ANALYSIS OF TEMPORAL AND SPATIAL CHANGES IN ISTANBUL NORTHERN FORESTS WITH SATELLITE IMAGES AND LANDSCAPE METRICS

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ABSTRACT:

There is an urbanization process on a global scale with population growth and technological developments. Especially in metropolitan cities, mega projects located on the city periphery lead to environmental pressure on natural areas and forests. Istanbul Northern Forests, the transition region of the Black Sea and Mediterranean flora, host various ecosystems due to its pseudomaki structure. However, the effects of big projects recently realized such as Istanbul Airport, Northern Marmara Motorway, and Yavuz Sultan Selim Bridge on the Istanbul Northern Forests can be noticed even with the naked eye. This study investigates land use/cover changes in Istanbul Northern Forests which are under intense urbanization pressure using LANDSAT and SENTINEL-2 satellite images in a time series of thirty-nine years (1984-2023). As a result of the analysis, it is seen that the class of impervious surfaces increased in Istanbul Northern Forests between 1984-2023, while the class of barren land, natural areas and agricultural areas decreased. Landscape metrics such as Total Class Area, Percentage of Landscape, and Interspersion Juxtaposition index were used to better understand the change in the study area between 2017 and 2023.

1. INTRODUCTION

Unplanned, uncontrolled, and patchy growth in Istanbul since 1950s as a result of a transport system based on highways and import substitution industrial policies started to pose the first threats on the Northern Forests. Transport network with a linear structure divide landscapes into parts along their routes due to the linear barrier effect they create in the landscape structure. Land use decisions taken for rent-seeking purposes have been the biggest supporter of the road-oriented development of Istanbul's transport system. With the construction of the 15 Temmuz Şehitler Bridge (1st Bridge) in 1973, the centers on both sides of the city were directed towards the north. Following the opening of the Fatih Sultan Mehmet Bridge (2nd Bridge) (1988), urban sprawl and agglomeration occurred along the ring roads. The impact of the Fatih Sultan Mehmet Bridge and the Trans European Motorway (TEM) has increased the pressure of constructions in the vicinity of the drinking water basins, forests, agricultural and rural areas in the north of the city. With Fatih Sultan Mehmet Bridge and TEM, it has become almost impossible to control the speed of urbanization.

Habitat loss due to land use changes is one of the top priority threats on the sustainability of ecological structure (Bierwagen, 2007). The concept of urbanization is associated with habitat loss, fragmentation, habitat isolation, changes in species composition, hydrology, and water cycles (Alberti, et al., 2003; Aurambout, et al., 2005; Ellis et al., 2006; Pauchard, et al., 2006).

Ecosystem fragmentation, also known as habitat degradation, is defined as the fragmentation of the habitat into small parts due to the inability of the habitat to maintain its characteristics and ensure its continuity as a result of external interventions (Wilcove, 1985; Andren, 1994). Habitat fragmentation causes losses in biological richness and the formation of unhealthy edge habitats. Fragmentation has three major components.

These are;

- attrition, loss of original habitat,
- shrinkage, reduction in the size of the unit in which the habitat is located.
- increasing isolation of habitat units.

Satellite images are an important data source for determining changes in land use/cover (LULC). Landscape metrics are frequently used in the evaluation of the results produced from satellite imagery. These metrics which help to question the spatial impact of socioeconomic changes provide quantitative results by calculating land cover classes at the unit, class, and landscape scale (Leitao et al., 2006). The structure and function of the landscape are determined by the shape, size, and position of landscape elements (Forman and Godron, 1986). In the literature, there are different studies on using landscape metrics to evaluate LULC change (Zhang and Wang, 2006; Zhang et al., 2015; Kumar et al., 2018; Azabdaftari and Sunar 2022; Aksu et al., 2022; Teimouri et al., 2023). In these studies, generally LULC types produced from satellite images have been analyzed using landscape metrics.

The aim of this study is to analyze the urbanization pressure, rapid increase in impervious surface and habitat fragmentation in the Istanbul Northern Forests which has great importance in the sustainability of the Marmara region and Istanbul. The objectives also include calculating landscape metrics, presenting them as quantitative data, and establishing a cause-and-effect relationship.

2. STUDY AREA AND DATASETS

2.1. Study Area

Istanbul is bounded by the geographical thresholds of the Black Sea and the Marmara Sea, which prevent its growth in the north and south directions (Figure 1). Due to the fact that the living resources of Istanbul are located intensively in the north of the city, there have been practices for the protection of the Northern Forests since the Ottoman Period. Until 1950s, with its transport structure based on sea and railway, the city developed linearly in the east-west direction parallel to the Marmara Sea, in order not to damage the existing natural resources.

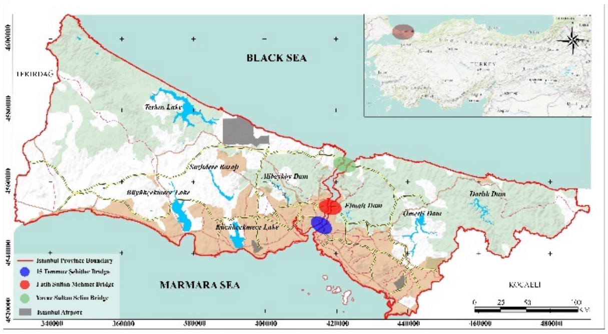


Figure 1. Location of Istanbul province in Türkiye, and provincial boundary

Istanbul is the city with the highest population density in Turkey. Therefore, although the need for natural resources is high in Istanbul, the pressure on natural resources is higher than any other city due to urbanization pressure. When the population growth of the city of Istanbul is analyzed by years, it is seen that the population of the city increased above the trend in the ten-year period following the construction of the 1st and 2nd bridges over the Istanbul Strait (Bosphorous). Especially with the opening of the 2nd Bridge and the TEM motorway joining the bridge, there has been a population explosion around the route and even in the drinking water basins.

Terkos Forests, Belgrade Forests, and Omerli Basin, which are in the Istanbul Northern Forests, have been determined to meet the criteria of internationally protected areas since they are biologically important. The coastal dunes along the Black Sea coastline are in a narrow area in the form of a strip on the shores of Istanbul. The density of endemic plants is high in dune areas, which are among the areas in need of absolute protection, and plant species adapted to dunes cannot maintain their continuity outside the dune areas (Akkemik, 2020). Istanbul Northern Forests which have been subjected to heavy destruction since 1980s is a transition region with a rich biodiversity with its integrated ecosystems belt and pseudomaki structure, where three different climate zones meet. The Northern Forests which are the source of life of the Marmara Region have been meeting the need for groundwater and surface water resources and clean air for thousands of years. Istanbul forests, which are subject to Forest Law No. 6831 enacted in 1956, were included under the scope of "areas to be protected absolutely" with the 2009 Environmental Plan. However, there is still no protection boundary covering the Northern Forests of Istanbul today. Istanbul Airport, Northern Marmara Motorway, and Yavuz Sultan Selim Bridge (3rd Bridge) projects that are among the scope of Istanbul Mega Projects are in Istanbul Northern Forests. There are many projects planned to be constructed within the forest which will cause great damage to the native habitat.

2.2. Data Sources

Satellite images were used to understand the pattern and morphological changes in the Istanbul Northern Forests over the past thirty-nine years. Within the scope of the study, Landsat-5 TM, Landsat-8 OLI which have 30 m spatial resolution, and Sentinel-2 satellite images, which are freely available, were used. Landsat satellite images from June 1984 to June 2017 downloaded from USGS (URL-1). For detailed analysis Sentinel-2 satellite images for 2017, 2020 and 2023 were downloaded from Copernicus (URL-2). Table 1 gives the technical specifications of the satellite data.

Table 1. Technical specifications of the satellite data

Satellite	Spectral Resolution (µm)	Spatial Resolution (m)	Radiometric Resolution (bit)	Temporal Resolution (day)
Landsat - 5 TM	(0.45-2.35)	Blue, Green, Red, NIR, SWIR1-2: 30 Thermal IR: 120 m	8	16
Landsat - 8 OLI	(0.43-2.30)	Coastal, Blue, Green, Red, NIR, SWIR1-2: 30 m Panchromatic: 15m	12	16
Sentinel-2 MSI	(0.44- 2.20)	Blue, Green, Red, NIR: 10 m Red Edge 1-3: 20 m SWIR1-2: 20 m Coastal, Water Vapor, Cirrus: 60 m	12	5

Turkish Statistical Institute (TUIK) database was used for population, demographic structure, other statistical and socioeconomic data (URL-3). 2020 data on existing motorways in Istanbul were obtained from the website of the General Directorate of Highways (URL-4).

3. METHODOLOGY

As the first phase of the study, it was decided to determine a study area boundary covering the Istanbul Northern Forests. As a result of literature review, it was determined that destruction started after 1985 in the Northern Forests. Therefore, 1984 was chosen as the starting year to perform the analyses and June 1984, 1990, 2000, 2009, and 2017 Landsat satellite data and 2017, 2020, 2023 Sentinel-2 satellite data were obtained. The study was carried out by considering five main phases (Figure 2).

These are:

- determination of a study area boundary that will clearly reveal the landscape structure changes,
- analyzing the changes in the LULC of the study area between 1984 and 2023,
- applying change analysis to LULC results of different years,
- determination of the areas of intensive destruction and habitat fragmentation by years,
- analyzing and interpreting the area of high destruction with landscape metrics sensitive to scale and resolution.

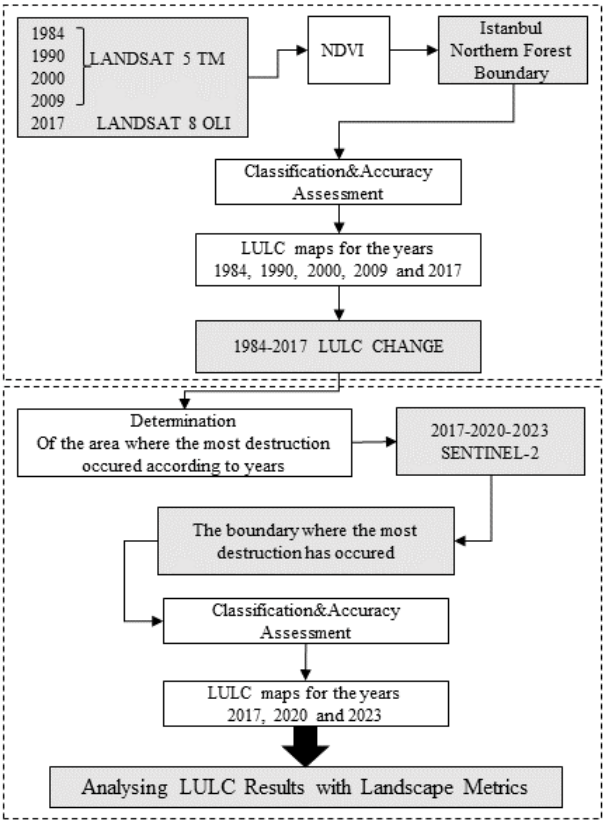


Figure 2. Methodological steps followed in the study

To determine Istanbul Northern Forests borders Normalized Vegetation Index (NDVI) transformation were used. NDVI which can take values between -1 < NDVI < 1 and represent healthy vegetation cover as it approaches 1, were used to determine the boundaries of the Northern Forests of Istanbul. Also, NDVI results were compared with Tasseled Cap transformation results (Kauth and Thomas, 1976; Sarı, 2020). Figure 2 shows the methodology followed in the study.

3.1. Landscape Metrics

Since it is impossible to measure the landscape structure directly, information about the components that make up the landscape structure can be obtained with the help of various landscape metrics. The land use of an area depends on the proportion and spatial configuration of these land cover. Landscape metrics can be used to describe the composition and spatial pattern of land cover in a landscape. Therefore, landscape metrics are used to determine urban structures and patterns.

In this study, it was decided to use landscape metrics as the most appropriate method to understand the changes in landscape structure since it enables the interpretation of the functions it contains depending on the spatial solutions. After the literature review and by expert opinions, the landscape metrics to be examined within the scope of the study are determined as Total Class Area, Percentage of Landscape, and Interspersion Juxtaposition Index. For the calculation of landscape metrics, the UNIX-based FRAGSTATS v4.2 program spatial statistics set that presents the components and characteristics of the landscape as quantitative data was used.

4. RESULTS

4.1. Determination of the Study Area Boundary

Since there is no access to forestry reports from the 1980s and before, which are considered to be the years with the least destruction in the Istanbul Northern Forests, and since there is no "Northern Forest Protection Boundary" determined by the decision- makers today, it was decided to determine a study area boundary covering the forests by adhering to the coastal line in the north within the borders of Istanbul province. While determining the study area boundary, the year 1984 was preferred as shown in Figure 3 (Sarı, 2020).

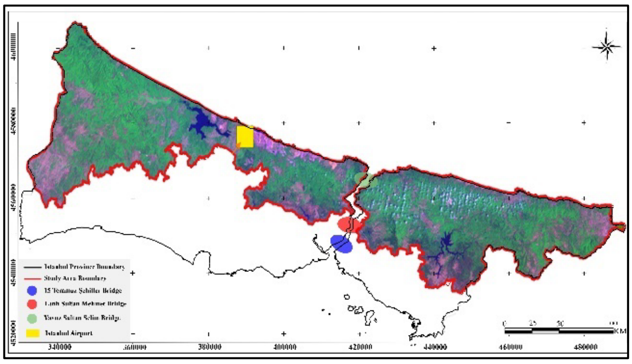


Figure 3. Istanbul Northern Forests

4.2. Land Use/Cover Classification

The main purpose of the study is to reveal how forest areas, agricultural areas, water surfaces, bare and natural areas are affected by the increase in impervious surfaces in the study area in the form of thematic maps and quantitative data. For this reason, the first level of CORINE (Coordination of Information on the Environment) classification system was utilized in the classification step.

For this purpose, ISODATA classification method (Lillesand et al., 2015) was applied to all satellite images and five different classes, namely (1) forest areas, (2) water surfaces, (3) agricultural areas, (4) bare and natural areas, (5) impervious surfaces were distinguished in the classification. After the classification, 300 random points were selected from each classification result for thematic accuracy. Thematic accuracy assessments of the classified images from error matrices were performed based on overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient (Congalton and Green, 1999).

As a result of the accuracy analyses, the overall classification accuracies of 1984, 1990, 2000, 2009, and 2017 were 81%, 82%, 81%, 80%, and 88%, respectively; whereas Kappa coefficients were 0.78, 0.76, 0.78, 0.74 and 0.85, respectively. Figure 4 shows the LULC maps of different years obtained as a result of classification and Table 2 shows the land cover classes according to years.

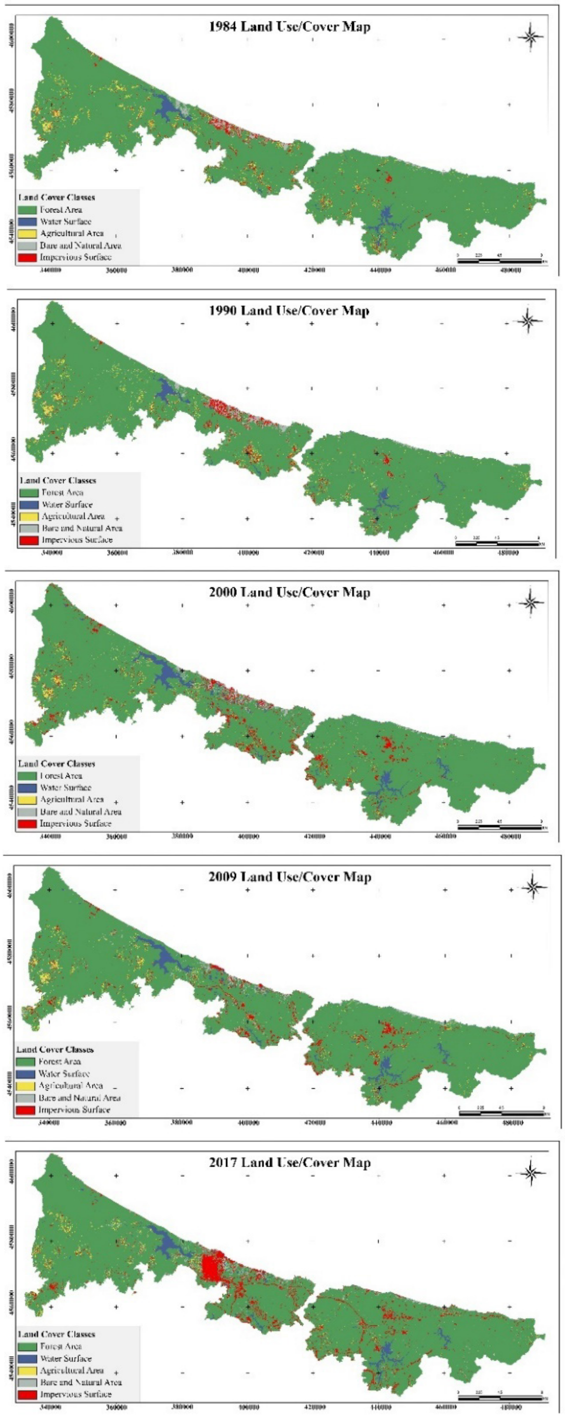


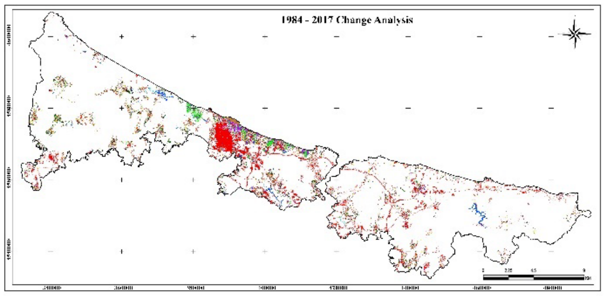
Figure 4. Thematic Maps

Table 2. Areas of land cover classes according to years

LULC	1984		1990		2000		2009		2017	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Forest areas	295568	93.01	295119	92.73	293844	92.24	292014.7	91.73	284629	89.38
Water surfaces	5521.14	1.73	6023.33	1.89	7734.86	2.42	7434.72	2.33	7033.10	2.20
Agricultural areas	5404.95	1.70	5318.73	1.67	3942.18	1.23	3042.04	0.95	2217.29	0.69
Bare, natural areas	4262.76	1.34	4047.79	1.27	2643.57	0.82	2068.98	0.64	1421.51	0.44
Impervious surfaces	7003.35	2.20	7728.26	2.42	20395.84	3.26	13780.04	4.32	22459.30	7.05

When the classification results from 1984 to 2017 are analyzed, there is a continuous increase in impervious surfaces in inverse proportion to the continuous decrease in forest areas, agricultural areas, bare and natural areas classes in thirty-three years. Especially as a result of the classification of 2017, an increase of 62.98% in impervious surfaces compared to 2009 is clearly seen.

To analyze the direction of change, change analysis was applied to the classification results of 1984 and 2017. By comparing the image matrices obtained from the classified images with this method, it was possible to obtain information about the areas that did not show any change, and the information about class transformations. The change map is shown in Figure 5. The matrix of 1984 and 2017 change analysis is shown in Table 3.



(a)

1984	2017	Area (ha)	Area (%)
Forest areas	Water surfaces	812.97	0.27
Forest areas	Agricultural areas	5.8	0.001
Forest areas	Bare, natural areas	38.2	0.01
Forest areas	Impervious surfaces	10908.25	3.69
Water surfaces	Forest areas	1.2	0.02
Water surfaces	Agricultural areas	6.3	0.11
Water surfaces	Bare, natural areas	0.2	0.003
Water surfaces	Impervious surfaces	49.31	0.89
Agricultural areas	Forest areas	823.29	15.23
Agricultural areas	Water surfaces	29.43	0.54
Agricultural areas	Bare, natural areas	1.4	0.02
Agricultural areas	Impervious surfaces	2347.14	43.42
Bare, natural areas	Forest areas	1.7	0.03
Bare, natural areas	Water surfaces	269.03	6.31
Bare, natural areas	Agricultural areas	0.2	0.004
Bare, natural areas	Impervious surfaces	2610.82	61.24
Bare, natural areas	Forest areas	0.03	0.02
Impervious surfaces	Water surfaces	457.54	6.53
Impervious surfaces	Agricultural areas	1.3	0.018
Impervious surfaces	Bare, natural areas	0.7	0.009

(b)

Figure 5. a) 1984-2017 change analysis spatial map b)1984-2017 change analysis result

Table 3. Land cover change matrix

	LULC (ha)	2017 Forest areas	Water surfaces	Agricultural areas	Bare, natural areas	Impervious surfaces	Change (%)
1984	Forest areas	283802.78	812.97	5.8	38.2	10908.25	-3.70
1984	Water surfaces	1.2	5464.13	6.3	0.2	49.31	27.38
1984	Agricultural areas	823.29	29.43	2203.69	1.4	2347.14	-58.97
1984	Bare, natural areas	1.7	269.03	0.2	1381.01	2610.82	-66.65
1984	Impervious surfaces	0.03	457.54	1.3	0.7	6543.78	220.69

When the change matrix is analyzed, it was seen that the class with the highest change between 1984-2017 was the impervious surfaces with an increase of 220.69%. There is a 66.65% decrease in the bare and natural areas. There is a 58.97% decrease in agricultural areas. The fact that the Darlık Dam and the water surfaces to the west of Terkos, which were not present in 1984, are present in the LULC of 2017 explains the 27.38% increase in the water surfaces class.

4.3. Landscape Structure Analysis

By analyzing the change for the years 1984-2017, it was seen that 10.939 ha of the forest area was transformed into impervious surfaces between 1984-2017. 67.5% of this change occurred between 2009 and 2017. Between 2009 and 2017 that caused a high rate of change in land use are analyzed, it is observed that Istanbul Airport, Yavuz Sultan Selim Bridge, and Northern

Marmara Motorway projects were implemented in this period. Figure 6 shows the spatial map of the area with the highest rate of destruction in Istanbul Northern Forests between 1984-2017.

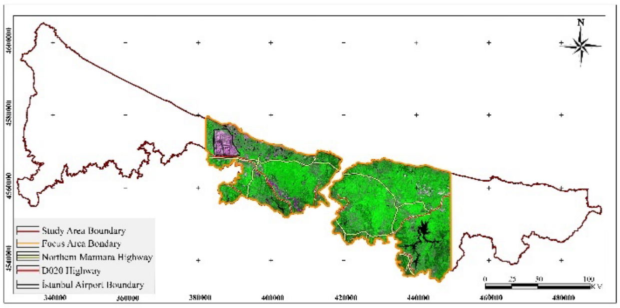
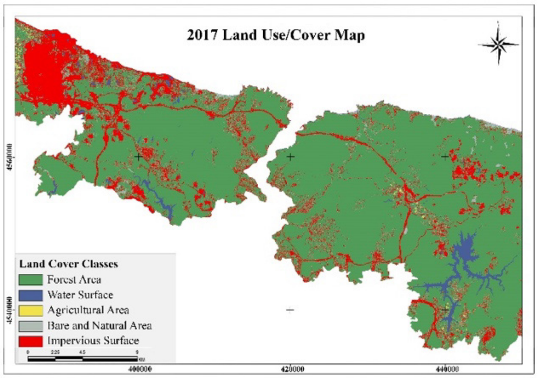
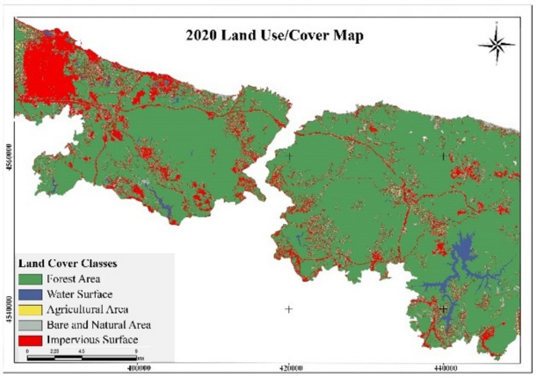


Figure 6. Spatial map of the area with the highest level of destruction in the Istanbul Northern Forests

To reveal the current situation of the Istanbul Northern Forests which hosts many natural ecosystems and living resources as of 2023 and to take the necessary measures before causing further losses, the remaining part of the study focuses on the area that has undergone the most change between 1984-2017. High-resolution Sentinel-2 satellite images of this area for the years 2017, 2020, and 2023 were classified, and the LULC results were revealed. It is aimed to analyze the LULC results of these years with scale and resolution-sensitive landscape metrics.

Sentinel-2 satellite imagery bands with 10 m spatial resolution for the years 2017, 2020, and 2023 were utilized for classification. As a result of the accuracy analyses, the overall classification accuracy is 90%, 92%, and 91%, respectively; whereas Kappa coefficients are 0.87%, 0.90%, and 89%, respectively. Figure 7 shows the LULC maps obtained as a result of classification and Table 4 shows the land cover classes according to years.





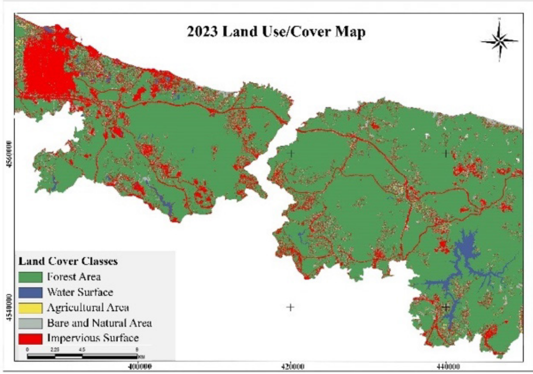


Figure 7. Land cover maps for 2017, 2020 and 2023 years

Table 4. Areas of land cover classes according to years

LULC	2017 Area (ha)	2020 Area (ha)	2023 Area (ha)
Forest areas	106876.33	106017.97	105809.21
Water surfaces	2730.15	2682.84	2492.80
Agricultural areas	292.15	284.64	274.03
Bare, natural areas	1007.81	987.79	940.33
Impervious surfaces	21195.20	22203.80	22453.17

4.4. Landscape Pattern Analysis

LULC results of 2017, 2020, and 2023 were analyzed at the landscape and class level with landscape composition and landscape configuration metrics. When the LULC results are analyzed with the Total Class Area metric, an increase of 0.75% was observed in the units belonging to the impervious surfaces in the six-year period, while a decrease of 0.7% was observed in the units in the forest areas during this period. The decrease in the classes of water surfaces, agricultural areas, and bare and natural areas are not significant. Equation 1 shows the formula used to calculate the Total Class Area, and Figure 8 denotes the total class area results of the land use maps for 2017, 2020 and 2023.

$$\text{Total Class Area} = \sum_{i=1}^{n} \text{aij}\left(\frac{1}{10.000}\right) \quad (1)$$

where a_{ij} - area of the unit (m^2)
unit- ha
range - TCA ≥ 0, unlimited

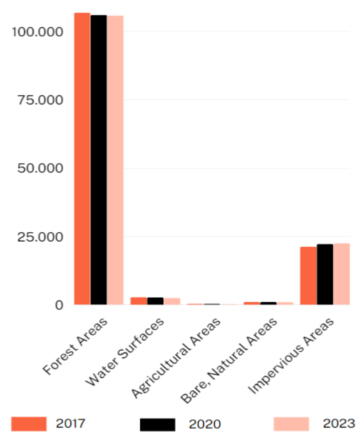


Figure 8. Total Class Area index result

When the classes forming the landscape are analyzed with the Percentage of Landscape metric, the class dominating the area is the forest area. During the six-year period, forest areas lost 0.8% and bare and natural areas lost 4.78%. There is an increase of 3.86% in the impervious surfaces. The reason for this increase in the impervious surfaces class is observed as the completion of the Istanbul Airport works and the opening of new auxiliary arteries connected to the Northern Marmara Motorway. Equation 2 shows the formula used to calculate the Percentage of Landscape, and Figure 9 shows the Percentage of Landscape results.

$$\text{Percentage of Landscape} = \frac{\sum_{j=1}^{a} aij}{A}(100) \quad (2)$$

where a_{ij} - area of the unit (m^2)
A - total landscape area (m^2)
unit - %
range - 0 < Percentage of Landscape ≤ 100

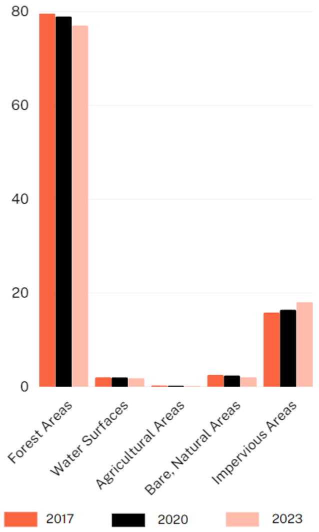


Figure 9. Percentage of Landscape index result

Clustering metrics Interspersion Juxtaposition index and Landscape Shape index are sensitive to spatial resolution and scale. The best results for these metrics are obtained with images of the same spatial resolution and the same areal size. Interspersion Juxtaposition index is the metric that allows revealing the distribution of LULC in the landscape. The units classified as agricultural areas have the highest Interspersion Juxtaposition value of 61.66. This is an indication that the agricultural area units are the most dispersed class. All classes are scattered in the landscape structure. This scattering is due to the lack of a certain controlling environmental factor. Equation 3 shows the formula used to calculate the Interspersion Juxtaposition index, and Figure 10 shows the Interspersion Juxtaposition index results.

$$\text{Interspersion Juxtaposition index} = \frac{-\sum_{k=1}^{m'}\left[\left(\frac{eik}{\sum_{k=1}^{m'} eik}\right)\ln\left(\frac{eik}{\sum_{k=1}^{m'} eik}\right)\right]}{\ln(m'-1)}(100) \quad (3)$$

where m - number of unit types in the landscape structure
eik - total edge length of unit species
unit - %
range - 0 < Interspersion Juxtaposition ≤ 100

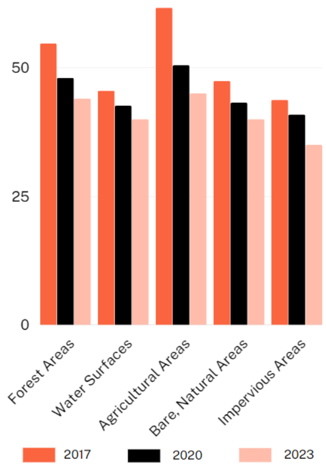


Figure 10. Interspersion Juxtaposition index result

5. CONCLUSION

According to the results obtained by analyzing the LULC maps, it is seen that the highway network is the land use that affects urban growth the most. In the analysis with landscape metrics, it has been observed that roads cause a significant decrease in the size of forest units and a decrease in the number of units, in other words, fragmentation. As a result of the linear division of forest units by road networks, it is seen that it causes a linear barrier effect in the landscape structure and interferes with the interaction of habitats with each other and interrupts their connectivity.

Analyses using landscape metrics have shown that habitats in the Istanbul Northern Forests have been damaged and destroyed. These analyses show that road routes cause a significant reduction in the size of forest units and fragmentation.

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