in consideration that built-up pixels are small, heterogeneous and mixed and the resolution of Landsat data is limited. Grassland/pasture growth also has significant influence on classifying bare soil, forest and grassland/pasture. The more flourish the grassland/pasture is, the lager value the near-infrared band will be. It is tough to get the perfect classification that can completely separate these three land types as the growth of grassland/pasture are sometimes similar among different types. The overall accuracy for land cover is still reasonable for land cover analysis and practicable to be used for land change analysis.

Land changes around the construction area of the new airport and its related road networks are quite clear in the maps. Large area of land is developed to built-up and construction areas which are classified as barren from other land types (forest, grassland/pasture, bare soil and water). Also, because of the road networks developed for the airport service, the impact of urban expansion due to the new airport actually extended to a broader scale along to the Asian side.

CHAPTER III

SPATIO-TEMPORAL PATTERNS OF LAND CHANGE IN İSTANBUL

3.1 Introduction

Spatial pattern refers to the organization of same or different kinds of landscape with regularity, including natural formed patterns such as the concentration of natural land cover like forest, water and species habitats and man-made patterns such as cities, towns and mining districts. Spatial pattern can reflect distribution and fragmentation changes of landscapes that can be very useful for analyzing the reaction of environment towards human activities qualitatively and quantitatively. Spatial pattern can be affected by spatial heterogeneity which is generally defined as the complexity and variability of a system property (Li and Reynolds, 1994). Spatial configuration and spatial composition are the basic spatial components of landscape heterogeneity (Gustafson, 1998). Spatial configuration, which is a major subset of spatial heterogeneity, is used to describe spatial structure such as size and shape of landscapes, density, connectivity and dimension. Spatial composition is non-spatial and is used to describe number of landscape categories and landscape diversity like richness and evenness together with structure (Gustafson, 1998). Common indicators used to describe land use change, like absolute area change and land change rate can only provide very limited information, especially information of landscape pattern (Seto and Fragkias, 2005). Thus, more specific indicators are needed to analyze landscape pattern.

Urbanization is a complicated and dynamic process that can change structure, shape and function of urban area involving economic, political and social factors, influencing the landscape at both temporal and spatial scales (Nor et al., 2017). The process can also bring to landscape patterns that significantly change the ecosystem patterns in a mostly negative way including habitat fragmentation involving both habitat loss and breaking apart of habitat within landscape and deforestation (Fahrig, 2003, Shrestha et al., 2012). Large infrastructure like the construction of the new airport will probably result to increasing landscape fragmentation. Those landscape and environmental changes like deforestation, wetlands loss and urban explosion usually need to be observed trough a broad scale of landscape (Riitters et al., 1995). Thus, more specific landscape indicators are needed to describe landscape patterns more comprehensively.

Landscape metrics, also named spatial metrics, quantify patches, classes of patches or entire landscape of specific spatial characteristics describing spatial and temporal patterns including spatial configuration and composition of urban land changes resulted from urban growth and urban development (McGarigal and Marks, 1995, Gustafson, 1998, Herold et al., 2002, Seto and Fragkias, 2005). Landscape metrics can provide a link between spatial pattern and process of urban development by calculating the segmentations of landscape patches with homogeneity, such as built-up land area, forest area, coastal area, etc. in order to monitor landscape changes such as deforestation, landscape fragmentation and ecological changes. Urban change, particularly, need higher spatial resolution as the components of urban land type are more complicated,

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mixed and smaller compared with other land cover types, and the direction of urban development is more relevant from urban to rural (Kowe et al., 2015). Calculation of landscape metrics involves shape, size, edge etc. that can indicate the fragmentation and connectivity between and within patches of landscape.

Landscape metrics can usually be defines at three levels: patch level, class level and landscape level (McGarigal et al., 2002). Patch level metrics focus on individual patches. Class level metrics integrate all the patches of certain land cover types with average or weighted average calculation. Landscape level metrics integrate all patch types with full extension over the entire landscape scale.

In this chapter, I focus on class level and landscape level metrics to describe landscape pattern and structure changes of the core construction area of the new airport.

3.2 Objectives

The objectives of this chapter are to calculate landscape metrics using the software FRAGSTATS to describe changes of landscape structure in the study area between 2000 and 2015. The major tasks of this chapter is to:

1) Select and calculate the proper indices that can describe the features of landscape on both class level and landscape level with FRAGSTATS.

2) Use the results to analyze the landscape change pattern happened in the area.

3.3 Materials and Methodology

Landscape metrics can quantitatively describe the landscape structure of landscape composition and landscape configuration (McGarigal and Marks, 1995). Landscape composition includes quantitative measurements of landscape features but

without spatial information. Landscape configuration contains spatial information that can illustrate the distribution of landscape patches within the class or landscape. Most metrics can provide unique landscape information different from other metrics (Hargis et al., 1998). In the study, a computer software program called FRAGSTATS Version 4.2 (McGarigal et al., 2012) is introduced to calculated landscape metrics. FRAGSTATS was released in the public domain in 1995 designed to compute a verity of landscape metrics (McGarigal and Marks, 1995).

In order to better focus on the central area of the airport construction to evaluate the direct impacts of İstanbul New Airport specifically on the surrounding habitats, a smaller scale of study area (Figure 7) is defined which includes three districts on the European side and two districts on the Asian side. The three districts on the European side are Arnavutkoy, Eyüp and Sarıyer and the two districts on the Asian side are Beykoz and Çekmekoy. This smaller area covers most of the area that land changes happened, especially where built-up land change occurred around the new airport according to the classification results. Core construction area (Figure 8) is also defined as a circle area with a radius of 7 kilometers. This area only covers the main construction area of the new airport, excluding other related construction like highways or roads construction. The direct impact of the airport construction can be better illustrated.
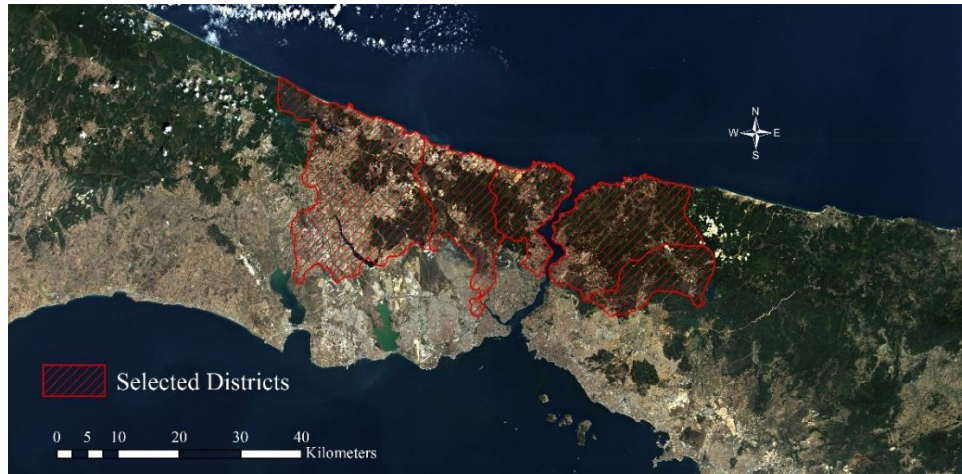
Figure 7. Selected districts on the European and Asian sides (Base map: Landsat 7 image on 09.04.2000)
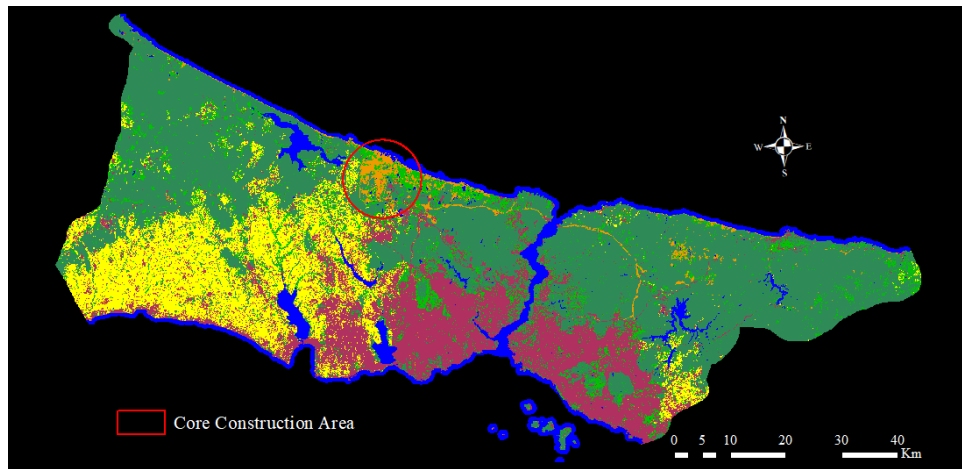
Figure 8. Core construction area

Three levels of spatial metrics can be computed in FRAGSTATS: patch level, class level and landscape level. In this study, class level metrics and landscape level metrics are calculated as the major concerns are about the relationship of patches across the landscape and among different classes while patch level metrics are calculated based on individual patches. Class-level indices contain indices of total area, number of

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patches, patch density, edge density, mean patch size and mean patch shape index.

Landscape-level indices include shape index, mean patch size and mean shape index.

These indices are calculated separately for the European side and Asian side for better

comparison.

For the spatial metrics selected, McGarigal (2014) gave the descriptions and

equations in the FRAGSTATS documents.

For selected class level metrics, total area (CA) is the sum of areas of all patches,

which is total class area. CA is calculated as:

$$CA = \sum_{j=1}^{a} a_{ij}(\frac{1}{10000}) \tag{2}$$

Where: a_{ij} is the area of patch ij. The unit is hectare (ha).

Number of patches (NP) is the number of patches of each patch class. NP is

calculated as:

$$NP = n_i \tag{3}$$

Where: n_i is the number of patches in the landscape of patch class i.

Patch density (PD) is the number of patches of the corresponding patch type

divided by total landscape area. PD is calculated as:

$$PD = \frac{n_i}{A}(10000)(100) \tag{4}$$

Where: n_i is the number of patches in the landscape of patch class i, A is total landscape

area. The unit is number per square kilometer (/km^2).

Edge density (ED) is the sum of lengths of all edge segments of patches, divided

by the total landscape area. ED is calculated as:

$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10000) \tag{5}$$

Where: e_{ik} is the total length of edge in landscape involving patch class I, A is total

landscape area. The unit is meter per hectare (m/ha).

Mean patch size (AREA_MN) is the sum of the area across all patches of the

corresponding patch type, divided by the number of patches of the same patch type.

Mean patch size by classes is calculated as:

$$AREA\_MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i} \tag{6}$$

Where: x_{ij} is the area of patch ij, n_i is the number of patches in the landscape of patch

class i. The unit is hectare (ha).

Mean patch shape index (MSI) is patch perimeter, divided by square root of

patch area, adjusted by a constant to adjust for a square standard. This index is used to

describe the complexity of patch shape compared to a standard shape of the same size.

For raster data, MSI is calculated as:

$$MSI = \frac{\sum_{j=1}^{n} \frac{.25 p_{ij}}{\sqrt{a_{ij}}}}{n_i} \tag{7}$$

Where: p_{ij} is the perimeter of patch ij, a_{ij} is the area of patch ij, n_i is the number of

patches in the landscape.

For selected landscape level metrics, Landscape Shape Index (LSI) is the sum of

the landscape boundary and all edge segments within the landscape boundary, divided

by the total landscape area, adjusted by a constant for a square standard. For raster data,

LSI is calculated as:

$$LSI = \frac{.25E'}{\sqrt{A}} \tag{8}$$

Where: E' is the total length of edge in landscape, A is the total landscape area.

Mean patch size (AREA_MN) is the sum across all patches in the landscape, divided by the total number of patches. Landscape AREA_MN is calculated as:

$$AREA\_MN = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}}{N} \tag{9}$$

Where: x_{ij} is the area of patch ij, N is the total number of patches in the landscape. The unit is hectare (ha).

Mean shape index (MSI) is the average shape index of patches in the landscape. For raster data, landscape MSI is calculated as:

$$MSI = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \frac{.25p_{ij}}{\sqrt{a_{ij}}}}{N} \tag{10}$$

Where: p_{ij} is the perimeter of patch ij, a_{ij} is the area of patch ij, N is the total number of patches in the landscape.

The above metrics are presented with charts according to the resulted data calculated by FRAGSTATS.

3.4 Results and Discussion

Spatial metrics results of class level are generated based on the results processed by FRAGSTATS. They can interpret the features of landscape fragmentation among classes and also the changes of landscape caused by the construction of the new airport.
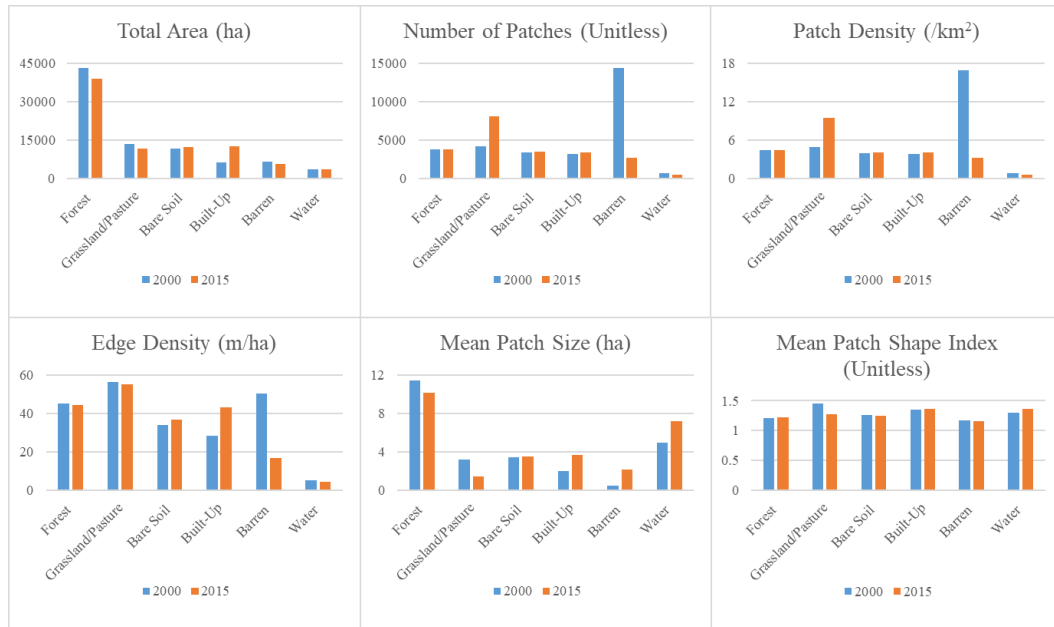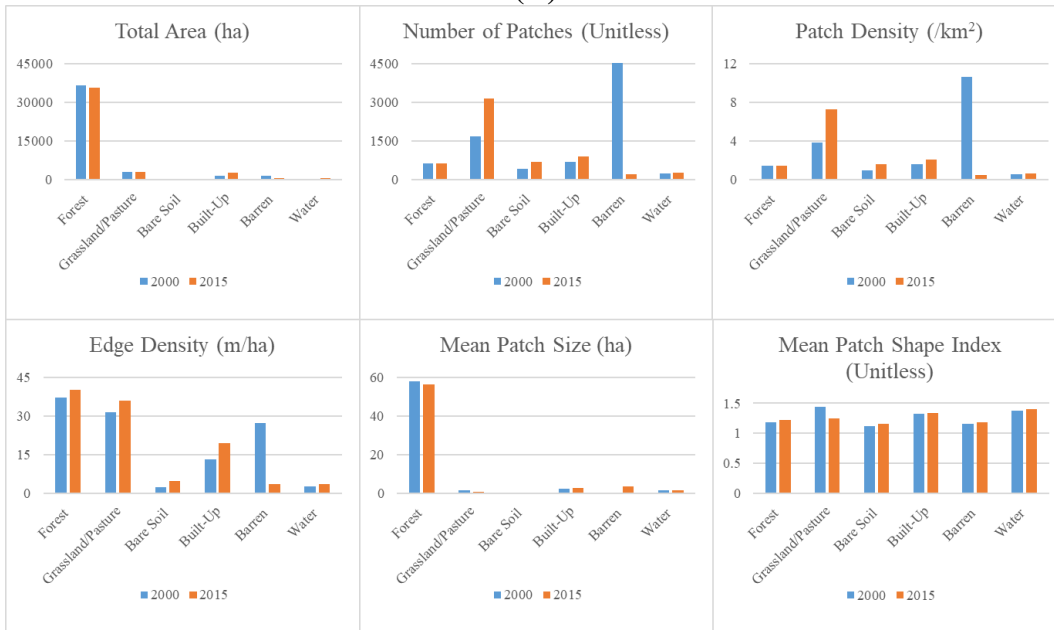
Figure 9. Spatial metrics results of class level on the (A) European side; (B) Asian side

For class level metrics (Figure 9), total area of forest decreased slightly and built-up total area increased in the selected districts on both the European side and the Asian side. The changing rate on the European side is more obvious than on the Asian side. As the major construction area is on the European side, these changes can indicate that the construction of the new airport has influenced the surrounding forest ecosystem. Total areas of other land types only had slight changes.

Number of patches, mean patch size and patch density are the three indices to describe the features of patches. For number of patches, grassland/pasture land greatly increased while barren land decreased dramatically on both sides. Mean patch size of forest and grassland/pasture land slightly decreased and increased for built-up land. These two indices show that forest and grassland/pasture land have more fragmentations and are more fragmental. Built-up land developed more fragments and became more concentrated and the development can be at the price of destroy forest and grassland/pasture fragmentations. These changes can also reflect by patch density. As for barren land changes, on one hand, barren also exploded and concentrated from uncultivated land and mine to construction areas which often have larger scales, on the other hand, the classification maps are influenced by classification confusions.

Edge density and mean patch shape index can describe shapes of patches. On the European side, edge density of forest land and grassland/pasture land subtly decreased and built-up land increased. While on the Asian side, edge density of forest and grassland/pasture increased slightly and built-up increased, as well. On both sides, mean patch size of forest and built-up subtly increased and grassland/pasture decreased. It can

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be indicated that built-up patch fragments became more complicated not only due to built-up land being more fragmental but also because there appeared some road networks serving the airport and roads can have relatively large proportion of edge length and area. Forests and grassland/pasture fragments also became more complicated and fragmental.

For landscape level metrics (Figure 10), landscape shape index decreased on both European and Asian sides while mean shape index almost remain the same. This can indicate that the shape of the landscape became less complicated. Mean patch size increased slightly on the European side and more on the Asian side, which means there are less fragments over the landscape. The results can be influenced by the airport construction, which gather the barren and built-up land, thus cause the fragments decreasing. There is also some misclassification of barren land.
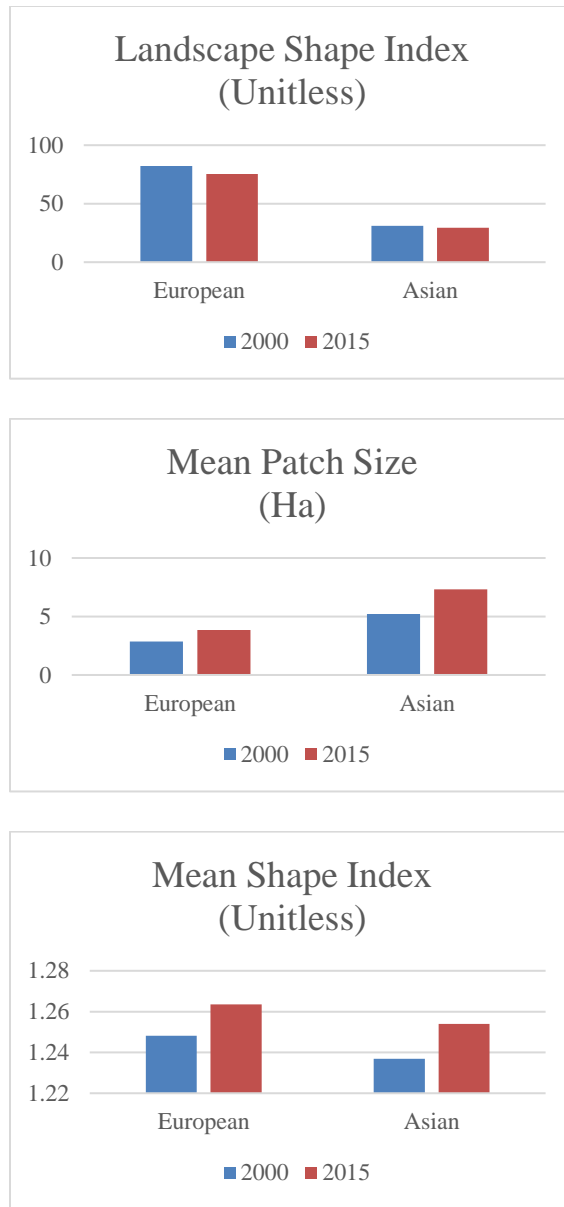
Figure 10. Spatial metrics results of landscape level

Table 6. Change matrix of land change from 2000 to 2015 for core construction area.

		2015 Land Cover (km²)					
		Bare Soil	**Forest**	**Built-Up**	**Barren**	**Grassland/pasture**	**Water**
2000 Land Cover (km²)	**Bare Soil**	6.4449	0	0.765	1.2537	0.5049	0.0828
	Forest	0.5472	42.1407	1.71	13.554	3.6855	0.2646
	Built-Up	0	0	4.6206	0	0	0
	Barren	0.5391	0	0.4293	6.9849	5.1381	2.1393
	Grassland/pasture	1.9728	0.8667	0.6327	11.4588	20.0889	1.5579
	Water	0.0081	0	0.0225	3.2868	0.7794	9.8073

Figure 11. Spatial metrics results for the core construction area

For the core construction area, a change matrix is presented (Table 6) to quantitatively explain the land changes. The results show that almost 70% of the barren land in 2015 are converted from forest and grassland/pasture. Accordingly, forest and grassland also have the greatest conversion to barren. There are also small areas that converted from water to barren. Those areas are converted to construction areas from mining wells and natural ponds. For results of class-level metrics (Figure 11), total area of forest decreased drastically and grassland/pasture also decreased, while both built-up and barren almost doubled. For number of patches and patch density, grassland/pasture increased greatly but barren decreased drastically. Mean patch size for both forest and grassland/pasture decreased while barren had a huge increase. Grassland/pasture had a slight decrease for mean patch shape index. Edge density for grassland/pasture and

barren decreased while urban increased slightly. The results of spatial metrics in the core

area show that not only forest habitat but also grassland/pasture habitat have been

influenced directly by the construction of the new airport. In fact, grassland/pasture

habitat is even more severely influenced as it became more fragmented into smaller

patches.

Another metric, Interspersion and Juxtaposition Index (IJI) is added as an

additional index for the core construction area (McGarigal, 2014). IJI is a

contagion/interspersion metric and is to measure the interspersion of patch types based

on patch adjacencies

The equation of IJI is:

$$IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m}e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m}e_{ik}}\right)\right]}{\ln(m-1)}(100) \tag{11}$$

Where: e_{ik} is the total length (m) of edge in landscape between patch types (classes) i

and k, m is the number of patch types (classes) present in the landscape, including the

landscape border, if present. The unit is percent.

The result the metric (Figure 12) shows that IJI of forest, grassland/pasture and

built-up increased, indicating the patches of these land types tend to be more evenly

interspersed. IJI of bare soil, barren and water decreased, indicating the patches of these

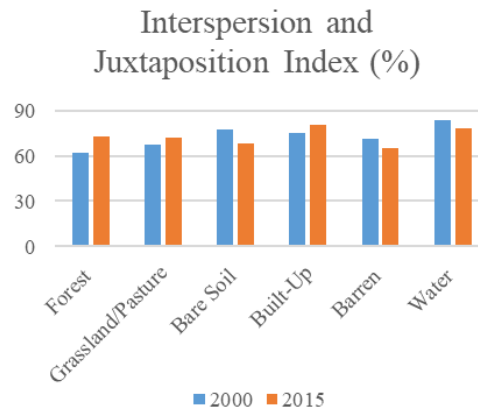land types tend to be less evenly interspersed.

Figure 12. Spatial metrics results for the core construction area

3.5 Conclusion

In this chapter, landscape metrics are used to qualitatively and quantitatively describe the spatial pattern of pattern at both class level and landscape level. From the results, the influence of İstanbul New Airport's construction over the surrounding landscape can be demonstrated. Landscape of the selected districts on both European and Asian side became more fragmental and more complicated. There is apparent reduction in amount and size of forest and coastal habitats and increase in patch number and isolation of patches, which is within expectation. Comprehensively, land patches of forest and grassland/pasture in the area are smaller and more scattered, while built-up and barren land patches developed greatly in size and scale. In addition, by comparing the two sides, it shows that the changes of landscape indices are more significant on the European side where the new airport is located other than on the Asian side. These changes can indicate the construction of İstanbul New Airport contributing to accelerating the fragmentation of forest and grassland/pasture land over the surrounding area.

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CHAPTER IV

SUMMARY AND CONCLUSIONS

In this study, an unsupervised classification method IsoData in ENVI is applied to classify land use and land cover of İstanbul. The classified result is proved to be satisfying and sufficient for this study. Land change results can clearly show the land change of major land types quantitatively and spatially over the entire study area of İstanbul. Land change maps provide a more visualized view of the land changes happened among forest, built-up, grassland/pasture, barren, bare soil and water. With FRAGSTATS, landscape metrics further illustrate the land change patterns within different land types and as a whole in a more concentrated area around İstanbul New Airport on both European side where the new airport is located and the Asian side. The outcomes show that the forest, grassland/pasture lands are more influenced by the construction on the European side than on the Asian side, which indicates the direct impacts of the construction of İstanbul New Airport on the surrounding forest habitats.

However, there are still classification issues, especially between built-up, barren and grassland/pasture which are also the major omission in the classification results that have relatively low accuracies. The first reason is that built-up pixels are often very small, mixed and heterogeneous. Built-up pixels can be confused with several different land type, particularly grassland/pasture, barren, bare soil which makes it extremely difficult to assign and label the accurate land use and land cover type of the single pixels. This problem may be solved with satellite images with higher resolution. Secondly,

spectral signatures among these confused land types are very similar. For example, roof tops of buildings in the residential areas in İstanbul are overwhelmingly made of clay, as a result, those pixels are classified as bare soil instead of the correct built-up land type. Since the data source is limited, efficient and effective pre-classification and post-classification methods are vital for accurate classified results. In this study, PCA and NBI indices are introduced to process pre-classification in order to enhance the spectral features of specific land change and to separate the certain land use and land cover types.

Although infrastructure can provide tremendous social and economic benefits, there is still challenge in managing their potential impacts on environment and ecosystems. We need to understand not only the immediate land impacts of the construction of the airport, but also the subsequent land changes due to processes linked to its construction. For instance, new roads in forest area can lead to drastically increasing deforestation not only because forest loss itself is spatially contagious but also due to continuous development of road networks can increase the spatial extent of habitat disruption over a broader scale (Laurance et al., 2015). The results of land change in this study can also indicate to decision makers the implication of landscape planning of the construction over such a large area; it can also inform policies to safeguard remaining habitats.

This study focused on analysis of land change and landscape fragmentation caused by 15 years of urbanization in İstanbul including the construction of the İstanbul New Airport. Future work could focus on the question of how much more land change

and landscape fragmentation are likely to occur over the next few decades, especially in

the north of the city, due to the new transportation infrastructure that is now in place.

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