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Determination of the Impact of Urbanization in Istanbul Northern Forests by Remote Sensing

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Abstract: Urban forests provide many benefits for the city's resiliency to climate change by improving the degree of shading, evaporative cooling, rainwater interception, and storage and filtration functions. With the increasing population and unplanned urbanization, the Northern Forests, which play a major role in Istanbul, are being destroyed over time. In this study, forest area changes were determined by using object-based classification and landscape metrics. 2009 and 2019 dated Landsat TM and Landsat OLI&TIRs images were used to detect the forest area changes in the selected area. Selected landscape metrics such as aggregation index, edge density, the largest patch index, and patch density are calculated from the classification results for understanding the devastation of urbanization in forest areas. According to the results, forest areas decreased from 318.2 km2 to 292.1 km2, and fragmented from whole and large pieces to smaller pieces.

Keywords: Forest Areas; İstanbul; Landsat; Object Based Classification; Landscape Metrics

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1. Introduction

Especially in large metropolitan areas, the increase in land uses such as trade, industry, residence, recreation, and tourism and the increasingly widespread use of transport networks connecting these land uses cause distortion, fragmentation, and change of habitats. The results of this rapid urbanization can sometimes reach irreversible depletion of natural resources[1]. A substantial decrease of global forest area from unprecedented human disturbance causes a huge loss of biodiversity[2].

Sarıyer and Beykoz, the study area, are districts of the province of Istanbul. Study area is situated at the intersection of the Bosphorus and Black Sea. Its northern part exhibits a more rural structure whereas its southern part exhibits an urbanized structure. Accordingly, the human profile is quite variable. The natural beauty of the countryside is a magnet for people fed up with the city environment. Therefore, it is a preferred region in the sense of both recreational and settlement area. This very versatile structure of the study area has contributed to its selection in order to make a change analysis[1]. The study area structure has been presented with the help of spatial analyses. For this, first of all, "Change Analysis" was applied to data classified over Landsat Satellite Images of the years 2009 and 2019. Remotely sensed data such as Landsat, have been explored extensively for land cover mapping because the data are freely available and contain a broad range of suitable spectral bands[3].

The Northern Forests, which are under constant pressure with bridges, ring roads, and auxiliary roads, have unfortunately been besieged with the announcement of the Yavuz Sultan Selim Bridge and Northern Marmara Highway projects to the public. 1,416 ha on the European Side and 1,126 ha on the Anatolian Side and a total of 2,542 ha of forest areas have been allocated for the Yavuz Sultan Selim Bridge[4].

Land use and land cover pattern are considered to have an important contribution to ecosystem functioning[5]. Land use and land cover patches may have various spatial arrangements such as size, shape, and connectivity in urban settings. Studying the relationship between urbanization and landscape patterns can provide support for urban ecological management[6].

The increasing population density of Istanbul is pushing urbanization toward the northern regions. The Northern Marmara Highway, the construction of which started in Istanbul in 2012 and was completed in 2016, has led to the destruction of northern forests. In this study, the effect of urbanization on northern forests was examined. 2009 and 2019 dated satellite images were classified with object-based classification. Landscape metrics were calculated from the classification results and the effect of urbanization on forest areas was calculated numerically.

2. Materials and Methods

In developing countries, big cities are exposed to a dynamic urbanization process due to population growth and migration. Depending on the acceleration of the urbanization process, the settlement components that are constantly built cause significant changes in natural areas. These changes generally have a negative impact on the ecosystem. Therefore, regular monitoring of LULC changes due to urbanization and determination of the current situation is important[7].

The flow chart of the study is shown in Figure 1.

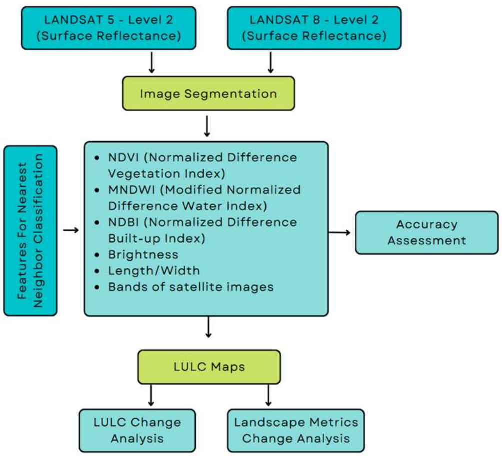


Figure 1. Flowchart of the study

2.1. Study Area and Data

In this study, two selected districts (Sarıyer and Beykoz) of İstanbul, Türkiye were selected as the study area. Sarıyer and Beykoz districts which are located on the transition route of the Northern Marmara Highway. The study area is shown in Figure 2.

Figure 2. Study area

Land cover data for Istanbul metropolitan area were derived from classified Landsat TM and OLI&TIRs sensors. The satellite images data used in this study to derive the land cover/land use datasets covered the same spatial extent at the same spatial resolution and were classified using object-based image classification. 2009 and 2019 dated satellite data were used for this study. The satellite images were classified into six types of land cover/land use: agricultural areas, urban areas, water areas, forest areas, barren areas, and roads.

2.2. Object-Based Image Classification

Object-based classification is a classification method that incorporates spectral, shape, textural, dimensional, and contextual information in high-resolution images into the classification process. The method generally consists of image segmentation and classification. In this method, firstly, similar pixels are grouped depending on the condition of meeting a certain homogeneity criterion, and image objects to be used in the classification process are created. This stage is the segmentation stage of the method. After the segmentation process, rule sets for classification are created to extract the desired details from the image. According to these created rule sets, homogeneous object groups are assigned to classes[8].

The segmentation values determined for the study area are shown in Table 1.

Table 1. Segmentation values

Years	Image Layer Weights (R-G-B-NIR-SWIR1-SWIR2)	Scale Parameter	Shape/Color	Compactness/Smoothness
2009	1,1,1,2,1,1	20	0.8/0.2	0.6/0.4
2019	1,1,1,2,1,1	20	0.8/0.2	0.6/0.4

For object-based classification, the nearest neighbor method was used. For 'NN' classification, visible bands, near and mid-infrared bands, brightness, length/width, NDVI, MNDVI, and NDBI features were used. Selected features are shown in Table 2.

Table 2. Features for nearest neighbor classification

Features for NN	Explanation
NDVI (Normalized Difference Vegetation Index)	To determine the vegetation density on the earth; NDVI = (NIR – RED)/(NIR + RED)
MNDWI (Modified Normalized Difference Water Index)	To determine the water areas on the earth; MNDWI = (GREEN – SWIR1)/(GREEN + SWIR1)
NDBI (Normalized Difference Built-up Index)	To determine the built areas on the earth; NDBI = (SWIR1 – NIR)/(SWIR1 + NIR)
Brightness	It calculates the average values of the objects in the image in all bands.
Length/Width	It determines the ratio of the lengths to the widths of the objects in the image.

2.3. Accuracy Assessment

An assessment of the accuracy of land cover classification from satellite imagery is necessary to ensure that land cover classes identified reflect the actual land cover classes on the ground. The reliability of subsequent analyses (i.e. the size of individual land cover classes, change analysis and the landscape metric) depends on the degree of accuracy of the identified land cover classes[9].

We selected 500 sampling points within the study area from the Landsat imagery using a stratified random sampling approach, with the strata being the classified land cover types from the imagery. These sample points were then converted into a kml file to be opened on Google Earth. The land cover type at each sample location was identified from the Google Earth imagery and recorded manually. The overall image classification accuracy was computed using the error matrix analysis approach.

2.4. Landscape Metrics

Landscape metrics calculate landscape composition and landscape configuration, which are defined as attributes of the landscape[10]. The purpose of classifying the landscape structure as units and examining it with metrics is to examine the composition and configuration character of the landscape structure and present the change in measurable numerical data[11]. More than one metric is needed to define the landscape pattern. The metric group should describe the pattern variety seen throughout the landscape but should be minimized in use, especially in indexes that are highly related to each other[12].

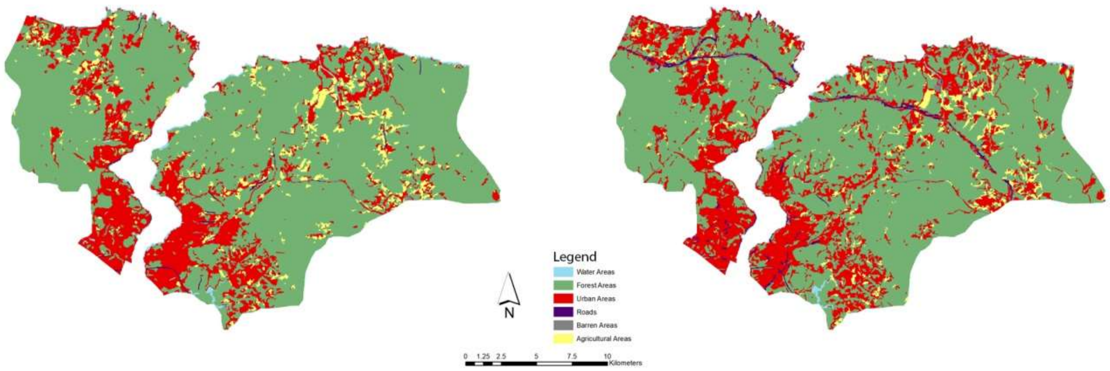
In this study landscape metrics were used to examine the effects of urbanization. The selected landscape metrics are explained in Table 3.

Table 3. Definition of metrics

Abbreviation	Metrics	Metric Type	Explanation
AI $AI = \left[\frac{g_{ii}}{\max \to g_{ii}} \right] (100)$ $0 \leq AI \leq 100$	Aggregation Index	Dispersion Interspersion Metric	It is used to measure the degree of clumping of patches.
ED $ED = \frac{\sum_{k=1}^{m} e_{ik}}{A} (10{,}000)$ $ED \geq 0$, limitless	Edge Density	Edge Metric	Edge density of all patches of the class
LPI $LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A} (100)$ $0 < LPI \leq 100$	Largest Patch Index	Area Metric	The ratio of the largest patch in the class to the class
PD $PD = \frac{n_i}{A} (10{,}000)(100)$ $PD > 0$, constrained by cell size.	Patch Density	Subdivision Metric	It shows the distribution and fragmentation of cells by patch type.

3. Result and Discussion

Satellite images are divided into 6 classes with object-based classification (Figure 3). These are agricultural areas, urban areas, water areas, forest areas, barren areas, and roads.



(a) (b)

Figure 3. (a) Classification result for 2009 (b) classification result for 2019

Accuracy assessment analysis was performed by adding random points to the classification results. Producer, user, overall accuracy and kappa ratio are shown in Table 4.

Table 4. Result of accuracy assessment

	2009		2019	
	PA (%)	**UA (%)**	**PA (%)**	**UA (%)**
Water	0.84	0.90	0.96	0.90
Forest Areas	0.92	0.98	0.94	0.97
Urban Areas	0.97	0.95	0.89	0.87
Agricultural Areas	0.94	0.82	0.89	0.89
Barren Areas	0.81	0.84	0.76	0.76
Roads	0.86	0.83	0.82	0.80
	2009		**2019**	
Overall Accuracy (%)	0.91		0.89	
Kappa Ratio (%)	0.89		0.86	

The change analysis was revealed by comparing the classification results. Change analysis is shown in Figure 4.

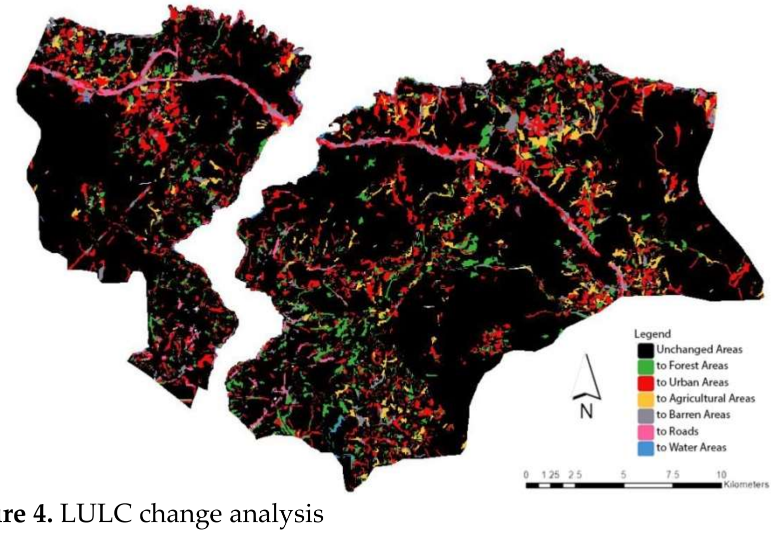


Figure 4. LULC change analysis

As a result of the classification, it was observed that forest areas decreased from 317.8 km² to 293.9 km². This shows that approximately 6% of forest loss is experienced in the study area. It has been observed that the built areas have increased from 88.6 km² to 109.6 km². The built areas increased by approximately 4%. The rate of change in classes is shown in Table 5.

Table 5. Change of classes

	2009		2019		Change Rate
	Area/km²	Percentage/%	Area/km²	Percentage/%	%
Water	4.99	0.8	3.99	0.8	-
Forest Areas	317.85	73.2	293.98	67.3	-5.9
Urban Areas	88.62	20.1	109.67	24.2	+4.1
Roads	1.42	0.37	5.79	1.3	+0.93
Barren Areas	1.82	0.33	7.27	2.6	+2.27
Agricultural Areas	22.71	5.2	16.73	3.8	-1.4

The classification results obtained were examined with FRAGSTATS and landscape metrics were calculated. Results are shown in Table 6.

Table 6. Results of landscape metrics

Metrics	Units	Forest	Urban Areas	Roads	Barren	Agricultural Area	Water
		2009-2019	2009-2019	2009-2019	2009-2019	2009-2019	2009-2019
PD	patch/ha	0.38 - 0.49	0.77 - 1.17	0.07 - 0.21	0.3 - 0.64	0.91 - 0.63	1.18 - 1.50
AI	%	96.8 - 95.7	89.6 - 87.7	67.8 - 73.7	69.0 - 73.3	80.8 - 78.9	66.5 - 60.9
ED	m/ha	31.3 - 38.5	28.0 - 40.7	1.43 - 4.72	1.66 - 6.02	13.5 - 10.9	3.67 - 3.49
LPI	%	45.8 - 40.3	6.64 - 5.18	0.05 - 0.15	0.04 - 0.05	0.17 - 0.15	0.13 - 0.13

The increase in ED in forest areas means that forest areas are fragmented from whole and large pieces to smaller pieces. An increase in the LPI value indicates that the small patches belonging to the road class combine to form the largest patch index. The same is not the case for the forest areas. While the PD metric results increase in patches belonging to this class, the decrease in AI and LPI metric results is an indication that the holistic structure of the class is disrupted and it is divided into small units that are separate from each other. As a result of the fragmentation of forest areas due to urban areas and roads, there is a decrease in the largest patch index of the forest areas class over the years.

The main reason why the barren areas increased in parallel with the road class is the presence of undefined areas as construction sites around the newly opened roads. The increase in road, barren and urban areas has led to a decrease in forest and agricultural areas. Especially forest areas in and around the Northern Marmara Highway were destroyed and land use was changed.

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