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Research article

Trends of changing land use dynamics in the Terkos Lake basin between 1980 and 2023 and their impact on natural ecosystems

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Abstract

Anthropogenic processes are one of the main causes of environmental change in this century. As an indicator of man's struggle for dominance over nature, the environment has been directly affected. These changes, which we encounter in every region of the place where we live, on a local and global scale, and which are due to man, cause the natural cycle of ecosystems to be disrupted. As in Türkiye in general, land use changes in the study area under the influence of direct and indirect factors in some regions are very rapid. No matter how much effort are made to control them, factors that have a direct impact on the environment, such as population growth, agriculture, industrial facilities, and the design of transport infrastructure, are the most important causes of change. In this direction, this study aims to identify the trends of land use changes around Lake Terkos and to reveal the deficiencies and fragilities of the relationship networks. It is also an indication of possible changes in the ecological status of the lake and its surroundings in relation to this situation. Terkos Lake's prolonged use as a crucial drinking water source for Istanbul makes it a valuable study site to investigate its ecological state and management practices. Nevertheless, it has recently been under pressure due to transportation (airport, Northern Marmara Motorway, Istanbul Canal and other transport networks), urban sprawl, and industry. In this context, first of all, the dynamics of land use and the rapidly changing areas (hot zones) between 1980 and 2023 have been identified and the extent of the changes over time has been shown. Possible future land use changes were analysed in the light of this data. As a result of the study, the speed of transformation of green areas was revealed. In this direction, especially in the field of the aquatic ecosystem, vulnerable areas were identified, the degree of being affected by future change was revealed and the trend in the dimensions of use and change was analysed.

Keywords: *Flora; land use and land cover change; Lake of Terkos; natural ecosystem*

1. Introduction

Land use and land cover change, which has been a very intensive area of study worldwide in recent years, has been analysed in different areas. These areas include cities (Garipagaoglu and Duman, 2018; Dadashpoor et al., 2019; Ozturk and Gunduz, 2019; Luo et al., 2020; Duran and Dogan, 2022; Karaoglu and Erdel, 2022), coastal areas (Guney and Polat, 2015; Abdullah et al., 2019), natural ecosystems, especially lake and river basins (Gulersoy, 2014; Sun et al., 2018; Peters et al., 2019; Ozcalik et al., 2020; Bahadir and Uzun, 2021; Kacmaz and Doker, 2021; Tas and Akpinar, 2021; Bayrak et al., 2022). People may encoumore than one environmental problem in their living environment. Climate change, the growth of urban areas, and the proliferation of industrial facilities lead to loss of diversity over time, the degradation of soils, the pollution of water, and thus the degradation of ecosystem services (Costanza et al., 2014; Meyfroid et al., 2018). Anthropogenic processes are the main driver of land use change (Lai et al., 2021). Among these changes on Earth, 60% are

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attributed to direct anthropogenic influence, while 40% are due to indirect factors, including climate change (Song et al., 2018).

Owing to the hastening of developmental endeavours in urban and rural regions during recent years, the proximal vicinity of Lake Terkos, located in the northern region of Istanbul, has experienced land use change processes such as the expansion of settlements, the reduction of the effectiveness of agricultural areas and the intensification of transport activities. The urban and rural expansion has had the most significant impact on these changes. Today, the implementation of changes in land use directly related to anthropogenic processes is expressed in terms of welfare and development. However, they remain the main causes of environmental problems. These problems include water and air pollution, erosion, decreasing agricultural area, and decreasing species of wetland ecology (Wei et al., 2017; Wu et al., 2018; Yilmaz et al., 2021).

According to United Nations and World Bank data, the world's population will reach 7,924 million by 2022 and 8,010 million by 2023. Worldwide, 55% of this population lives in urban areas (World Bank, 2019), and 76% of Turks will live in cities by 2020. By 2030, it is estimated that 65% of the world's population will live in cities (CSB, 2019). As the urban population continues to grow, many challenges will be faced. In Istanbul, the population has been growing steadily. This has led to the development of new areas. As a result, new transportation networks and development activities have revealed many different situations, such as loss of vegetation cover and pollution. The most important of these changes are undoubtedly the new airport, the Northern Marmara Motorway, new residential areas, and the planned study of the Istanbul Canal. The existing lake basin is under serious pressure from all these activities (Yalcin et al., 2020; Yilmaz et al., 2021).

Sustainable ecological planning of the Lake Terkos basin is important for the continuity and usefulness of the rapidly developing local economy and urbanization in the region. Non-sustainable practices that fail to serve the interests of the future will hasten the degradation of the basin. Therefore, planning should consider the ecologically important areas. Conservation is the first principle to be considered. In this study, the natural ecosystem of the lake and its surroundings and the changes it has undergone were analysed using satellite images from different years. In this way, periods of change and trends in land cover were identified and compared. The level of the lake was determined from each satellite image and the directions of water level changes were revealed.

1.1. Conceptual framework

Environmental studies are generally carried out in two categories (Johnston and Sidaway, 2016). One of them is to analyze the existing structure and define the natural environment (Detwyler and Marcus, 1972; Berry, 1974; Berry and Horton, 1974; Douglas, 1983; Douglas, 2013), and the second was on the identification of environmental problems (O'Riordan, 1971a; 1971b). Both types of the study tracked and analyzed the traces of changes in the environment.

There have been different definitions of the environment because the environment is an area which is the subject of study in different branches of science. (Daramola and Ibem, 2010). In the view of the sociologist Bain, the environment refers to the external and impersonal conditions that affect people within a region. The environment refers to the external and impersonal conditions that affect people within a region. It is the sum of all conditions surrounding a person at any given time (Bain; 1973).

As obvious from these definitions, the environment is the natural systems that govern the existence and interaction of all the natural elements of the environment and establish a relationship between them (Johnson, 1992; Efobi, 1994; Muoghalu, 2004).

Disruption of the balance established within these systems poses a serious threat to environmental sustainability and ecology (Marcuse, 1998). Today, changes in land use and land cover are very rapid in intensively used urban areas and in the regions where they interact. The increase in the rate of change of these two closely related elements has a negative impact on the carrying capacity of the environment. Therefore, changes in the geographical ecology expand the boundaries of the Ecological Footprint (Stoel, 1999; Luo et al., 2018). As a result of environmental degradation, humans, who are part of the environment, have begun to pollute soil, water and air as a result of urbanization and industrialization. To some extent, the ecological footprint, which shows the need for natural resources, is felt more in urban areas where consumption is intense (Sagir, 2012; Senol, 2012; 2015; 2023).

With the increase in population size, population density has concomitantly risen, particularly in cities. In Istanbul, Türkiye's largest and most important city in many respects, the population is growing faster than the national average each year (Avci, 2010; Ozturk et al., 2017). This situation has brought with it a wide range of problems (Yulu, 2017). According to 2021 data, 18.7% of the country's population lives in Istanbul, Türkiye's most vibrant city, with a population density of 2,900 (TUIK, 2021).

Urban population growth has driven outward expansion, including in Istanbul's Lake Terkos and its urban development zone, notable for its rapid expansion. The transport investments made in the region in the last five years and new projects (Canal Istanbul) have started to put the region in a rapid urbanization process. As one of the places in Istanbul where land use and land cover changes are most pronounced, it has been a place to focus on for years because it is a watershed where the city's drinking water, agricultural and livestock center and oxygen-producing forests are located (Altay et al., 2015; Yilmaz et al., 2021).

1.2. Study area

The Terkos Lake Basin is located in the northeast corner of Istanbul between 28° 5′ 51″-28° 43′ 41″ east longitude and 41° 27′ 29″-41° 13′ 39″ north latitude. The basin lies west of Istanbul, north of the Çatalca peninsula, and on the coast of the Black Sea. While a large part of it is in the Arnavutköy, Çatalca, and Silivri districts of Istanbul, a very small part is in the Saray district of Tekirdağ. The most important streams in the basin are mainly Istranca, Kayınpınar, Kapaklı, Çeşme and their tributaries, which feed Lake Terkos (Durusu). The basin, which has maintained its drinking water quality for years, covers an area of approximately 735 km² within the boundaries formed by the rivers. There are no large settlements in the basin; there are 11 rural settlements in the form of villages, mainly engaged in agriculture and animal husbandry. However, the region is important in terms of attracting major investment and population in 2018 and beyond. The villages, which until now have existed as small settlements, are now attracting large populations. However, it is still one of the least developed regions of Istanbul. Most of the Terkos Lake basin is less than 200 meters above sea level. The western and south-western parts of the basin are

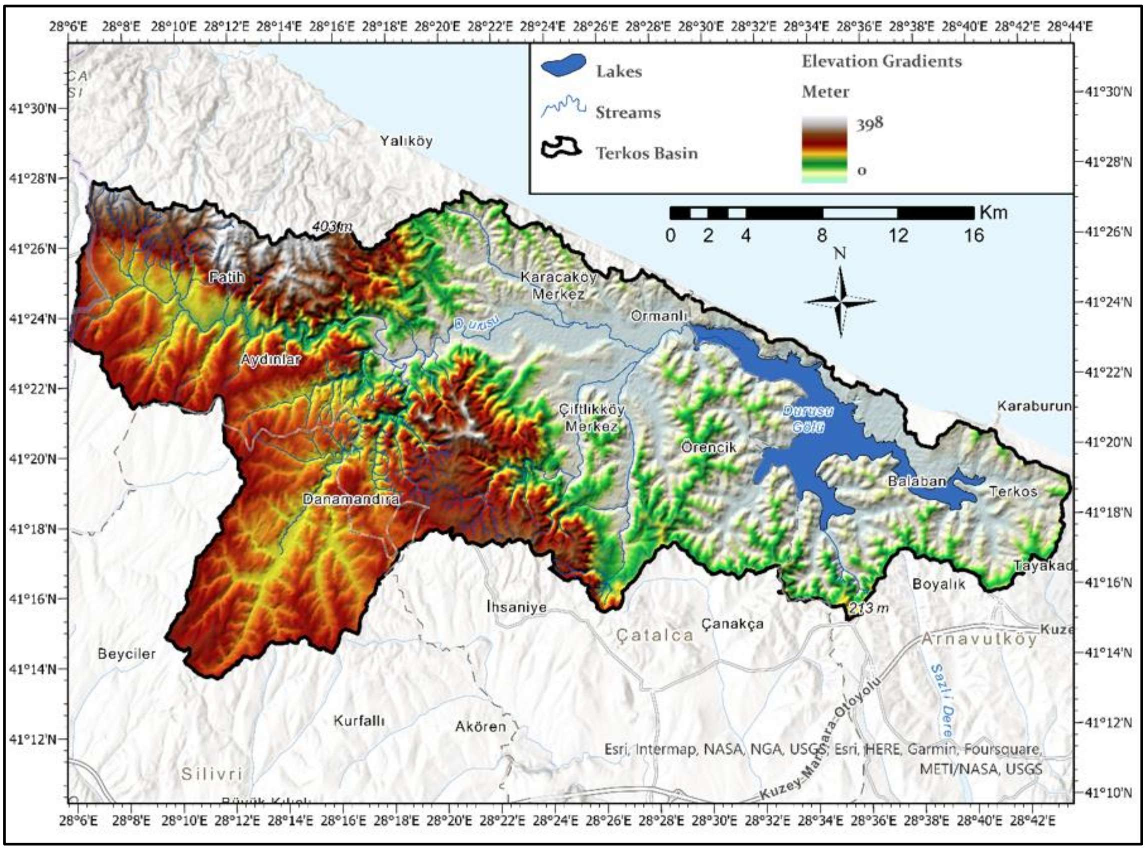

Fig. 1. Map of the Terkos Basin.

higher than other areas. The source of the lake's feeding rivers is in the highlands, which gradually slope towards it. Terkos Lake is fed by Belgrad, Fındık, Kanlı, Deli Yunus, Başköy, Karacaköy and Çiftlikköy Streams. (Fig. 1) (Sozen et al., 2021; Yilmaz et al., 2021; Bozkurt et al., 2023).

2. Material and methods

NDVI, NDWI, Natural Color, and Near Infrared bands were extracted from raw Sentinel 2, Landsat 1-5, Landsat 4-5, Landsat 7, and Landsat 8-9 data using ArcMap Pro software. First, the satellite images were clipped to the study area using the raster clip tool.

Then

- NDVI formula using red and NIR band data for NDVI band: (NIR - Red) / (NIR + Red)
- NDWI formula using Green and NIR band data for NDWI band: (Green - NIR) / (Green + NIR) was used.

The Natural Color and Near Infrared formula and band combinations vary depending on the satellite image. For the Natural Color band in Sentinel 2 satellite imagery, the RGB composite band was created with the combination 4,3,2 using Red, Green, and Blue band data. The Near-Infrared band was also created using the 8,4,3 combination.

NDVI, NDWI, Natural Color, and Near Infrared images were created by combining the bands obtained. The formulae and Python codes required for image acquisition are described in detail in the Results section. As a result, the changes in different satellite images over the years were revealed by remote sensing method and the land use and spatial changes of the basin were analyzed. Finally, the satellite images of different bands obtained in the field were analyzed on a pixel basis using the "Supervised Classification" tool in ArcMap Pro software to measure land use change, and the raster data obtained were converted into vectors and spatial measurements were made using the "Calculate Geometry" tool. Finally, to determine the rate of change, the "Change Detection" tool was used to identify the areas of greatest change around Lake Terkos.

3. Results and discussion

In the study, the changes observed in the land as a result of the analyses of satellite images in 1980-2000-2020 and 2023 were handled in four stages. In this period, the spatial development and change in the Terkos Lake Basin were analyzed as a whole. In the first one, the land use of 1980 was analyzed with different satellite images, and the basic data for this year were compared with 2000. Likewise, the year 2000 was compared with 2020 and the differences between the years were revealed. The image of the year 2023 was also analyzed in order to draw attention to the changes in the land as a result of some new activities and constructions such as the new airport, new transportation network, and developing urban area in the northeast corner of the basin and to reveal the difference of the change. In this direction, the following process steps and findings are presented and the direction and trend of change are revealed.

Satellite sensors can image the Earth in different regions of the electromagnetic spectrum. Each region in the spectrum is called a band. Sentinel-2 has 13 bands. The true color composite uses the red, green, and blue visible light bands in the respective red, green, and blue color channels, resulting in a natural color product that is a good representation of the Earth as people would see it naturally (Sentinelhub Playgraund, 2023). What is meant by true color here is finding the color range closest to natural colors. It means that the colors of the object in the image

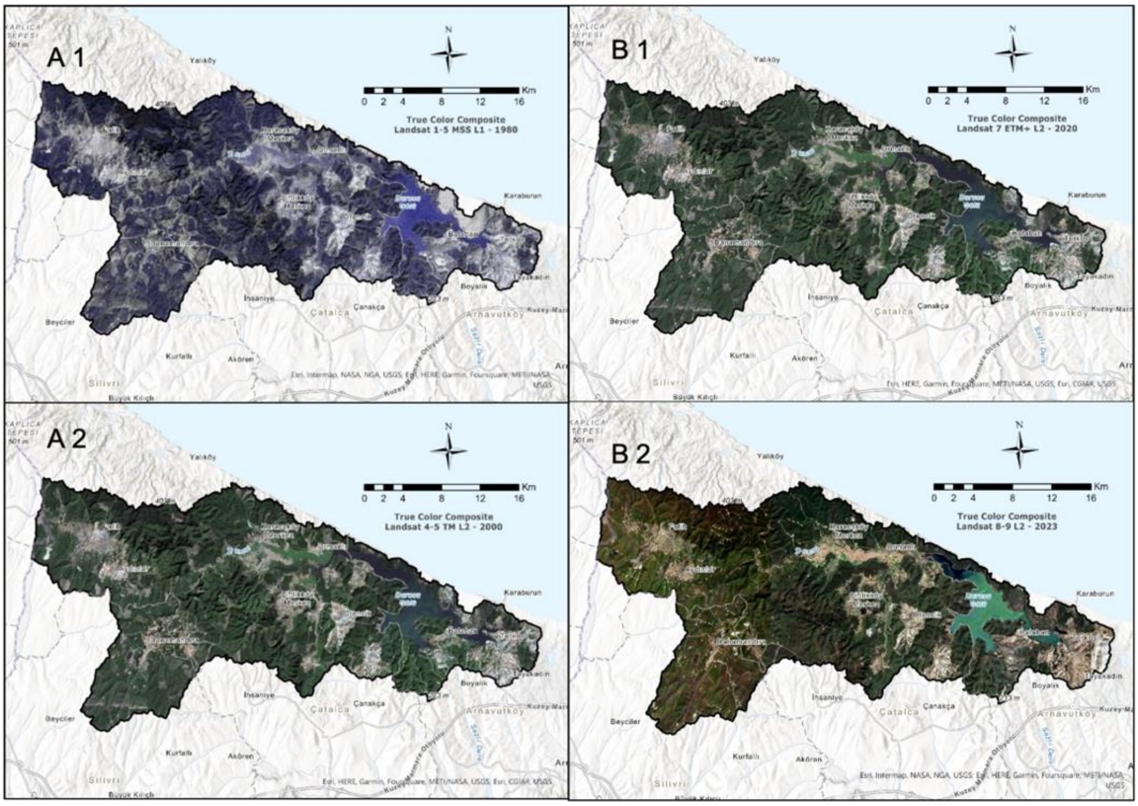

Fig. 2. Terkos Lake Basin 1980-2000 (A 1-2)-2020-2023 (B 1-2) True-color composite.

are displayed in the same color range as they appear in nature when viewed by the human eye. A true-color image shows the area in its true color, for example, vegetation in green, rivers and lakes in blue. It covers the entire visible spectrum, mapped to the image's RGB color space using the satellite's red, green, and blue/green spectral bands (Fig. 2).

In the true color composite, Sentinel-2 maps the band values B04, B03, and B02 to the R, G, and B components, respectively corresponding to the red, green, and blue parts of the spectrum.

In this composite
- For Sentinel-2: BO4, B03, B02
- For Landsat 4-5 TM: B03, B02, B01
- For Landsat 7 ETM: B03, B02, B01
- For Landsat 8: B04, B03, B02
- For MODIS: B01, B04, B03 band combinations are used.

Also sample Python code for Sentinel 2 image;

```
//VERSION=3
function setup() {
  return {
    input: ["B04","B03","B02", "dataMask"],
    output: { bands: 4 }
  };
}
function evaluatePixel(sample) {
    return [2.5* sample.B01, 2.5* sample.B02, 2.5* sample.B03, sample.dataMask];
}
```

(Costum Scripts, 2023; GitHub, 2023; Sentinelhub Playgraund, 2023).

False color compositing uses at least one non-visible wavelength to image the Earth. False-color compositing using the near-infrared, red, and green bands is very popular. A band is a region of the electromagnetic spectrum; a satellite sensor can image the Earth in different bands. False-color imagery is most commonly used to assess plant density and health, as plants absorb red and reflect near-infrared and green light. Cities and exposed soil appear grey or brown, and water appears blue or black (Sentinelhub Playgraund, 2023).

The false-color infrared composite maps the near-infrared spectral band B8 and the red and green bands B4 and B3 directly to the sRGB components. Because plants absorb red and reflect near-infrared and green light, it is most commonly used to assess plant density and health. Areas covered with plants appear dark red because they reflect more near-infrared light than green. The denser plant cover is darker red. Cities and exposed soil appear grey or brown, and water appears blue or black (Fig. 3) (GISGeography, 2023; Sentinelhub Playgraund, 2023).

- For Sentinel-2: B08, B04, B02
- For Landsat 1-5 MSS: B04, B02, B01
- For Landsat 7 ETM+: B04, B03, B02
- For Landsat 4-5 TM: B04, B03, B02
- For Landsat 8: B05, B04, B03
- For MODIS: B02, B01, B04 band combinations are used.

Also, sample Python code for Sentinel 2 for the image;

```
//VERSION=3
function setup() {
  return {
    input: ["B08","B04","B03", "dataMask"],
    output: { bands: 4 }
  };
}
function evaluatePixel(sample) {
    return [2.5* sample.B08, 2.5* sample.B04, 2.5* sample.B03, sample.dataMask];
}
```

(Costum Scripts, 2023; GitHub, 2023; Sentinelhub Playgraund, 2023).

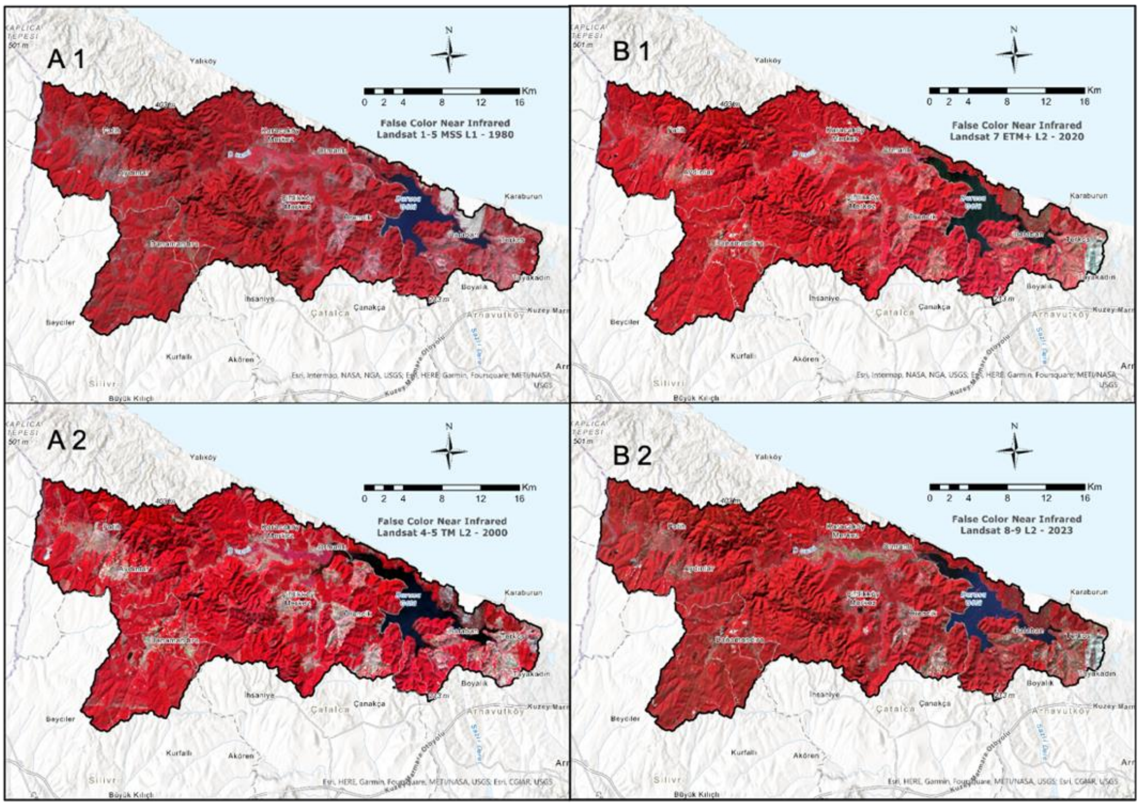

Fig. 3. Terkos Lake Basin 1980-2000 (A 1-2) - 2020-2023 (B 1-2) False colour view in the near infrared.

The normalized difference vegetation index is a simple but effective index for measuring green vegetation cover. It is a measure of the health of vegetation based on how plants reflect light at certain wavelengths. The value range of NDVI is -1 to 1. Negative NDVI values (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) correspond to barren areas, usually consisting of rock, sand, or snow. Low, positive values represent shrubland and grassland (about 0.2 to 0.4), while high values indicate temperate and tropical rainforest (Sentinelhub Playgraund, 2023) (Fig. 4). NDVI is obtained from satellite images and different bands are used according to different satellite images.

These are

- Landsat 8 NDVI{:target="_blank"} = (B05 - B04) / (B05 + B04)
- Landsat 5 and 7 NDVI = (B04 - B03) / (B04 + B03)
- MODIS NDVI = (B02 - B01) / (B02 + B01)
- ENVISAT MERIS NDVI = (B13 - B07) / (B13 + B07)
- Landsat 1-5 MSS NDVI = (B04 - B02) / (B04 + B02)
- Landsat 4-5 TM = (B04 - B03) / (B04 + B03)
- Landsat 7 ETM+ NDVI = (B04 - B03) / (B04 + B03)

(GitHub, 2023).

NDVI formula is;

NDVI = (NIR-RED)/(NIR+RED)

NIR - reflected light in the near infrared spectrum

RED - reflected light in the red range of the spectrum

According to this formula, the density of vegetation at a given point in the image (NDVI) is equal to the difference of the reflected light intensities in the red and infrared range divided by the sum of these intensities (EOS Data Analiytics, 2023).

Also the image's sample Python code for Sentinel 2;

```
//VERSION=3
const colorRamp = [[0,0x000000],[1,0xffffff]]
let viz = new ColorRampVisualizer(colorRamp);
function setup() {
  return {
    input: ["B08","B04", "dataMask"],
    output: [
      { id:"default", bands: 4 },
      { id: "index", bands: 1, sampleType: 'FLOAT32' }
    ]
  };
```

}(GitHub, 2023; Costum Scripts, 2023; Sentinelhub Playgraund, 2023).

NDWI stands for Normalized Difference Water Index and is an index used to identify and map areas of standing water in satellite imagery. NDWI is calculated by dividing the difference between the green and near infrared (NIR) bands of an image by their sum. It is based on the idea that water strongly absorbs NIR light and reflects green light (Sentinelhub Playgraund, 2023).

In areas of standing water, the NDWI value will be positive, indicating a high difference between the green and NIR values. In other areas, such as vegetation or bare ground, the NDWI will be negative, indicating a small difference between the green and NIR values. NDWI can be used to detect water bodies in a variety of landscapes, including wetlands, rivers, lakes, and even urban areas with built infrastructure (Fig. 5).

NDWI is obtained from satellite images and different bands are used according to different satellite images.

These are

- Sentinel-2 NDWI = (B03 - B08) / (B03 + B08)
- Landsat 1-5 MSS NDWI = (B01 - B04) / (B01 + B04)
- Landsat 4-5 TM NDWI = (B03 - B05) / (B03 + B05)
- Landsat 7 ETM+ NDWI = (B02 - B04) / (B02 + B04)
- Landsat 8 NDWI = (B03 - B05) / (B03 + B05)

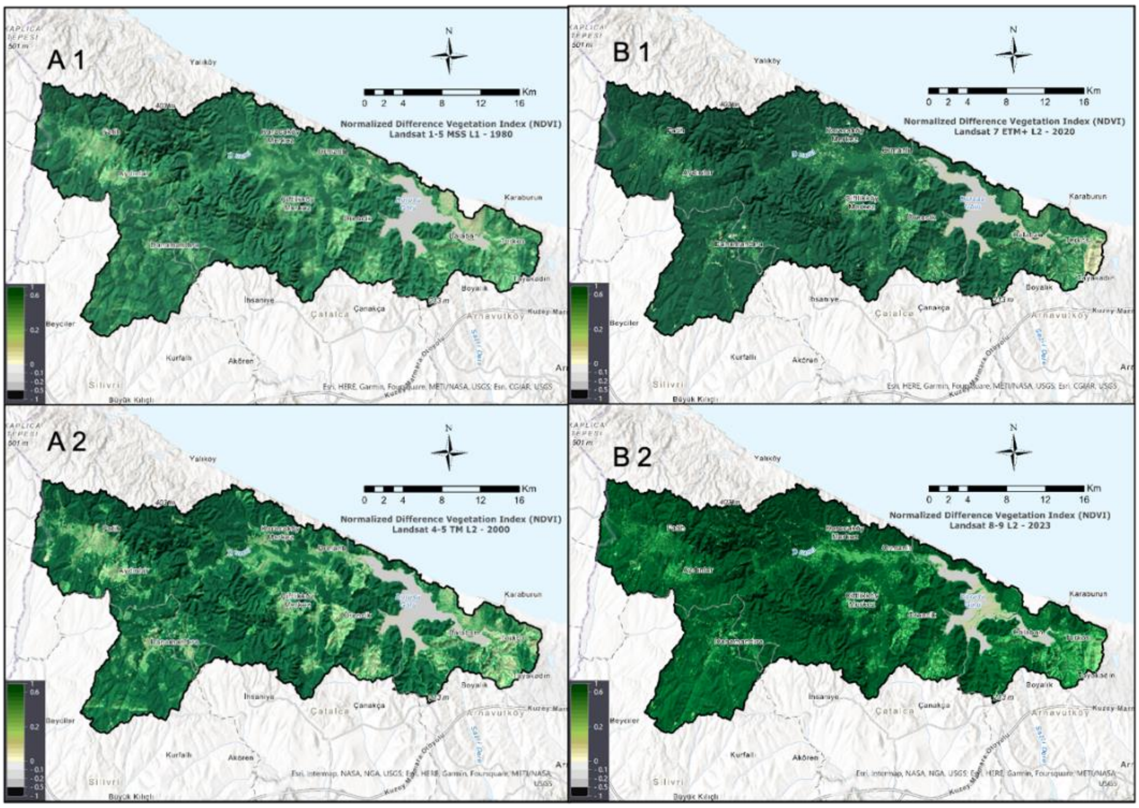

Fig. 4. Terkos Lake Basin 1980-2000 (A 1-2)-2020-2023 (B 1-2) NDVI view.

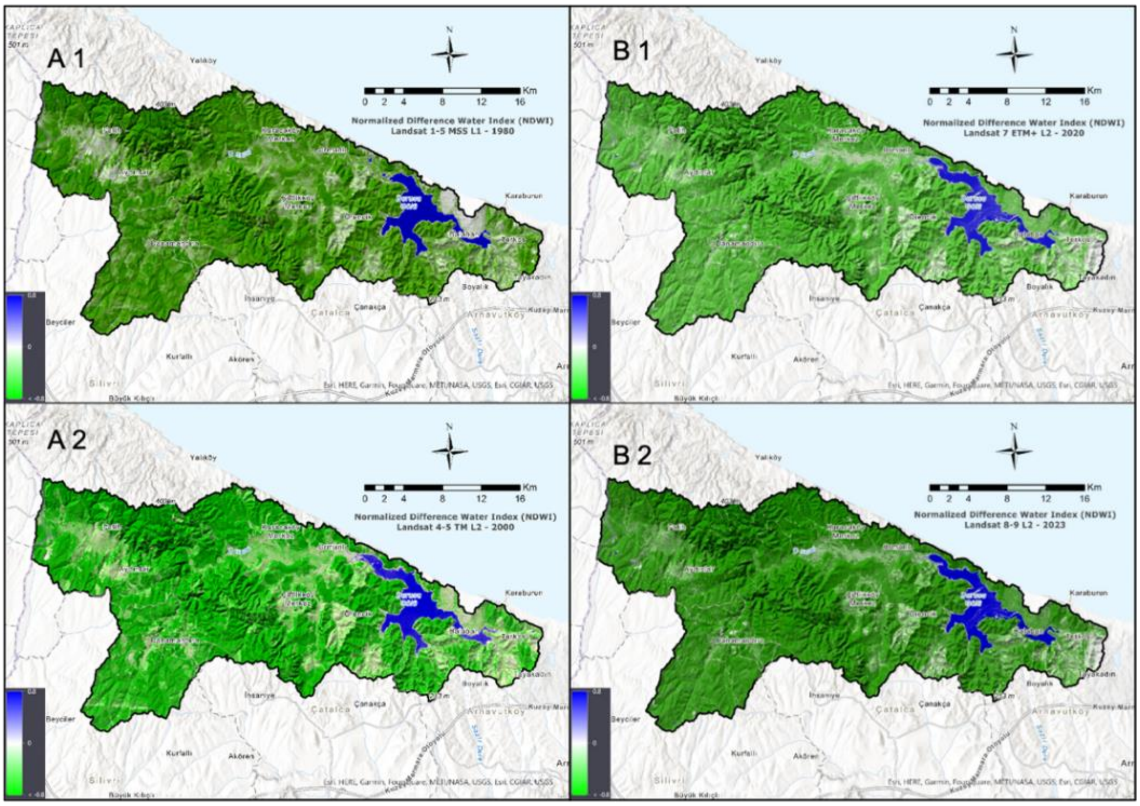

Fig. 5. Terkos Lake Basins 1980-2000 (A 1-2)-2020-2023 (B 1-2) NDWI View.

- MODIS NDWI = (B04 - B02) / (B04 + B02)

The formula for the Normalized Difference Water Index (NDWI) is as follows

NDWI = (GREEN - NIR) / (GREEN + NIR)

Where Green is the green band and NIR is the near infrared band. This formula is used to calculate the NDWI value for each pixel in the image. The resulting NDWI values range from -0.8 to 0.8, with positive values indicating the presence of water. The exact bands used for green and NIR can vary depending on the satellite sensor and data processing method, but the bands commonly used for Sentinel-2 are B03 (green) and B08 (NIR).

Also the image's sample Python code for Sentinel 2;

```
//VERSION=3
const colorRamp = [[0,0xffffff],[1,0x005824]]
let viz = new ColorRampVisualizer(colorRamp);
function setup() {
  return {
    input: ["B03","B08", "dataMask"],
    output: [
      { id:"default", bands: 4 },
      { id: "index", bands: 1, sampleType: 'FLOAT32' }
    ]
  };
}
```

(Costum Scripts, 2023; GitHub, 2023; Sentinelhub Playgraund, 2023).

The rapid increase in population in Istanbul has accelerated the process of change in urban and forest areas. The rapid and uncontrolled expansion of cities in urban areas affects forest and water areas. Although the extent of the impact varies, the result is economic and social problems such as pollution, inadequate infrastructure, and land management (Deniz, 2009).

The expansion of human settlements leads to a decrease in green areas and a deterioration of biodiversity and ecological balance. Istanbul’s population initially concentrated in coastal areas and near transport routes, began to expand towards the north of the city with the construction of bridges. After the second bridge, illegal settlements grew rapidly in Arnavutköy, Sultançiftliği, and Habipler. During this period, settlement accelerated and began to threaten forests and water basins (Kılıçaslan, 1981; Terzi and Bolen, 2010). The process experienced after the rapid population growth has entered a new process with the third bridge. In this process, Istanbul has entered a process of expansion toward the urban periphery (Kanbak, 2013). The most important and most affected area within this area is undoubtedly the Terkos Lake basin. The fact that it is Istanbul’s main source of drinking water makes it even more important.

Land use and lake level changes in the Terkos Lake Basin were analyzed in two periods, 1980 and 2023. The 1980 satellite image was generated using Landsat 1-5 MSS L1 data from the SentinelHub Explorer module. The land use status in 2023 was generated using Landsat 8-9 L2 data from the SentinelHub Explorer module (Sentinelhub Playgraund, 2023).

ArcMap Pro software was used for both image analyses. In the software, digitization was performed using the supervised classification module of the Image Classification Wizard tool. This method used natural color, infrared, NDVI, or NDWI color bands for detection and pixel sampling. Hundreds of pixel samples were taken in different categories such as water bodies, bare land, agricultural land, settlements, and forest areas and these were categorized according to pixel colors by considering maximum similarity. Calculations were then performed on these digitized areas using the Calculate Geometry tool to determine land use change.

To measure the accuracy of land use, the 2023 satellite image was verified with Google Earth by assigning more than 500 points. A high accuracy of 92% was obtained. The 1980 image of the land was verified with the Landsat 1-5 MSS L1 image and an accuracy rate of 90.7% was achieved. Although such margins of error exist in pixel-based land use change analysis due to similar colors, a very high accuracy rate was achieved (Fig. 6).

When analyzing the land use of the Terkos Lake Basin in 1980, it can be seen that rivers and lakes occupy 2% of the land with 13.3 km². This ratio is the lowest lake level in the study period, and in the following periods, the amount of water in the basin first increased slightly and then decreased again. However, despite the decrease, as seen in the 2023 data, it still has more than twice the water mass compared to 1980, covering 4% of the area with an area of 28.7 km² (Fig. 6-7, Table).

Another category is non-green land. These areas are divided into bare rocky land, non-agricultural land, roads, residential areas and other buildings (facilities). However, these areas are grouped together as non-green areas, both because it is difficult to distinguish between them in such a large area due to the similarity of pixel colors, and to avoid going beyond the purpose of the study. For example, non-green areas, which accounted for 210.8 km² and 29% of land use in 1980, decreased to 26% and 193.6 km² in 2023. In this process, settlement and construction, various afforestation activities around the lake, which has a sensitive ecosystem, and the expansion of the agricultural area, as well as the increase in the water level and the expansion of its area, have led to a slight decrease (Fig. 6-7, Table).

As a result of the analysis, there is an increase in non-green areas and water levels. One of the main reasons for this increase is primarily the human activities in the basin. The airport built in the east of the basin and the intensification of transportation

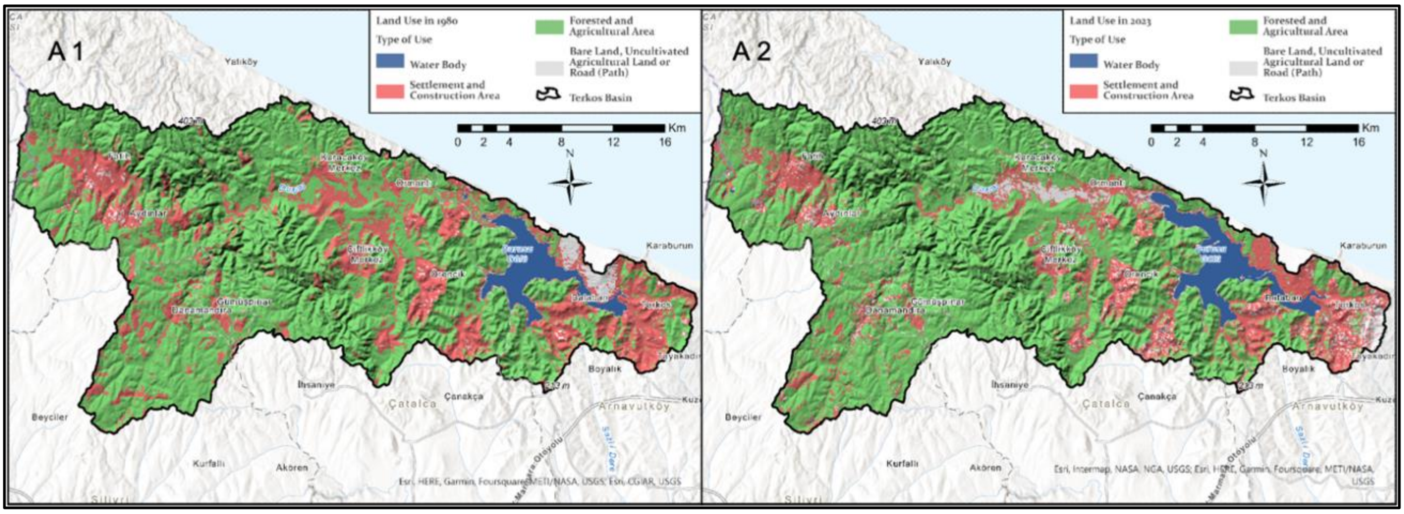

Fig. 6. Land use in Lake Terkos between 1980 (A 1) and 2023 (B 2)

Table
Land use in Lake Terkos between 1980 and 2023.

Class Name	Subclass Name	Subclass Area (Km^2)		Class Area (Km^2)		Area (%)	
		1980	2023	1980	2023	1980	2023
Water	Water body	13.33	28.72	13.33	28.72	2	4
Non-green area	Bare land, uncultivated agricultural land or road (path)	24.84	40.14	210.85	193.69	29	26
	Settlement and construction area	186.02	153.55				
Green area	Forested and agricultural area	511.31	513.18	511.31	513.18	69	70

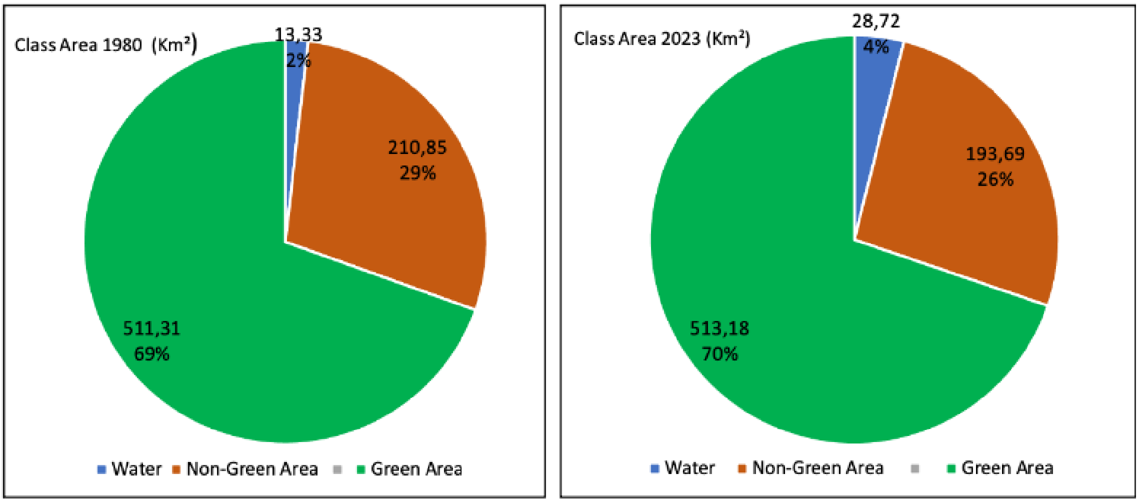

Fig. 7. Land use in Terkos Lake in between 1980 and 2023.

networks in the region have led to an increase in non-green areas. The increase in the water level is based on the principle of protecting and even raising its level in terms of being a drinking water basin. There has been a slight increase in forest and agricultural lands in the area and this is due to the expansion of agricultural areas in the basin and afforestation in the lake basin.

Finally, when analyzing the category of green and agricultural areas, these areas, which covered 69% of the basin in 1980 with 511.3 km², have slightly increased by 1% to 513.1 km² and 70% in 2023. This is due to the reforestation work carried out, in particular around the lake (dune reforestation) and the restriction of agriculture in ecologically sensitive areas by increasing the agricultural area, as mentioned above (Fig. 6-7, Table).

As can be seen from the data, ¾ of the catchment consists of green areas and lakes. These areas have been protected by the measures taken in the period 1980-2023 and the change has been relatively small. However, the facilities that have been built in the lake and its immediate surroundings in recent years, as well as the major projects that are planned, could disrupt the lake's ecosystem if the necessary measures are not taken. In particular, Istanbul Airport, which will be operational in 2019, is expected to destroy green areas in a relatively large area (about 8 km²) in the eastern part of the basin (Fig. 7-9). Moreover, the fact that it encourages the spread of structures like settlements, housing or roads is a major pressure.

When analyzing the changes in the area covered by Lake Terkos, it was found that there were increases and decreases depending on the time period. NDWI images of the lake surface were obtained from Landsat 1-5, Landsat 7 and Landsat 8-9 satellite images taken in 1980, 2000 and 2023. These images, which stand for Normalized Difference Water Index (NDWI), are a relatively accurate index used to determine or map standing water areas.

According to these images; The surface area of Lake Terkos in 1980 was approximately 24.8 km². This was the lowest surface area recorded during the measurement period. After this period, the area of the lake started to increase, especially after 1994. The most important reasons for this are the modernization of the regulation system built around the lake during this period and the controlled change of the water level. As a result, the surface area of the lake increased by about 36% to 39.1 km² in 2000. After this period, dune reforestation work was carried out around the lake in the 2000s to protect and raise the lake level. However, despite these efforts, the lake has been shrinking in recent years. In the last 15 years in particular, the use of the lake's water has reached its maximum level, due to factors such as the spread of settlements, increasing agricultural activity and rapid population growth. As a result, the water surface has shrunk considerably.

According to the latest measurement, in 2023, the lake area decreased by 28.3% compared to the previous period, shrinking to 30.5 km² (Fig. 10). The level of the lake waters, which flow into the Black Sea through a narrow and deep valley with a lake pillar in the eastern part of the lake, is controlled through regulators by building embankments in front of it. The regulator has the duty of regulating the level and water quality. Here, the gates of the regulator are set at a certain level and when the level is exceeded, the water continues to flow over the gates.

The lake is currently not at its natural level (the natural level is 4.5 meters), but its level has been raised. The natural depth can vary between 8-16 m over time. The locks here play a role during these level changes. In periods when the level rises too high, the dune afforestation area is in danger of being flooded, so the gates are opened, and discharges are made. This is important as it is part of protecting the lake area (Fig. 11). Another measure to protect the lake area is to create grove areas. Protection zones have been established around Terkos Lake at certain intervals (such as 100-300-700-900 m) from the shoreline. These protection areas are implemented within the framework of the regulation and are restricted in terms of a settlement.

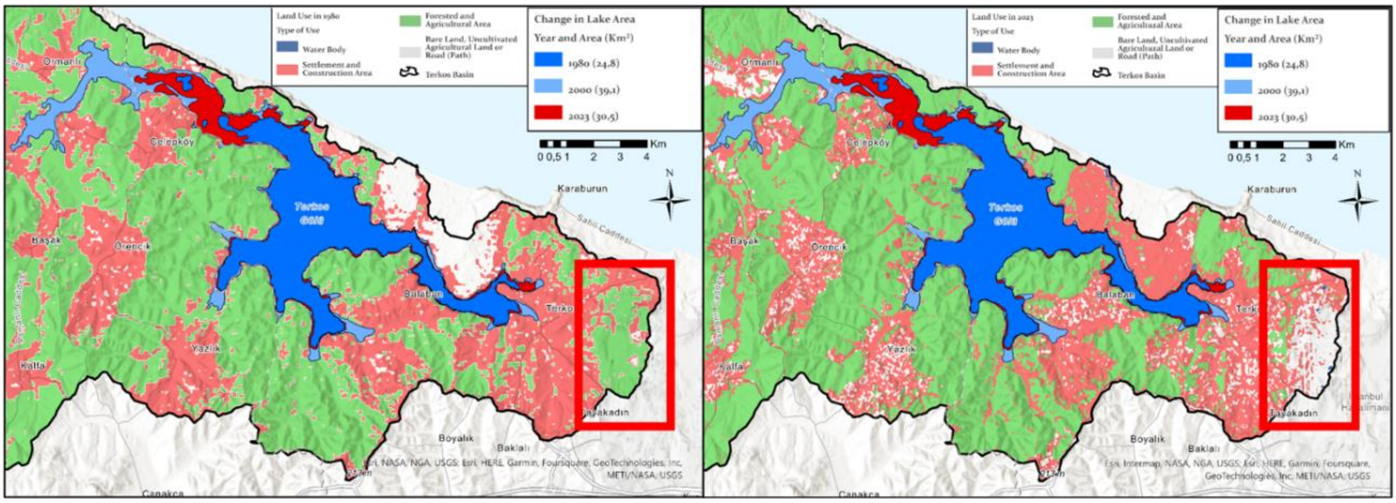

Fig. 8. Changes in land use and lake area around Terkos Lake.

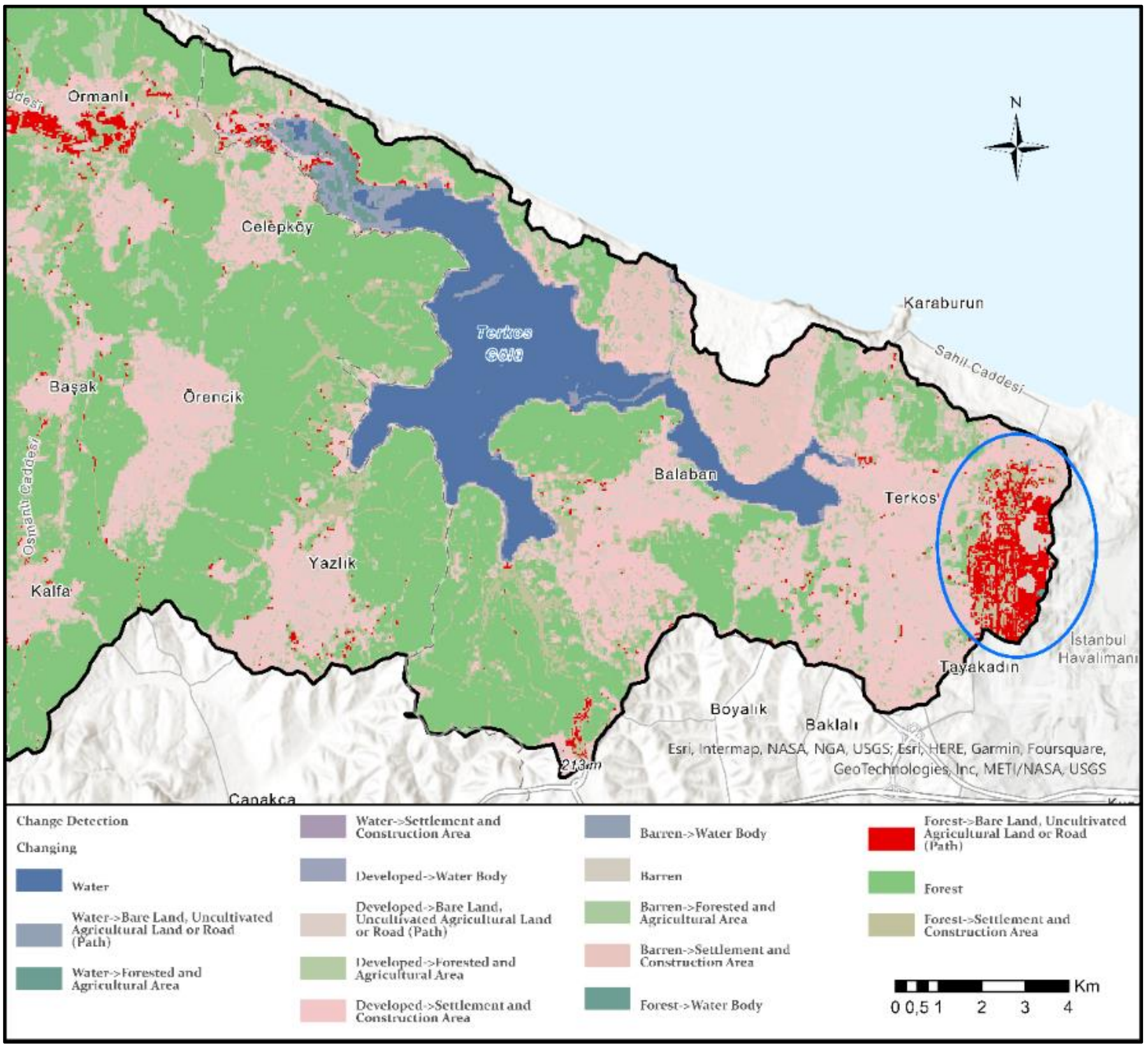

Fig. 9. Changes caused by Istanbul Airport in the eastern basin of Lake Terkos.

The world-famous dune afforestation area was established as one of the most important protection measures in Lake Terkos. It is the first dune afforestation area in Türkiye. Many delegations from England and other countries come here to see the afforestation, do research, and write reports. Two gates, situated 16 km apart, control access to the region housing water treatment plants, dune afforestation, and the lake. Security personnel are present to safeguard the dune afforestation system and the lake against potential harm (Fig. 12).

4. Conclusion

It is very important to protect the ecological environment of Lake Terkos, which is one of the 135 wetlands of international importance designated in Türkiye by the RAMSAR Convention. A small mistake here can damage the entire ecosystem of the lake. For this reason, the dune reforestation area in particular is being protected very carefully.

If the trees disappear, the lake will be in danger. This would

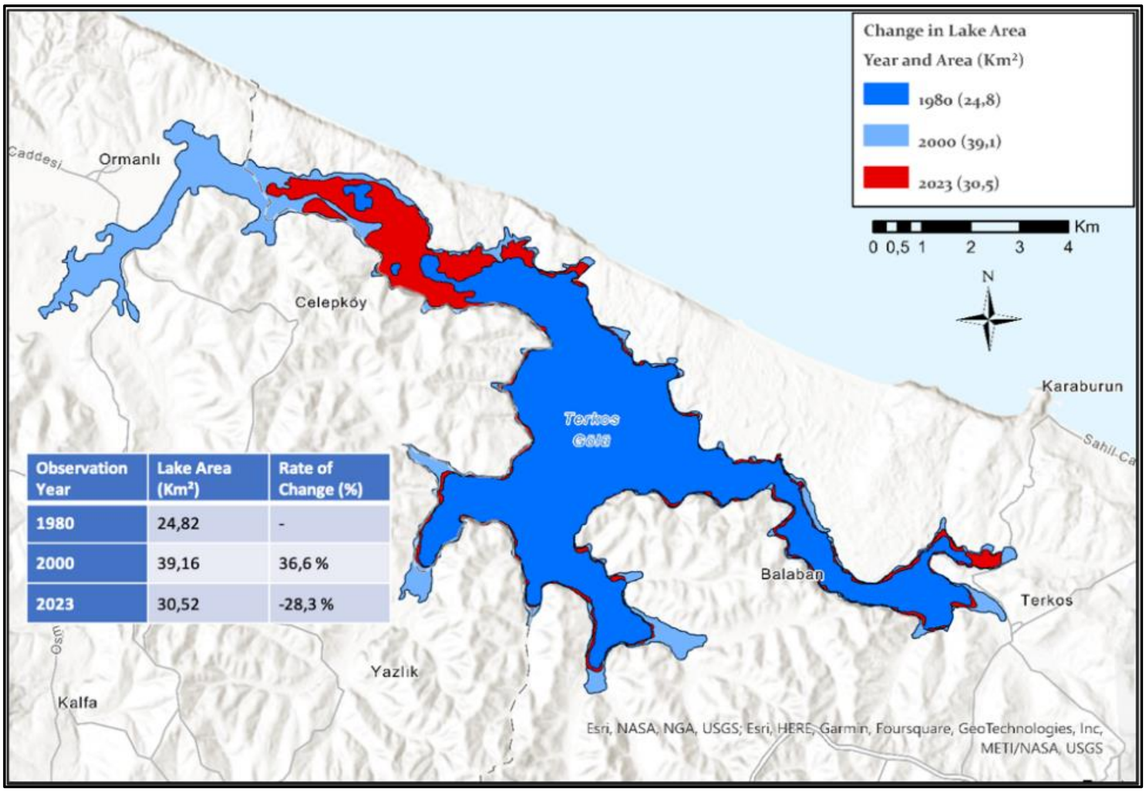

Fig. 10. Changes in the area of Lake Terkos between 1980-2000-2023.

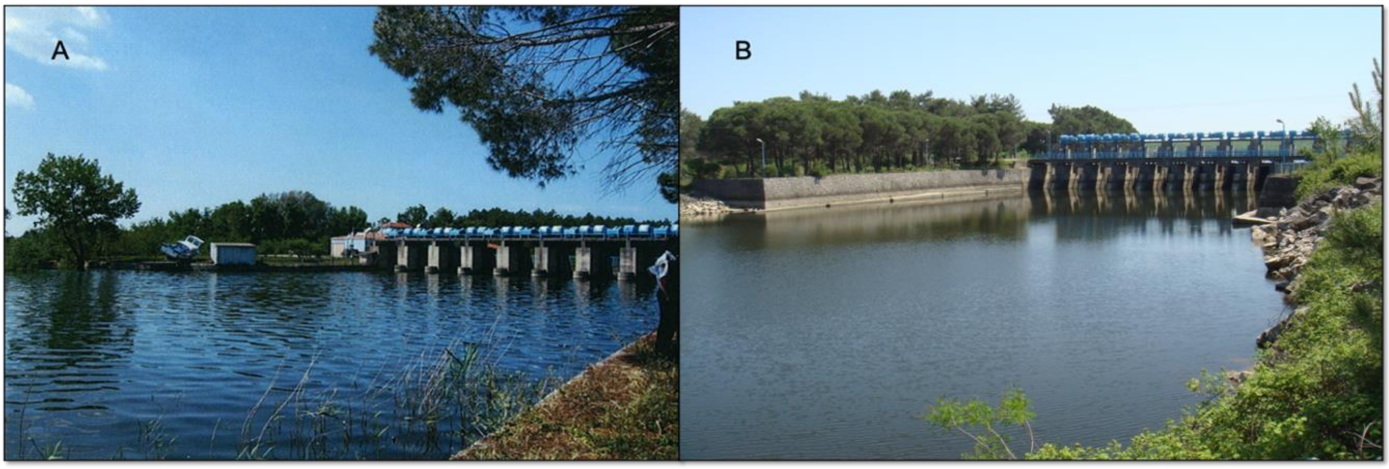

Fig. 11. Regulators for the regulation of the water level in the lake of Terkos (Durusu).

Fig. 12. Red pine and black pine trees in the dune afforestation area, protecting the lake ecosystem from the dunes.

mean the loss of about 150-300 million m^3 of water, about 1/3 of Istanbul's annual water needs. The reservoir here is fed by dams built on the streams that flow from Istranca, which keeps the water fresh. This reduces pollution and preserves the lake's water.

It has also been found that the water is better than other reservoirs in terms of freshness and drinkability. So much so that the water can be drunk with a glass immersed in the lake. To protect the water quality and maintain the productivity of the lake ecosystem, activities such as fishing, hunting, picnicking, camping, etc. should not be allowed in the area. Tourist and educational trips should be carried out in a controlled manner by professionals.

In addition, projects have been carried out in recent years, and some are still in the planning stage, which can put a lot of pressure on the lake's ecosystem. These projects include large and complex construction elements that have very high economic returns but need to be carried out very carefully in terms of their negative impacts. The project with the highest impact is currently the Istanbul Airport project. The airport, whose construction has been completed, has resulted in the destruction of approximately 8 km² of green space in the eastern part of the lake. In addition, the motorway projects that followed the construction of the airport and the attractive environment created by the bridge threaten the basin by increasing the number of new settlements or illegal constructions around the lake. Another major project, the Istanbul Canal, has not yet been realized and its possible effects are still being debated. It is believed that the project's impact on groundwater or aquifers could affect the lake's water quality, increasing salinity and reducing the quality of drinking water. It is also estimated that the project will intensify settlement around the basin, increase the amount of drinking water to be abstracted from the lake, and cause imbalances in the lake's water level. In addition, the project can be expected to cause air pollution, landslides, corrosion, liquefaction, or ground collapse and indirectly affect the lake.

On the other hand, important projects have been initiated to protect the lake ecosystem. Projects such as Taşoluk Drinking Water Treatment Plants, Terkos İkitelli Transmission Line, Terkos Advanced Biological Wastewater Treatment Plant are important initiatives that have been launched in recent years to make the most efficient use of the lake's water and to protect the lake's ecosystem. The increase of these and similar initiatives should be encouraged, the opening of new settlements in the lake and its immediate vicinity should be strictly prevented, and the basin planners should be among the planning stakeholders by revealing various risk factors through multidisciplinary academic studies.

Conflict of interest: The authors declare that they have no conflict of interests.

Informed consent: The authors declare that this manuscript did not involve human or animal participants and informed consent was not collected.

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