Global NEST Journal, Vol 25, No 3, pp 103-114

Monitoring the changes of Lake Uluabat Ramsar site and its surroundings in the 1985-2021 period using RS and GIS methods

Topal TU[1*] and Baykal MT[2]

[1]Department of Landscape Architecture, Faculty of Fine Arts, Design and Architecture, Tekirdağ Namık Kemal University, 59030, Tekirdağ, Turkey

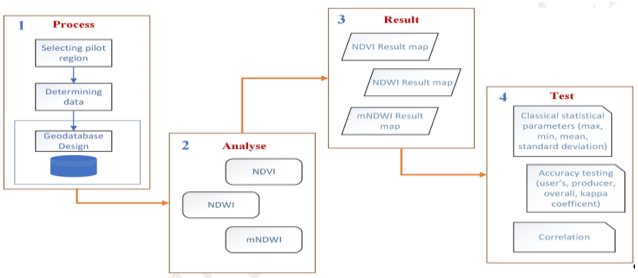
[2]Department of Geomatics Engineering, Faculty of Engineering, Artvin Çoruh University, 08100, Artvin, Turkey

Received: 11/09/2022, Accepted: 08/12/2022, Available online: 09/12/2022

*to whom all correspondence should be addressed: e-mail: tugbaustun61@gmail.com

https://doi.org/10.30955/gnj.004479

Graphical abstract



Abstract

Ramsar sites are important ecosystems that are protected by international status, have great value in terms of biodiversity, and constitute a resource in terms of economic, cultural, scientific and recreational aspects. In this study, the change of Lake Uluabat Ramsar Site and its surroundings, between the years 1985-2021 has been observed. For this, Remote Sensing (RS) and Geographic Information Systems (GIS) methods were used. Vegetation change in the lake and its surroundings in 1985, 2000, 2015 and 2021 with Normalized Difference Vegetation Index (NDVI), and changes in water surfaces with the water indices Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (mNDWI) were analyzed by using Landsat multi-band satellite images (Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI/TIRS) as RS data. The resulting changes were monitored and the success of the indices in determining these areas and the relations of the indices with each other were questioned by Accuracy index, Kappa coefficent, and Correlation analyses. The results show 36-year long-term changes and reveal a 13.06% shrinkage of Uluabat Lake wetland and surrounding water areas with the highest kappa coefficients for mNDWI as 0.83, 0.90, 0.93, 0.97, respectively, over the years studied.

KeyWords: NDVI, NDWI, mNDWI, remote sensing, GIS, Lake Uluabat, Bursa

1. Introduction

Wetlands, which have an important place for life, have many environmental, social, economic and recreational functions (providing habitat, providing environmental sustainability, providing production and information, etc.) (Halls, 1997; Yağmur and Musaoğlu, 2020; Faruque *et al.*, 2022). However, the world's water resources, and water bodies are turning into ecosystems that are gradually shrinking and disappearing due to both climate change and human activities. As a matter of fact, wetlands with shallow water depths and large areas are among the water bodies that are most affected by climate change (Chang *et al.*, 2017; Musaoğlu *et al.*, 2020). However, wetlands are also deteriorating due to many reasons such as agricultural transformation to meet the increasing population and food demand, developing residential areas, digging for irrigation, drying, filling, drainage, pollution, excessive resource consumption (Mozumder *et al.*, 2014; Akdeniz *et al.*, 2015; Yagmur and Musaoğlu, 2020; Mukherjee and Pal, 2021).

With the understanding of the necessity of taking some measures against these deteriorations, wetlands have become the focus of international protection activities since the early 1970s (Fletcher, 2011). In this way, Ramsar Convention, one of the oldest multilateral environmental agreements was signed in 1971 in Ramsar, Iran, with the aim of protecting wetlands. The purpose of the contract are regulation of the water regimes of the regions where wetlands are located, providing shelter for characteristic plant and animal communities, especially waterfowl, preventing movements that may cause loss of wetlands as they constitute economic, cultural, scientific and recreational resources, recognizing that wetlands are an international resource due to the crossing of borders as a result of seasonal migrations of waterfowl and therefore the protection of wetlands and their dependent plant and animal communities. In addition, with the agreement, it is aimed to ensure the rational use of wetlands while protecting them with the goal of sustainable development around the world (Çağırankaya and Meriç, 2013; Demirel, 2005; Anonymous 2021a).

Despite the existence of legislation to protect wetlands, degradation in wetlands occurs more rapidly than in other ecosystems (Mozumder *et al.*, 2014). So much so that 50%

of the wetlands in the Mediterranean region have disappeared since 1970 (Anonymous, 2022a). However, the degradation and destruction of wetlands, one of the most productive and important ecosystems in the world, is a serious threat to biodiversity (Ekumah *et al*., 2020; Ashok *et al*., 2021; Paul and Pal, 2020). In this context, habitat monitoring, evaluation and conservation activities are critical to support the conservation of biodiversity (Ludwig *et al*., 2019; Teng *et al*., 2021). For this reason, it is necessary to determine the changes caused by climate change and human activities in wetlands and to determine the effects of these changes on the environment and society. In this context, mapping is very important for the protection, planning and management of wetlands (Ashok *et al*., 2021; Mallick *et al*., 2021).

Türkiye, which signed the Ramsar Convention in 1994, has very favorable and rich wetlands in terms of biodiversity. 14 of the 93 wetlands in Türkiye are designated as Ramsar Sites. The total surface area of the areas currently designated as Ramsar sites in Türkiye is 184,487 ha. (Anonymous, 2021a,b). However, wetlands are under pressure in Türkiye as well as in the rest of the world. Lake Uluabat Ramsar Site is one of the important wetlands of Türkiye, which is also under pressure. As a matter of fact, the Uluabat Wetland Workshop and the final report held on February 5, 2022 showed that there is an urgent need to develop better protection measures (Anonymous, 2022b).

The fact that water management decisions require the use of modern methods (Chalkidis *et al*., 2016) has made Remote sensing (RS) and geographic information systems (GIS) have become one of the widely used tools that provide significant potential and information to assess the status of wetland ecosystems, at the point where the developments in science and technology have come, especially in the last few decades (Eid *et al*., 2020a; Musaoğlu *et al*., 2020; Brinkhoff *et al*., 2022). RS-GIS-based techniques have been adopted because they allow effective temporal evaluation through satellite images, as well as being efficient in terms of labor and cost (Maleki *et al*., 2016; Mukherjee and Pal, 2021; Li *et al*., 2021). Areas covered by water can be determined by water index equations based on the ratio of bands in multi-band satellite images (McFeeters, 1996; Xu, 2006). There are many studies in the literature to accurately determine the changes in water-land surfaces using spectral indices (Ashok *et al*., 2021; Mozumder *et al*., 2014; Fitoka *et al*., 2020; Eid *et al*., 2020b; Mukherjee and Pal, 2021; Paul and Pal, 2020; Bhatnagar *et al*., 2020; Debanshi and Pal, 2020; Ludwig *et al*., 2019; Szabo *et al*., 2016; Rokni *et al*., 2014).

In this study, Remote Sensing (RS) and Geographic Information Systems (GIS) methods were used to analyze the change between the years 1985-2021 in and around the Lake Uluabat Ramsar Site. Landsat multi-band satellite images (Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI/TIRS) were used as RS data. The change in vegetation in and around the lake in 1985, 2000, 2015 and 2021 was analyzed with the Normalized Difference Vegetation Index (NDVI), the change in water surfaces was analyzed with the Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (mNDWI). The resulting changes were evaluated and the success of the indices in determining these areas was questioned, and the relations of the index results with each other were determined. For this, Quantitative Accuracy index, Kappa coefficient, Correlation analyzes and calculations were carried out. Finally, recommendations were developed within the scope of the study.

2. Materials and methods

2.1. Methodology

The study consists of 9 stages:

- Selecting the study area
- Determining the characteristics of the study area
- Obtaining Landsat satellite images of 1985, 2000, 2015 and 2021 from the United States Geological Survey (USGS) Earth Expolorer
- Organizing the obtained data in ArcGIS 10.8 program and creating the geodatabase
- Defining the edited data in the WGS 84- 35N projection system and making it ready for analysis
- Performing analysis by calculating NDVI, NDWI and mNDWI
- Mapping the results obtained
- Testing and evaluation of results from indexes
- Conclusions and recommendations

2.2. Study area

The study was carried out in and around Uluabat Lake, located in the Susurluk basin, also known as Apolyont and Ulubat. Uluabat lake is located in Karacabey district of Bursa province, south of Balıkesir highway, 34 km from Bursa city center. There are four islands in the lake, whose geographical coordinates are 40°10'N 28°35'E. The Ramsar area covers an area of 19,900,00 hectares consisting of the lake and its surroundings. Eskikaraağaç and Gölyazı settlements are included in the Ramsar area. Uluabat Lake is a swampy, Eutrophic freshwater lake formed by tectonic depression. The depth of the lake is 3 m. It is 8 m above sea level (Anonymous, 2022c,d). The lake is fed by the Mustafa Kemal Paşa Stream from the southwest. Its only exit is in the northwest and pours into Kocasu Stream from here (Hacısalihoğlu *et al*., 2016).

In order to observe the change in the lake and its surroundings, a 15 km buffer zone area was created in the area covering the lake and its surroundings starting from the borders of the ramsar area and this area was determined as the borders of the study area (Figure 1).

Figure 1. Study area

2.2.1. Natural and cultural landscape features of Lake Uluabat Ramsar site

Uluabat Lake is located on the migration routes of birds from the north and has high biological diversity and biological productivity (Akdeniz *et al*., 2015). Uluabat Lake was published in the Official Gazette dated 15.04.1998 and numbered 23314 and declared as a wetland within the scope of the Ramsar convention. It carries the criteria numbered 2,4,5,8 out of 9 criteria of the Ramsar Convention (Table 1). Uluabat Lake Management Plan, prepared by the former Ministry of Environment, entered into force on 27 December 2002. The plan was revised in 2007, 2011 and 2015 (Anonymous, 2020). In addition, since the 4th International Conference at EXPO 2000, it has been included in the International Living Lakes Network, an international non-governmental organization partnership project (Hacısalihoğlu *et al*., 2016; Anonymous, 2021c).

Table 1. Criteria carried by Lake Uluabat Ramsar Site (Ramsar Convention Bureau, 2004; Anonymous, 2022d)

Criteria	Explanation
Criterion 2: *A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities"*	Among them, *Hirudo medicinalis* (The medicinal leech) is listed in UICN as near threatened, *Pelecanus crispus* (Dalmatian pelican) is a vulnerable species living in the Uluabat Lake. Also, *Sagitaria sagittifolia* and *Stachys palustris* are vulnerable plant species also found in the region.
Criterion 4*: "A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions."*	*Lutra lutra* (otter) is an internationally protected mammal species. The area is the most important breeding ground for *Phalacrocorax pygmeus* in Türkiye. It is also a nesting, wintering and breeding ground for many birds. *Pelecanus crispus, Aythya nyroca* and *Microcarbo pygmaeus* are known to be winter visitors.
Criterion 5: *"A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds."*	According to a study carried out in 1996 429,437 birds were recorded, and in 2002 more than 25.000 birds were counted in the region.
Criteria 8: *"A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend."*	The Lake Uluabat provides source of food and spawing ground for many fishes. 21 fish species live in this lake.

When the herbaceous plant taxa around the lake were evaluated, it is reported that the endemism rate of Lake Uluabat is very high as 36.14% (Akdeniz *et al*., 2015). Almost all the shores of the lake are covered with underwater plants (Hacısalihoğlu *et al*., 2016). Lake Uluabat Wetland has plant species included in the "LC-Least Concern" category in the Red List of the The International Union for Conservation of Nature (IUCN). *Nymphaea alba* (water lily), *Ceratophyllum demersum* (hornwort), *Butomus umbellatus* (flowering rush) are among the species in the lake ecosystem. Species found in the lakeshore ecosystem include *Phragmites australis* (reed), *Typha domingensis* (southern cattail), *Tamarix smyrnensis* (tamarisk). Some bird species found in the area are on the IUCN red list. These are *Pelecanus crispus* (great crested grebe) in the "VU-Vulnerable" category, *Aythya nyroca* (ferruginous duck), *Microcarbo pygmaeus* (pygmy cormorant catalan) in the "NT-Near Threatened" category, and *Chlidonias hybrida* (the whiskered tern), *Ardeola ralloides* (the squacco heron), *Platalea leucorodia* (Eurasian spoonbill catalan), *Nycticorax nycticorax* (the black-crowned night heron) in the "LC-Least Concern" category (Anonymous, 2022c). Among the mammal species detected around the lake, there are *Canis aureus* (the golden jackal), *Vulpes vulpes* (the red fox), *Meles meles* (badger) ve *Lepus capensis* (the cape hare), as well as the *Lutra lutra* (otter), which is endangered in the IUCN red list and has international protection status (Akbana and Bulut, 2021).

In addition, the lake provides many ecosystem service components such as water supply, food supply, spiritual and inspirational properties, and potential for recreation and tourism (Table 2).

2.2.2. Topographic and climatic features of the study area

This stage of the study is the definition of the physical and climatic properties of the selected study area. At this point, topographic maps of the region (elevation, slope and aspect) were produced. According to the results of the slope analysis, 38,25% of the study area has a slope of 0-3%, and these areas cover 69,352 ha. Areas with a slope of 3-10% cover 52.007 ha. Areas with a slope of >45 in the study area have the lowest percentage with 0.54% and 984 ha. it covers. As the slope percentages increase, the ha. occupied by these areas appears to be decreasing. In the study area, in general, the areas in the west and northwest parts are flat and have almost flat slopes, while the south and southwest parts have a slope of more than 45% (Figure 2a, Table 3a). The aspect map of the study area is divided into 9 classes as flat areas, intermediate directions and cardinal directions. The results show that flat areas are more common than other areas. It is seen that the other areas distribute in close proportions to each other. Accordingly, flat areas cover 35,652 ha and these areas constitute 19.66% of the study area (Figure 2b, Table 3b). The height map from the generated maps is divided into 10 classes. According to the results, areas of 0-50 m are 68,161 ha and cover 37.59% of the study area.

The maximum elevation of the land is 920 m. (Figure 2c, Table 3c).

Considering the long-term climatic data for Bursa province, the average temperature between 1928-2021 is 14.6°C annually. The average monthly precipitation amount was recorded as 709.5 mm (Anonymous, 2021d). It has been noted that the average temperature tends to increase, especially between 1985 and 2020 (Demir, 2020; Dervişoğlu, 2021). According to the long-term average precipitation data in the same period, it has been noted that the precipitation varies between 500-1400 mm. This difference shows that Bursa does not have a homogeneous climate structure and the air masses that Bursa is affected by vary according to years (Demir, 2020). Dervişoğlu (2021) reported the average annual precipitation for Uluabat Lake as 707.13 mm and the average annual evaporation as 1149.62 mm for 1985-2020. Accordingly, the evaporation/precipitation ratio is calculated as 1.63.

Table 2. Ecosystem services provided for uluabat lake (adapted from anonymous, 2022c)

Ecosystem Services		Example	Degree*		
			L	M	H
Provisioning Services	Water supply	Using			X
	Non-Food Services	Sedge cutting	X		
	Food Source for Human	Fishery	X		
		Grazing	X		
Regulating Services	Regulating the Water Regime	Storing water			X
	Controlling Climate Change	Microclimatic feature			X
	Flood Control	Flooding control			X
Cultural Services	Recreation and Tourism	Land hunting			X
		Aquaculture hunting			X
		Nature observation (bird, plant, butterfly)			X
	Spiritual and Inspiring Features	Cultural heritage (historical and archaeological)			X
		Aesthetics			X
		Spiritual and religious value			X
Supporting Services	Biodiversity	Supporting different types of plants, animals and microorganisms			X

**L: Low, M: Medium, H: High*

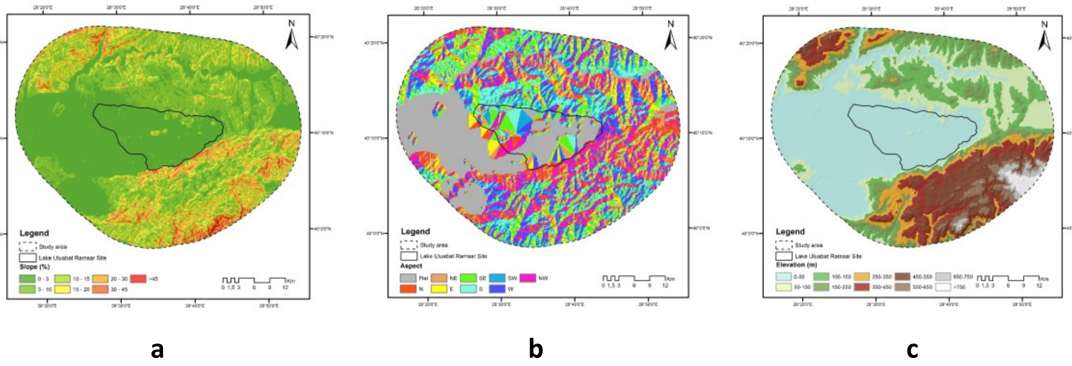


Figure 2. Topographic maps of the study area (a: slope, b: aspect, c: elevation)

Table 3. Statistical results of topographic maps

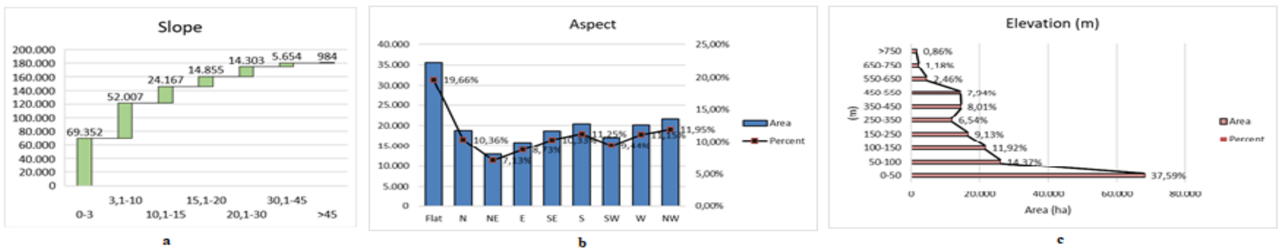


Table 4. Features of satellite images used in the study

Date	Path/Row	Satellite and Sensor ID	Spatial Resolution (m)	Temporal Resolution (day)
01/07/1985	180/032	Landsat 5 TM	30x30	16
02/07/2000	180/032	Landsat 7 ETM	30x30	16
20/07/2015	180/032	Landsat 8 OLI_TIRS	30x30	16
05/08/2021	180/032	Landsat 8 OLI_TIRS	30x30	16

Table 5. NDWI classes considered in the study

NDVI Values	Class
-1-0	water /snow/cloud
0-0.2	barren land/built up/rock
0.2-1	vegetation

2.3. Data

As can be seen, Uluabat Lake Ramsar Site, which forms an important ecosystem with the effect of many components it contains and has a great biological diversity, constitutes the main material of the research. Landsat series satellite images were used to determine the change of Uluabat Lake Ramsar site and its surroundings by years with remote sensing techniques. Such temporal changes in lakes can be calculated using Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) and The Operational Land Imager (OLI) images (Ashok *et al*., 2021; Eid *et al*., 2020b).

The images downloaded for use in the study belong to the years 1985, 2000, 2015 and 2021. Images with less than 10% cloudiness were selected in order to obtain more accurate results. In order to avoid confusion due to the differences arising from seasonal water situation changes, the images of the summer months of July and August were selected. In addition, the data is Level 2 and atmospheric and radiometric calibrations have been made. Therefore, no preprocessing was required in terms of atmospheric and radiometric correction before the analysis. The features of the satellite images used in the study are given in Table 4.

2.4. Method

2.4.1. NDVI

Considering the literature, it is seen that various spectral measurements and indices are used to understand and predict the condition of vegetation both qualitatively and quantitatively (Eid *et al*., 2020a). Among these, the most widely applied index in environmental and climate change research is NDVI (Normalized Difference Vegetation Index) (Eid *et al*., 2020b).

The Normalized Difference Vegetation Index (NDVI) analysis developed by Rouse *et al*. (1973) examines the state of vegetation. NDVI is detected by calculation from multi-band remote sensing data (Szabó *et al*., 2016; Ekumah *et al*., 2020). This analysis is performed using combinations of red and near infrared bands of multispectral satellite images (Faruque *et al*., 2022).

Calculation formula of NDVI (Rouse *et al*., 1973; Tucker and Seller, 1986) (eq.(1)).

$$\mathbf{NDVI} = \left(\mathbf{NIR} - \mathbf{Red}\right) \;/\; (\mathbf{NIR} + \mathbf{Red} \qquad (1)$$

Water and wet surfaces show strong absorption in the near infrared (NIR) spectrum (Ludwig *et al*., 2019). NIR and Red represent spectral reflectance values obtained in the near-infrared and red part of the electromagnetic spectrum, respectively. NDVI values range from -1 to +1. NDVI values from -1 to 0 indicate no vegetation, while values close to +1 indicate the highest green vegetation density (Ekumah *et al*., 2020).

2.4.2. NDWI

The Normalized Difference Water Index (NDWI), introduced by McFeeters (1996), is a widely used analysis that uses the green and near infrared spectrum of satellite images to explain the presence of water bodies on the land surface. It is designed to maximize reflection from water while minimizing low reflection in the near infrared band (Eid *et al*., 2020b; Mishra *et al*., 2021; Faruque *et al*., 2022).

Calculation formula of NDWI (McFeeters, 1996): (eq.(2)).

$$\mathbf{NDWI} = \left(\mathbf{Green} - \mathbf{NIR}\right) \;/\; \left(\mathbf{Green} + \mathbf{NIR}\right) \qquad (2)$$

NDWI value ranges from -1 to 1. Positive values indicate water pixels and negative values indicate non-water pixels (Paul and Pal, 2020). NDWI has been successfully applied for water body mapping in several studies (Ludwig *et al*., 2019).

2.4.3. mNDWI

In the NDWI index, open water and residential areas are represented by positive values. This can cause confusion in areas with high construction. Xu (2006) replaced the NIR band with the short-wave infrared 1 (SWIR1) band in order to distinguish the settlement pixels from the water pixel in this index, and named it the modified Normalized Difference Water Index (mNDWI). In this way, the mixing of open water bodies with residential areas has been reduced (Ludwig *et al*., 2019; Debanshi and Pal, 2020).

Calculation formula of mNDWI (Xu, 2006; Szabó *et al*., 2016): (eq.(3)).

$$\mathbf{mNDWI} = \left(\mathbf{Green} - \mathbf{SWIR}\right) \;/\; \left(\mathbf{Green} + \mathbf{SWIR}\right) \qquad (3)$$

There are many studies in which both NDVI and NDWI index are used together for wetland change detection (Rokni *et al*., 2014; Mukherjee and Pal, 2021; Kaplan *et al*., 2016; Kaplan and Avdan, 2017; Bhatnagar *et al*., 2020).

In this study, the changes were calculated by applying NDVI, NDWI and MNDWI to the satellite images.

2.5. NDVI, NDWI and mNDWI Analyses Criterias

NDVI defines values from -1.0 to 1.0, where negative values are mainly formed from clouds, water and snow, and values close to zero are primarily formed from rocks and bare soil. Very small values (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand or snow. Moderate values (from 0.2 to 0.3) represent shrubs and meadows, while large values (from 0.6 to 0.8) indicate temperate and tropical forests (Anonymous, 2022e). Based on this, the class ranges determined for the study are shown in Table 5. Values below 0 for NDWI and mNDWI indicate areas without water, values above 0 indicate areas with water.

2.6. Testing NDVI, NDWI and mNDWI

Regarding the evaluation of accuracy, firstly, the classical statistical parameters maximum, minimum, mean and standard deviation (σ) values were examined. In addition, correlation coefficients were calculated with Pearson correlation analysis to question the relationships according to the NDVI, NDWI and mNDWI results.

The quantitive accuracy index is adopted to conduct accuracy water body extraction analysis. The quantitive accuracy index is a widely used method that uses random sample points and high-resolution images. This method involves generating random water and non-water sample points at which water extraction results are verified (Jiang *et al*., 2021; Lombana and Martinez-Grana, 2022).

The method used in this study is discussed as follows:

1. A total of 60 sampling points were selected for the study area. Analyzes were performed using the ArcGIS program.
2. High resolution images were used as reference data to verify and adjust the Random sampling points, and then ground reference points were established.
3. Ground reference points were added above the dewatering results to verify the accuracy of each random sampling point.
4. The accuracy of each method was evaluated by applying four evaluation indices. For this purpose, the confusion matrix was created (Table 6). By comparing the extracted water and non-water points with the reference data, four types of pixels were obtained (Acharya *et al*., 2018):

- True positive (TP): The number of correctly extracted water pixels;
- False negative (FN): The number of undetected water pixels;
- False positive (FP): The number of incorrectly extracted water pixels; and
- True negative (TN): The number of correctly rejected non-water pixels.

Based on four pixels, Producer's accuracy, User's accuracy, the overall accuracy (OA), and kappa coefficient (kappa) were used to assess the accuracy of the produced maps (Jiang *et al*., 2021; Lombana and Martinez-Grana, 2022). These are:

$$Producer's\,accuracy = \frac{TP}{TP+FN} \quad (4)$$

$$User's\,accuracy = \frac{TP}{TP+FP} \quad (5)$$

$$Overall\,accuracy = \frac{TP+TN}{T} \quad (6)$$

$$Kappa\,coefficent = \frac{T(TP+TN)-((TP+FP)(TP+FN)+(FN+TN)(FP+TN))}{T^2-((TP+FP)(TP+FN)+(FN+TN)(FP+TN))} \quad (7)$$

3. Findings

3.1. Determining the NDVI, NDWI and mNDWI results and examining the change over the years

At this stage of the study, NDVI, NDWI and mNDWI calculations were made using satellite images for the years 1985, 2000, 2015 and 2021, respectively. As a result of the calculations, the change of vegetation and water areas for the study area by years was mapped. All index results show that the water body in Lake Uluabat has gradually decreased from 1985 until 2021 (Figure 3).

3.2. Reclassification and analysis of NDVI, NDWI, mNDWI results according to selected analysis criteria

In order to better interpret the results obtained from the NDVI, NDWI and mNDWI index calculations, the images were reclassified according to the criteria and value ranges previously determined in the method (Figure 4). Then, the changes over the years were compared in terms of area and percentage (Table 7). NDVI results show that between 1985 and 2021, water areas decreased by 15.85%, with a loss of 1.953 ha. On the other hand, it is seen that the areas classified as barren land/built up/rock decreased by 48.93%. It can be said that comprehensive handling of the classification both as a type of land use and a range of values is effective in the emergence of this situation. Considering the change in vegetation areas, it is seen that it increased by 42.53%. Pettorelli (2013) stated that NDVI values ranging from 0.2 to 0.5 represent shrubs, grasslands or aging plants (Ashok *et al*., 2021). Accordingly, the NDVI results in our study were close to each other for all the years examined, but the highest was measured as 0.666617, suggests that the growth of vegetation and the increase in leaf widths reveal the index values of Uluabat Lake and its surroundings, rather than the presence of dense and/or very dense vegetation in the area (Figure 4, Table 7). When the NDWI results are considered, it is seen that the water areas have decreased by 12.84% by losing 1.632 ha, while the none-water areas have increased by 0.97%. When the mNDWI results are taken into consideration, it is seen that the water areas decreased by 13.06% by losing 1,734 ha, while the none-water areas increased by 1.03%.

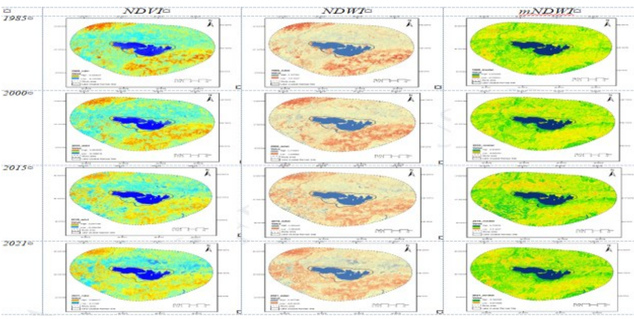


Figure 3. Changes of NDVI, NDWI and mNDWI over the years

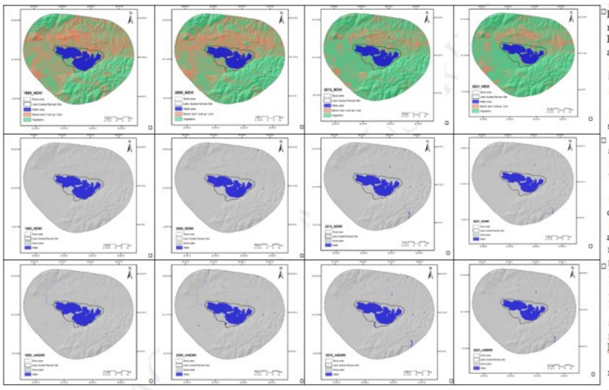


Figure 4. Reclassified images of the study area showing the changes according to NDVI, NDWI and mNDWI results

Figure 4. Reclassified images of the study area showing the changes according to NDVI, NDWI and mNDWI results between 1985-2021

When the changes in 1985, 2000, 2015 and 2021 are examined in detail, respectively, it is a remarkable result that all index results show the decrease in water areas. MNDWI considers the maximum area as the water area according to the other two indexes each year. It is seen that NDVI and NDWI show close values for water areas. However, the greatest change in water areas between 1985-2021 was measured by the NDVI index (Figure 5). The results in which the change in the boundaries of the Lake Uluabat are handled in more detail can be seen in Figure 6.

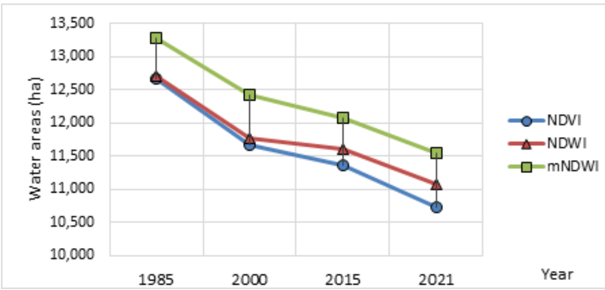


Figure 5. Changes of different indexes for the Uluabat Lake Ramsar Site and its surroundings's water areas during the period between 1985 and 2021.

In order to evaluate the change in the lake area in detail, raster data were converted to vector. When the figures are examined, it is seen that the most change in the coastal edge line is experienced in the south and southwest parts of the lake. It is also noteworthy that between the water indexes NDWI and mNDWI, the mNDWI results show the Mustafa Kemal Paşa Stream feeding the lake more prominently.

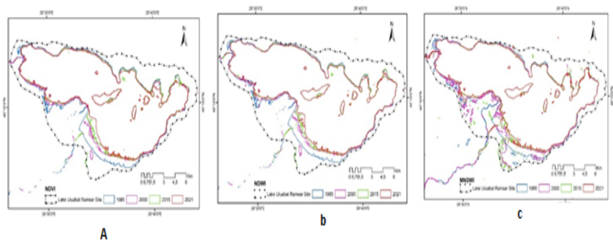


Figure 6. Change in the water surface area over the years (a: NDVI, b:NDWI, c:mNDWI)

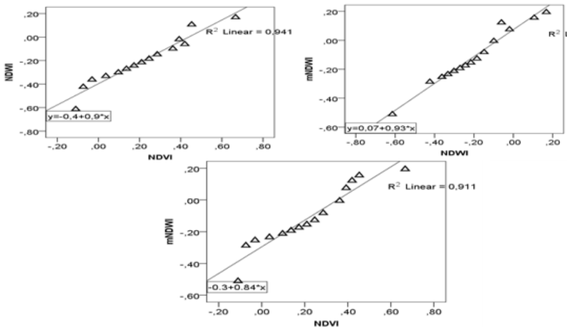


Figure 7. Relationships between indexes for 2021 a) NDVI and NDWI b) NDWI and mNDWI and c) NDWI and mNDWI

3.3. Accuracy and Correlation testing

Regarding the evaluation of accuracy, first of all, classical statistical parameter values were examined. When the results are evaluated, it is seen that the Standard deviation value is the highest for NDVI in all the years examined. Between the water indices NDWI and mNDWI, NDWI shows the highest deviation. This shows that this index has more uncertainty in determining the water areas. The mNDWI results show the lowest value for the years 2000, 2015 and 2021 compared to other indexes (Table 8). These results showed that mNDWI gave the most successful results in identifying water areas.

The accuracy of the vegetation and water body extraction indices used in mapping vegetation, water and other areas for the Lake Uluabat Ramsar Site and its surroundings were evaluated by applying the Producer's Accuracy, User's Accuracy, Overall Accuracy, and Kappa coefficient statistics (Table 9). According to the Table 9, it is seen that all indices are good enough to describe the wetland, but overall accuracy and kappa coefficient values give higher accuracy for mNDWI.

In addition, Pearson correlation coefficients were calculated according to the NDVI, NDWI and mNDWI results of 2021. For this, 20 locations were selected from the values of each index. The result shows the high positive correlation between the indexes (Table 10). Here, high R^2 value indicates good correlation between NDWI and mNDWI (Figure 7).

A strong positive (r=,970) and significant ($p<0,05$) relationship was found between NDVI and NDWI. The variance explained by the variables on each other is 94.41%. A strong positive (r=,983) and significant ($p<0,05$) relationship was found between NDWI and mNDWI. The variance explained by the variables on each other is 96.70%. A strong positive (r=,955) and significant ($p<0,05$) relationship was found between NDVI and mNDWI. The variance explained by the variables on each other is 91.10%.

4. Discussion

NDVI, NDWI and mNDWI results showed the wetland loss of Uluabat Lake. In addition to global climate change, human activities are also effective in the emergence of these results in Uluabat Lake. As a matter of fact, water I s drawn from Uluabat Lake with pumps and used for irrigation. The use of water for agricultural purposes affects the water level. According to the data of Directorate General for State Hydraulic Works (DSI) 1stRegional Directorate (2020), the volume of the lake is 840,000 hm^3, its irrigation area is 6.344 ha and the amount of water withdrawn from the lake is 19.000 hm^3/year (Anonymous, 2020). In addition, the mixing of chemicals such as boron and chromium into the lake as a result of the activities of settlements, industries, coal and mining facilities in the basin and the transport of fertilizers and pesticides used in agriculture to the lake with drainage water causes water pollution in the lake. Wastewater treatment plants are both insufficient and not adequately operated. The erosion problem in the surrounding forests causes the lake to fill up. During the forbidden seasons and excessive amounts of fishing, introducing alien fish species, unplanned use of recreation and tourism areas, superstructure projects such as highway power plant adversely affect the lake life. Numerous studies conducted in the lake basin confirm that water pollution, sediment accumulation, eutrophication, species decline, and heavy metal pollution continue in the lake (Salihoğlu ve Karaer, 2010; Hacısalihoğlu *et al*., 2016; Hacısalihoğlu ve Karaer, 2020; Dervisoğlu, 2021). This increase in pollution in the area and the inability to protect the area effectively despite being declared a Ramsar area threatens the lake and its environment from an ecological point of view.

Table 6. Confusion matrix

		Reference Data		User
		Water	**Non- Water**	
Classified Data	Water	TP	FP	TP + FP
	Non-Water	FN	TN	FN + TN
Producer		TP + FN	FP + TN	T = TP + FP+ FN + TN

Table 7. Changes in NDVI, NDWI and mNDWI results over the years

	Type	1985 Area (ha)	1985-2000 Percentage change (%)	2000 Area (ha)	2000-2015 Percentage change (%)	2015 Area (ha)	2015-2021 Percentage change (%)	2021 Area (ha)	1985-2021 Percentage change (%)
NDVI	Water	12.673	-7,99%	11.661	-2,57%	11.361	-5,64%	10.720	-15,41%
	Barren land/built up/rock	76.289	-10,75%	68.089	-42,05%	39.460	-1,26%	38.962	-48,93%
	Vegetation	92.359	+9,97%	101.571	+28,48%	130.500	+0,87%	131.639	+42,53%
NDWI	Water	12.714	-7,42%	11.771	-1,36%	11.611	-4,56%	11.082	-12,84%
	None-water	168.607	+0,56%	169.550	+0,09%	169.710	+0,31%	170.239	+0,97%
mNDWI	Water	13.282	-6,53%	12.415	-2,78%	12.070	-4,32%	11.548	-13,06%
	None-water	168.039	+0,52%	168.906	+0,2%	169.252	+0,31%	169.773	+1,03%

Table 8. Maximum, minimum, mean and standard deviation (σ) values for NDVI, NDWI and mNDWI indexes considered in the study

		NDVI	**NDWI**	**mNDWI**
1985	Mean	0,209302	-0,220225	-0,167372
	Standart deviation	0,117668	0,110906	0,114191
	Max	0,543027	0,167493	0,272339
	Min	-0,119255	-0,512047	-0,733501
2000	Mean	0,222031	-0,234810	-0,170702
	Standart deviation	0,128705	0,119310	0,101026
	Max	0,563955	0,475964	0,504097
	Min	-0,498816	-0,524944	-0,685094
2015	Mean	0,261966	-0,261654	-0,171520
	Standart deviation	0,134711	0,131815	0,099266
	Max	0,657148	0,205522	0,239536
	Min	-0,164454	-0,663208	-0,514097
2021	Mean	0,261589	-0,262904	-0,172213
	Standart deviation	0,125575	0,119374	0,092021
	Max	0,666617	0,167745	0,194489
	Min	-0,110280	-0,614312	-0,511599

On the other hand, the results of our study support the results of previous studies in terms of the reduction of water areas. Aksoy and Ozsoy (2002) examined the change of Lake Uluabat Ramsar Site and its surroundings between 1984-1998 and calculated that the lake area decreased by 12%. Saçın (2010) found that Lake Uluabat shrank by 8.5% between 2000 and 2005. The researcher determined that the most changes in the shoreline of the lake occurred in the southern parts of the lake. Tağıl (2004) examined the change between 1975 and 2000 and concluded that the water surface has decreased, the area covered by the reeds and open soil surfaces has increased, the presence of a rapid landfall process in the lake has been detected, and the landfall threatens especially the south of the region. This change in the southern parts is in line with the results of our study in which the change was observed between the years 1985-2021 (Figure 6). These results reveal that the lake is being lost year by year. Accordingly, water withdrawal from the lake, precipitation and evaporation status, sediment accumulation, and alluvial accumulation can be listed among the causes of water loss observed in the lake.

Within the scope of the method used in the study, the studies in the literature showed results specific to each study area. Studies have confirmed that not all indexes show the same accuracy for every field. Among the indexes used, mNDWI provided results with higher accuracy in some studies (Szabo *et al*., 2016; Lombana and Martinez-Grana, 2022), while it showed lower accuracy in some studies (Rokni *et al*., 2014; Acharya *et al*., 2018). In this study, in line with the method followed, the results of the index were compared and statistical analyzes were carried out.

5. Conclusion and recommendations

The results of this study show 36-year long-term changes and reveal a 13.06% shrinkage of the Lake Uluabat wetland with the highest kappa coefficients for mNDWI as 0.83, 0.90, 0.93, 0.97, respectively, over the years studied. The results showed that water areas decreased, barren land/built up/rock areas decreased and vegetation areas increased.

Table 9. Producer's Accuracy, User's Accuracy, Overall Accuracy and Kappa coefficient results for the NDVI, NDWI and mNDWI indexes considered in the study

		Producer's Accuracy			**User's Accuracy**			**Overall Accuracy (%)**	**Kappa coefficient**
		W* (%)	**B/B/R* (%)**	**V* (%)**	**W* (%)**	**B/B/R* (%)**	**V* (%)**		
NDVI	1985	100.00	83.33	100.00	100.00	100.00	80.00	93.33	0.90
	2000	100.00	65.52	94.12	70.00	95.00	80.00	81.67	0.73
	2015	100.00	70.83	77.78	90.00	85.00	70.00	81.67	0.73
	2021	76.92	93.33	100.00	100.00	70.00	95.00	88.33	0.83
		W*	**N-W***		**W***	**N-W***		**Overall Accuracy**	**Kappa coefficient**
NDWI	1985	100.00	83.33		86.67	100.00		93.33	0.86
	2000	100.00	81.08		76.67	100.00		88.33	0.76
	2015	96.30	87.88		86.67	96.67		91.67	0.83
	2021	96.67	96.67		97.67	96.67		96.67	0.93
mNDWI	1985	100.00	85.71		83.33	100.00		91.67	0.83
	2000	100.00	90.91		90.00	100.00		95.00	0.90
	2015	100.00	93.75		93.33	100.00		96.67	0.93
	2021	100.00	96.77		96.67	100.00		98.33	0.97

**W: Water, N-W: None-water, B/B/R: Barren land/built up/rock, V: Vegetation*

Table 10. Correlation between NDVI, NDWI, and mNDWI

		NDVI	**NDWI**	**MNDWI**
NDVI	Pearson r	1	,970*	,955*
	P		,000	,000
NDWI	Pearson r		1	,983*
	P			,000
MNDWI	Pearson r			1

** The correlation is significant at the p<0.01 level.*

This paper shows that the study area provides a high ecosystem service and the area is an economic resource in many respects. The wetland is also an important source of livelihood for the local people. However, the Ramsar Convention supports the rational use of these natural resource-generating areas. The results of this study clearly emphasize the need to provide a good value for conservation use for sustainable use. In this way, this area will continue to contribute to the landscape, tourism and the city's economy with its existence. For this, the boundaries of legislation and practices need to be well drawn. Otherwise, wetlands will be doomed to disappear. The results reveal that the Uluabat Lake Management Plan and the practices within the framework of this plan should be discussed and re-evaluated in order to supervise the provision of effective conservation-use. Excessive use should be restricted. This study will create a useful base for taking action with its qualitative and quantitative results. On the other hand, awareness of the problems experienced in the area should be created among the local people. Local governments and planners have responsibilities in this regard.

General recommendations regarding the study can be listed as follows: 1) Our study was carried out with images between the years 1985-2021. If images from previous years could be included, the scope of the study could be expanded. 2) Wetlands are fed by seasonal precipitation and flood waters, so the body of water in these areas looks different every year and at different seasons of the year. Therefore, it will be important to monitor changes for different seasons as well. 3) Making future predictions and creating scenarios for wetlands using computer technologies can lead to important results for the future of wetlands. 4) In our study, mNDWI was found to be successful with higher accuracy in wetland mapping. Therefore, mNDWI can be used as a reliable wetland determination method in this region.

Acknowledgements

We would like to thank the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov) for providing open source satellite images, and https://www.openstreetmap.org for providing spatial information about the study area, Republic of Türkiye Ministry of Agriculture And Forestry General Directorate of Nature Conservation And National Parks for providing open source for wetlands of Türkiye and Turkish State Meteorological Service for meteorological data.

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