Research Article
https://doi.org/10.33904/ejfe.1318353

Eur J Forest Eng 2024, 10(2):100-111

Assessing Two Decades of Land Use/Land Cover Changes in the Uluabat Lake Ramsar Site using Satellite Imagery

Emre Kılınçarslan, Burhan Gencal, İnanç Taş*

Bursa Technical University, Faculty of Forestry, 16310 Bursa, Türkiye

Abstract

The Ramsar Convention on Wetlands designates over 2,000 sites of international importance, providing crucial habitats for diverse species. Uluabat Lake faces anthropogenic pressures such as urbanization, agriculture, and industrialization, affecting its ecological integrity. The land use/land cover (LULC) changes in the lake's catchment area were assessed using multi-temporal Landsat 7 and Landsat 9 satellite images from 2002 and 2022, along with 2019 management plans. Data were pre-processed with ENVI and stored in ERDAS Imagine program. Then, pixel-based image analysis with maximum likelihood classification (MLC) was employed to generate LULC maps and evaluated classification accuracy using ground truth data and the kappa coefficient. The results revealed a 15.8% reduction in lake area, from 136.1 km² in 2002 to 114.5 km² in 2022, primarily due to sediment transport from surrounding agricultural land and tributary streams. Urban-agricultural and reed-swamp areas increased by 74.7% and 59.6%, respectively, while shrubs and forests declined by 35.64%, largely from reed conversion to agriculture in the Mustafakemalpaşa River delta. Overall classification accuracy ranged from 88.2% to 91% with a kappa coefficient of 0.81 to 0.82, respectively. These transformations highlight the increase in reed and swamp areas and the decrease in lake area, emphasizing the need for effective conservation and management practices.

Keywords: Classification, land use land change, Ramsar area, satellite images, wetlands.

1. Introduction

The Ramsar Convention on Wetlands aims to protect and conserve wetland areas of international importance. These areas are crucial for biodiversity, water regulation, and carbon sequestration (Bandara et al., 2019). Wetlands are dynamic ecosystems that are influenced by land use and land cover changes (LULC) (Lambin et al., 2003). LULC changes can have significant impacts on wetlands, including alterations in forest cover, agricultural expansion, and urbanization, which can lead to wetland area declines (Mao et al., 2021). Additionally, the conversion of land use, such as deforestation and agricultural activities, can affect soil carbon stocks and the global carbon cycle (Deng et al., 2014). The impact of human activities on land use and land cover change is a major concern, especially in areas designated as Ramsar sites. These changes can lead to the degradation of wetlands, affecting water quality, biodiversity, and ecosystem services (Nielsen et al., 2012). Furthermore, the relationship between population growth and land cover change is evident, highlighting the need for sustainable land management practices (Samsuri et al., 2022). The governance and management of wetlands in Ramsar sites are essential for their conservation. Effective management strategies, including protection zone and the application of remote sensing and frameworks for assessing land use impacts, are crucial for preserving these valuable ecosystems (Zeng et al., 2014; Gunathilaka et al., 2022). Moreover, the monitoring of wetland dynamics through geospatial analysis provides valuable insights into the changes occurring in these areas (Zekarias et al., 2021).

Wetlands play a vital role in maintaining ecological balance and providing habitats for diverse species, contributing to the preservation of biodiversity. These wetlands also offer various benefits to ecosystems and all forms of life (Gardner and Finlayson, 2018). Wetlands, including those found in deltas, provide numerous benefits to ecosystems and all forms of life. They support biodiversity conservation, acting as habitats for diverse species. Wetlands also contribute to water filtration and purification, flood control, climate regulation, shoreline stabilization, nutrient cycling, and offer recreational opportunities (Vollmer et al., 2013; Gardner and Finlayson, 2018). Preserving and safeguarding these ecosystems is crucial for maintaining ecological balance and supporting sustainable development. The attractive green and coastal areas of deltas located near urban centers serve as appealing destinations for individuals seeking to escape crowded city environments (Volmer et

*Corresponding Author: Tel: +90 2243003430 E-mail: inanc.tas@btu.edu.tr
Received: 22 June 2023; Accepted: 08 July 2024

al., 2013). Deltas possess unique flora and fauna, as well as fertile soils, emphasizing the need to safeguard their natural characteristics.

Recognizing the urgent need for action against the degradation of wetlands, international protection efforts have focused on wetlands since the early 1970s (Fletcher, 2011). The Ramsar Convention, one of the oldest multilateral environmental agreements, was signed in Ramsar, Iran, in 1971, with the objective of safeguarding wetlands. The convention aims to regulate the water regimes in wetland areas, provide refuge for distinctive plant and animal communities, particularly waterfowl, prevent activities that may lead to wetland loss, as wetlands hold economic, cultural, scientific, and recreational value, and recognize wetlands as an international resource due to the migratory patterns of waterfowl across borders (Demirel, 2005; Çağırankaya and Meriç, 2013).

Türkiye became a party to the Ramsar Convention on Wetlands in 1994, with the goal of preserving and enhancing wetlands and conserving water resources. As part of its commitment, 14 wetlands covering a total area of 184,487 hectares were included in the Ramsar List of Wetlands of International Importance. These wetlands encompass Sultan Marshes, Seyfe Lake, Burdur Lake, Manyas (Bird) Lake and Göksu Delta, Akyatan Lagoon, Kızılırmak Delta, Uluabat Lake and Gediz Delta, Yumurtalık Lagoon, Meke Lake, Kızören Sinkhole, Kuyucuk Lake, and Nemrut Caldera. Additionally, between 2014 and 2023, 91 new wetlands were designated, consisting of 59 wetlands of national importance and 32 wetlands of local importance. Presently, Türkiye has a total of 105 wetlands, covering an area of 1,146,420 hectares (Anadolu Agency, 2023).

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) is of great importance in studying and monitoring land use and land cover (LULC) changes, particularly in Ramsar areas. RS provides valuable satellite imagery data, while GIS enables the analysis and visualization of spatial information. This integration allows researchers to assess and understand the dynamics of LULC changes within Ramsar sites. By utilizing RS and GIS techniques, decision-makers can make informed choices regarding land management and conservation efforts in these ecologically significant wetland areas. In this study, conducted in the Lake Uluabat Ramsar Site, RS and GIS were used to analyze the LULC changes occurring between 2002 and 2022. It was not only aimed to identify the patterns of change but also explore the underlying causes of these alterations in the Lake Uluabat ecosystem. The study utilized satellite imagery (Landsat 7 ETM and Landsat 9 OLI/TIRS) and ground truth data to assess the changes in LULC within the lake's catchment area over a two-decade period. The 20-year period was meticulously chosen to capture the subtleties of ecological and anthropogenic changes impacting the lake's environment. This duration is crucial for observing the cumulative effects of various factors, including climatic variability, land use modifications, and socio-economic developments, which significantly influence the lake's ecological balance. The two-decade span is particularly pertinent given the dynamic nature of wetland ecosystems, which are sensitive to both immediate and gradual environmental transformations. Pixel-based image analysis and maximum likelihood classification (MLC) techniques were employed to generate LULC maps for each year, and the accuracy of the classification was evaluated using ground truth data and the kappa coefficient. The study highlights the absence of similar applications in previous research within Ramsar sites. Integration of RS and GIS provided a holistic view of the environmental changes occurring in the Lake Uluabat Ramsar Site, which enables to identify specific areas of concern and patterns of change that were previously undetected. Furthermore, this approach not only enhances understanding of ecological dynamics in wetlands but also sets a precedent for the application of advanced technologies in environmental monitoring and conservation efforts. Thus, this research can open up new possibilities for the use of RS and GIS in studying other Ramsar sites globally, offering a valuable tool for policymakers and conservationists in their efforts to preserve these vital ecosystems.

2. Materials and Methods

2.1. Study Area

Uluabat Lake is situated in the Karacabey district of Bursa province (Figure 1), located south of Balıkesir highway and 34 km away from the center of Bursa city. The lake contains four islands and is positioned at geographical coordinates 40°10'N 28°35'E. The Ramsar area encompasses the lake and its surrounding region, covering an area of 19,900 hectares. The settlements of Eskikaraağaç and Gölyazı are included within the Ramsar area. Uluabat Lake is a swampy, eutrophic freshwater lake that formed due to tectonic depression. It has a depth of 3 meters and is situated 8 meters above sea level. The lake is fed by the Mustafakemalpaşa River and its outlet is in the northwest, where it flows into the Kocasu River (Hacısalihoğlu et al., 2016).

The decision to define this area’s size was influenced by the need to encompass the entire lake and its immediate ecological surroundings, as indicated in the survey by Welch and Welch (1998). Uluabat Lake is a swampy, eutrophic freshwater lake formed due to tectonic depression, with a depth of 3 meters and situated 8 meters above sea level. The lake is fed by the Mustafakemalpaşa River from the southwest, and its sole outlet is in the northwest, where it flows into the Kocasu River. The size of the study area was determined to capture the entirety of the lake's ecosystem, including its water inflows and outflows, as well as the significant bird habitats identified in the survey, which are integral to understanding the ecological dynamics of the Ramsar site (Hacısalihoğlu et al., 2016).

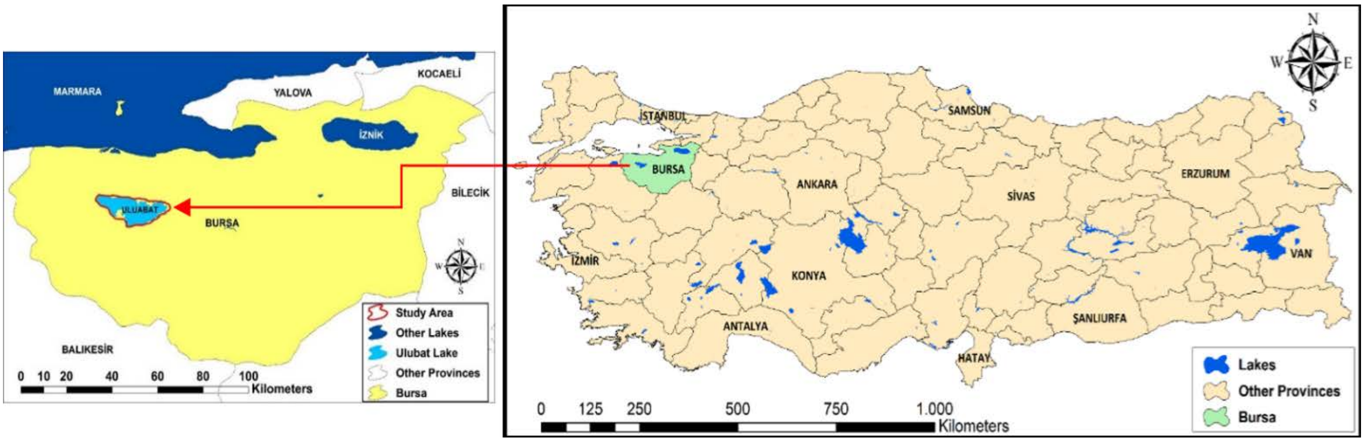

Figure 1. Location of Uluabat Lake

Lake Uluabat, is a significant Ramsar site, designated to protect its ecological importance "Valuing Water Resources in Turkey" (World Bank Group, 2016). The lake faces various environmental challenges, including water quality assessment (İşçen et al., 2007), soil erosion risk (Ozsoy et al., 2012), non-point pollution loads (Katip and Karaer, 2013), and heavy metal relationships in water and sediment (Hacısalihoğlu and Karaer, 2016). These issues necessitate comprehensive monitoring and assessment, which have been addressed through the application of GIS and remote sensing (Ozsoy et al., 2012; Hacısalihoğlu et al., 2016; Tu and Baykal, 2022). Additionally, participatory approaches, such as fuzzy cognitive mapping and stakeholder group analysis, have been utilized for ecosystem conservation in Uluabat Lake (Özesmi and Özesmi, 2003). Furthermore, the evaluation of water quality in eutrophic shallow lakes, including Uluabat, has been a subject of study (Hacısalihoğlu and Karaer, 2018).

The selection of the study area, Uluabat Ramsar Area, was based on several significant factors. Firstly, the area's strategic location as a major transportation hub connecting Istanbul to southwestern Anatolia through maritime, railway, and road networks renders it highly relevant for land use and land cover change analysis. These transportation connections facilitate the movement of goods, people, and services, contributing to regional development and economic activities. Secondly, the study area encompasses valuable and limited natural resources that are increasingly under pressure due to urban growth. The presence of forests, agricultural lands, a peninsula, and a lake within conservation boundaries highlights the diverse ecosystems and ecological sensitivity of the area. Simultaneously, industrial and mining activities, energy investments, and tourism policies exert additional pressures on the natural environment, necessitating a comprehensive understanding of land use and land cover changes. Thirdly, the chosen study area provides a representative example that covers various land cover types, including urban, agricultural, forested, wetland, and water bodies. This comprehensive coverage facilitates a holistic examination of land use dynamics and the associated implications for ecosystem services, environmental sustainability, and socio-economic development. The inclusion of Uluabat Lake Ramsar Area as the study area (Figure 2) contributes to the scientific understanding of land use and land cover change processes in ecologically sensitive regions characterized by diverse land cover types and human interventions. Through the examination of these dynamics, this research can provide valuable insights for sustainable land management, conservation strategies, and informed decision-making, both in the study area and in similar contexts globally.

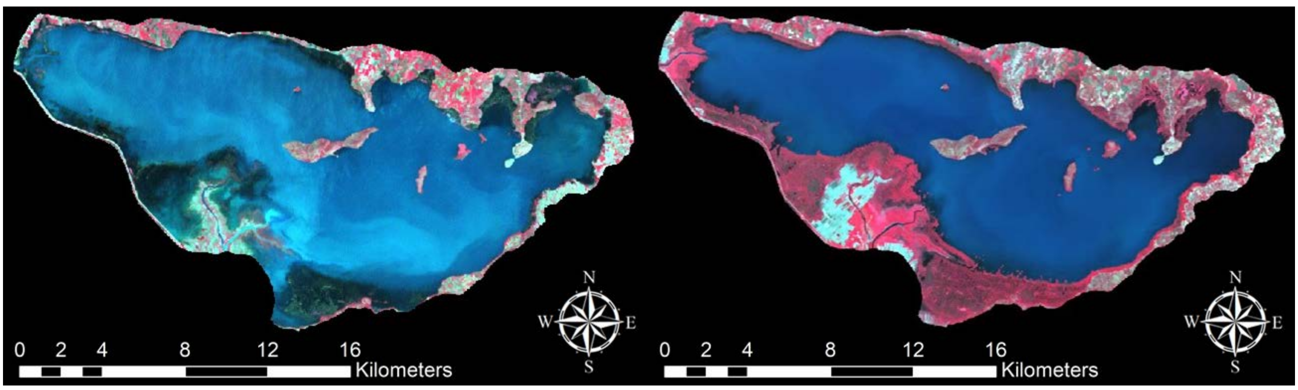

Figure 2. Study areas for 2002 (left) and 2022 (right)

2.2. Methods

The methodology of the study follows a systematic approach consisting of four main stages: pre-processing, image classification, post-processing, and land use land cover change detection. In this study, the selection of Landsat imagery was motivated by its cost-efficiency, availability, and compatibility in terms of spatial resolution (30 m), enabling a wide range of applications. To acquire the necessary data for analysis, satellite images from Landsat 7 (acquired in 2002 May) and Landsat 9 (acquired in 2022 May) were obtained from reliable sources such as the US Geological Survey (USGS). This time span allows for the comprehensive analysis of changes in land use and land cover, providing valuable insights into long-term trends and patterns. Over the past several decades, many studies have emphasized the importance of studying LULC patterns and their changes over time like two decades (Burian et al., 2002; Symeonakis et al., 2007; Hadeel et al., 2011; Sajikumar and Remya, 2015; ; Bai et al., 2016; Mahaxay et al., 2016; Li et al., 2018; Saharan et al., 2018; Verma et al., 2021; Rahmi et al., 2022; Rizwan et al., 2022; Bermoy et al., 2023; Albalawi, 2023). This period, spanning 20 years, is meticulously chosen to capture the subtleties of ecological and anthropogenic changes impacting the lake's environment. Such a duration is crucial for observing the cumulative effects of various factors, including climatic variability, land use modifications, and socio-economic developments, which significantly influence the lake's ecological balance. The two-decade span is particularly pertinent given the dynamic nature of wetland ecosystems, which are sensitive to both immediate and gradual environmental transformations. This timeframe allows for an in-depth analysis of trends, patterns, and shifts in the ecosystem, providing a comprehensive view of the lake's response to external pressures. Studies in similar ecosystems, like the Ethiopian highlands, have demonstrated the value of multi-decadal analyses in understanding the complex interplay between human activities and natural habitats over time (Muche et al., 2023).

Furthermore, this period coincides with significant advancements in RS and GIS technologies, offering a robust framework for precise and detailed environmental monitoring. The combination of ENVI, ERDAS and ArcGIS software platforms has been widely adopted in previous studies (Corner et al., 2014; Hishe et al., 2020) due to their effectiveness, efficiency, and availability of relevant tools and techniques. Researchers have acknowledged the advantages of this approach, as it offers a cost-effective and time-efficient solution for analyzing and monitoring land use and land cover changes. By utilizing these established methodologies, this study contributes to the growing body of literature on land use and land cover change analysis while providing valuable insights for land management and planning in the Uluabat region and similar contexts.

The availability of high-resolution satellite imagery and improved data processing techniques during this period enhances the study's accuracy and reliability. From a policy and management perspective, a 20-year analysis aligns well with the strategic planning cycles of environmental conservation and land use management. The insights gleaned from this study can inform decision-making processes, aiding in the development of sustainable management practices and conservation strategies for the Uluabat Lake region. In conclusion, the selection of a two-decade timeframe in this study is a judicious choice, balancing the need for a longitudinal perspective with the practical aspects of technological capability and policy relevance. It provides a rich, data-driven understanding of the environmental changes in the Uluabat Lake region, serving as a critical resource for future ecological assessments and interventions.

2.2.1. Pre-processing stage

During the pre-processing stage, various operations were performed to prepare the satellite images for analysis. Geometric corrections were applied to ensure accurate alignment and spatial consistency among the images. Also, radiometric and atmospheric corrections were carried out using the FLAASH module available in the ENVI software. These corrections play a crucial role in reducing noise and atmospheric effects, thus enhancing the quality and reliability of the images (Figure 3 and Figure 4).

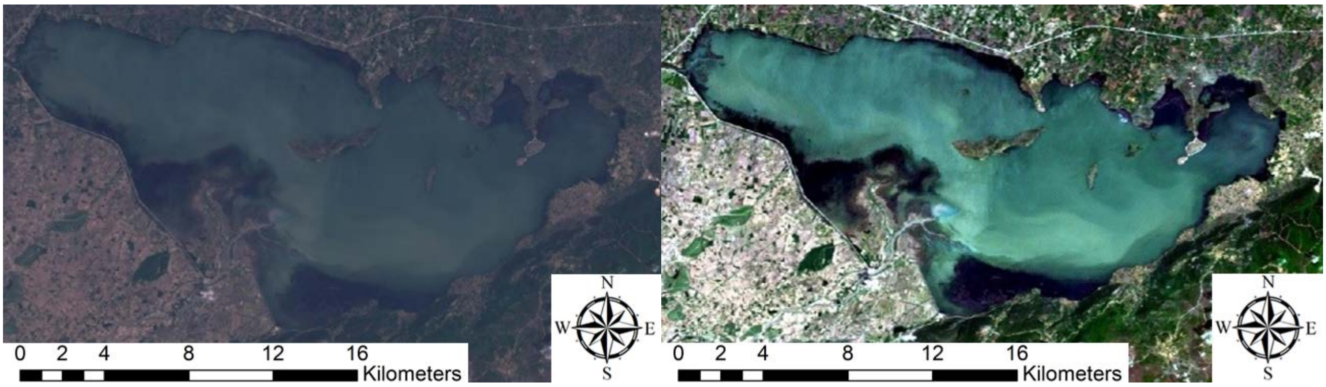

Figure 3. Landsat 7 image from 2002, initial view (left) and after pre-processing (right)

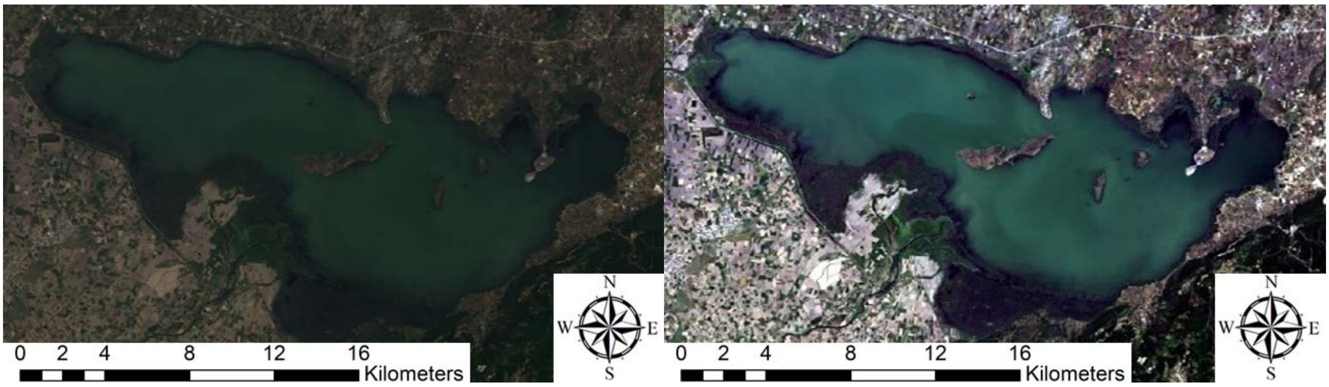

Figure 4. Landsat 9 image from 2022, initial view (left) and after pre-processing (right)

2.2.2. Supervised classification

Following the pre-processing stage, the images for each year were subjected to supervised classification using maximum likelihood algorithms implemented in the ERDAS Imagine 2015 software. This classification technique utilizes known sample points to train the algorithm in distinguishing different land cover classes. The accuracy of the classified images was then assessed to evaluate the performance and reliability of the classification process. To begin the classification process, training sites with known class labels were identified for each of the four categories: Reed and Swamp Areas, Lake, Shrubs and Forests, and other areas. For both the years 2002 (256 points) and 2022 (256 points), a total of 512 points were randomly placed each year to represent the variety within each class. The distribution of these points for the year 2002 was as follows: Reed and Swamp Areas (44 points), Lake (170 points), Shrubs and Forests (23 points), and other areas (19 points). In 2022, the distribution was slightly altered to Reed and Swamp Areas (48 points), Lake (145 points), Shrubs and Forests (30 points), and other areas (33 points).

The decision to use 256 points for each year was based on established practices and researches in remote sensing for ensuring adequate representation of each class while maintaining a manageable dataset for accurate classification (Djimadoumngar and Adegoke, 2018; Gencal et al., 2018; Kadhim et al., 2020; Habte, 2021). This number strikes a balance between oversampling (which could lead to overfitting) and undersampling (which might not capture the full variability within each class). Signatures were generated based on these training sites to represent the spectral characteristics of each class. This classification approach allowed for a comprehensive analysis of these specific land cover categories, enabling a better understanding of their spatial patterns and changes over time.

Accuracy assessment is a crucial step in the classification process, involving statistical analysis to evaluate the correctness of the classification results. It serves as a vital component for change detection (Cetin, 2009) and plays a pivotal role in making informed decisions for future developments and effective resource management, as it provides valuable information about the location and spatial interaction of resources (Congalton and Green, 2009). According to various studies (Deng et al., 2009; Ikiel et al., 2013, Butt et al., 2015), overall accuracy values exceeding 80%–85% are considered acceptable levels for image classification. It is worth noting that the Landsat-7 image of 2002 exhibited the highest accuracy among all the raster layers, emphasizing the influence of the dataset version on the accuracy. The accuracy assessment process (Figure 5) provided valuable insights into the reliability and precision of the land use and land cover classification results, contributing to the overall assessment of LULC changes in the study area.

2.2.3. Post-processing

To further refine the results, post-processing was conducted using correction techniques in the widely used ArcGIS software (10.5 Edition). This step aimed to minimize any remaining errors (if necessary spatial filtering, image enhancement clearing or smoothing) or inconsistencies in the classified images (Sarzana et al., 2020). By utilizing advanced correction tools available in ArcGIS, the quality of the images was significantly improved, leading to more accurate and reliable land cover information.

2.2.4. Land use land cover change

In the final stage, the corrected images were utilized for land use and land cover change detection. By comparing the classified images from different years, changes in land cover patterns and dynamics over time were identified and analyzed. Measures such as the Kappa coefficient and overall accuracy were used to quantify the degree of agreement between the classified images and ground truth data (management plans then collecting points from DGPS). Differential Global Positioning System (DGPS) is an enhancement to the standard GPS that provides improved location accuracy. DGPS works by using a network of fixed ground-based reference stations that have known precise locations. With higher values of these measures, the corrected images proved to be valuable in detecting and monitoring land use and land cover changes in the study area.

3. Results

LULC changes have been observed in the wetland ecosystems of Bursa Uluabat Lake, a Ramsar site, over the past two decades. The LULC categories for the study area are depicted in Figure 5, along with the corresponding years 2002 and 2022. The analysis of land use/cover changes in the Uluabat Lake Ramsar Site from 2002 to 2022 has revealed several critical transformations. The most notable change is the increase in Reed and Swamp Areas by 59.63% and the significant decrease in the lake area by -15.88%. These findings are particularly significant when compared to the study by Aksoy and Özcan (2002), which examined changes from 1984 to 1998 (Table 1).

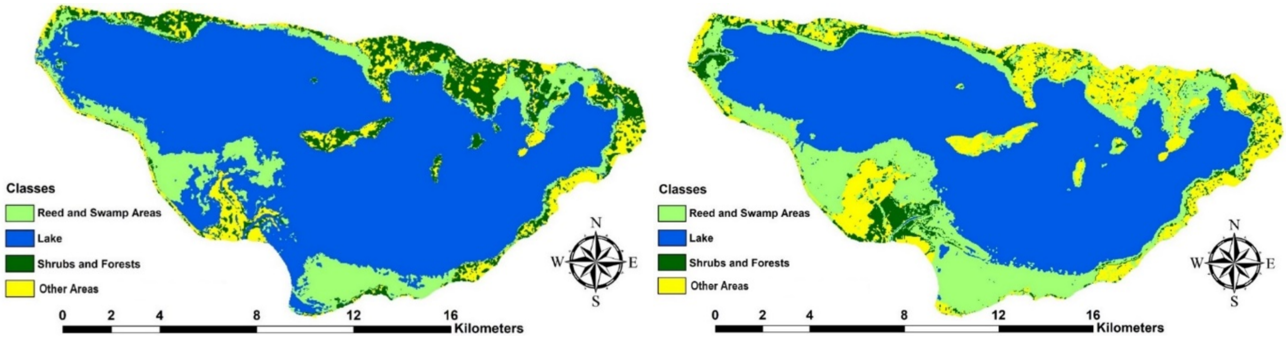

Figure 5. Classified satellite images of 2002 (left) and 2022 (right)

Table 1. Land cover types

Land use land cover classes	Area (ha) 2002	2022	% Change
Reed and Swamp Areas	2737.9	4370.7	59.64%
Lake	13606.7	11445.6	-15,88%
Shrubs and forests	1927.5	1240.5	-35,64%
Other areas	1627.9	2843.2	74,65%

Analysis of land use and cover changes within the wetland area from 2002 to 2022 revealed the following percentage changes and annual rates of change:

- Reed and Swamp Areas: The area covered by reed and swamp increased from 2737.9 hectares in 2002 to 4370.7 hectares in 2022, indicating the highest percentage change of 59.63%.
- Lake: The extent of the lake decreased from 13606.7 hectares in 2002 to 11445.6 hectares in 2022, representing the largest negative percentage change of -15.88%.
- Shrubs and Forests: The area covered by shrubs and forests decreased from 1927.5 hectares in 2002 to 1240.5 hectares in 2022, indicating a substantial decline of 35.64%.
- Other Areas: The area occupied by settlements and agricultural activities increased from 1627.9 hectares in 2002 to 2843.2 hectares in 2022, reflecting the highest positive percentage change of 74.65%.

It is important to note that the negative percentage change for the lake signifies a reduction in its size, whereas the positive percentage changes for the other categories indicate an expansion or increase in their respective areas.

To evaluate the accuracy of the classification results, an accuracy assessment was conducted, which involves statistical analysis to measure the correctness of the classified maps by comparing them to ground truth data. In this study, a total of 512 points were distributed across the study area, covering both years of satellite imagery. The points were randomly selected and allocated to different land cover classes to ensure representation of the entire area and capture the variability of the classes. The selected points were then compared to the ground truth data to assess the accuracy of the classification (Figure 6).

The accuracy assessment results (Table 2 and Table 3) were obtained through the development of an error matrix, which quantifies and summarizes the classification accuracy. The error matrix provides important elements for accuracy assessment, such as user accuracy (UA), producer accuracy (errors of omission), overall accuracy, and kappa index. Kappa coefficient (k) (Cohen, 1960) was used as a robust multivariate technique to assess the agreement between categorical variables, taking into account all elements in the confusion matrix.

For each time period (2002 and 2022), the accuracy assessment was performed, and the overall accuracy and kappa coefficient values were determined. The results showed that the classified maps of the study area exhibited overall accuracies ranging from 88.28% to 91.02% and kappa coefficients ranging from 0.82 to 0.81. These values indicate that the accuracy of the classified maps is acceptable, and the results can be considered reliable.

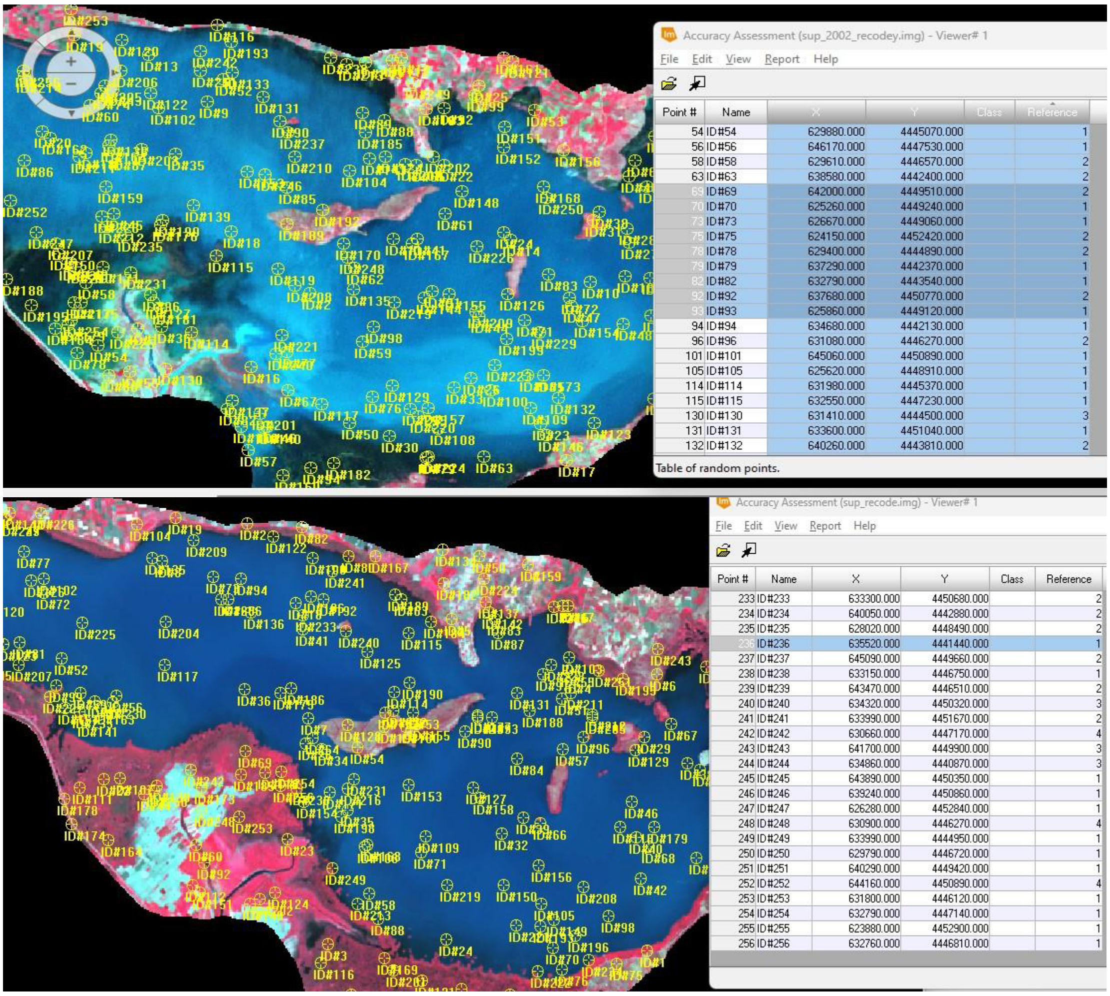

Figure 6. Accuracy assessment stages of 2002 (top) and 2022 (bottom)

Table 2. Accuracy assessment table of LULC obtained from satellite data 2002

Classified Data	Reed and Swamp Areas	Lake	Shrubs and Forests	Other Areas	UA
Reed and Swamp Areas	33	3	0	0	0.8994
Lake	11	166	3	1	0.7533
Shrubs and forests	0	1	18	2	0.8430
Other areas	0	0	2	16	0.8800
Total	44	170	23	19	
Overall Classification Accuracy = 91.02%					
Overall Kappa Statistics = 0.8180					

Table 3. Accuracy assessment table of LULC obtained from satellite data 2022

Classified Data	Reed and Swamp Areas	Lake	Shrubs and Forests	Other Areas	UA
Reed and Swamp Areas	43	1	10	0	0.7143
Lake	5	144	1	2	0.9077
Shrubs and forests	0	0	11	3	0.7573
Other areas	0	0	8	28	0.7449
Total	48	145	30	33	
Overall Classification Accuracy = 88.28%					
Overall Kappa Statistics = 0.8055					

Accuracy assessment results for the year 2002 showed an overall accuracy of 91.02% and a kappa value of 82%. Similarly, for the year 2022, the overall accuracy is 88.28% with a kappa value of 81%. These accuracy values provide an indication of the reliability and precision of the classification results for the respective years. The obtained accuracies suggest a moderate level of agreement between the classified images and the reference data, indicating that the classification results for 2002 and 2022 should be interpreted with caution. Further assessment and validation of the results could provide a more comprehensive understanding of the accuracy and reliability of the classification process for these specific years.

The classification of the wetland area using Landsat data resulted in the identification of four land cover types: Reed and Swamp Areas, Lake, Shrubs and forests, other areas (Table 1). The analysis of the Landsat data allowed for the examination of these land cover types and their respective changes within the study period. By comparing the classified images from different time periods, it was possible to observe and quantify the changes that occurred in the wetland area over time. This information is valuable for understanding the dynamics of the wetland ecosystem and can contribute to effective land management and conservation efforts.

Despite multiple attempts, distinguishing between settlements and agricultural areas etc. based solely on spectral values proved challenging due to the similarities in their spectral signatures. Extensive experimentation with various classification methods and parameter settings consistently revealed overlapping or indistinguishable spectral information for these land cover types. Recognizing the limitations of spectral data in achieving accurate differentiation, the decision was made to combine settlements and agricultural areas etc. into a single class (Other Areas). This decision was driven by the persistent lack of discriminatory power exhibited by spectral values alone. However, it is crucial to acknowledge the potential implications of this choice in subsequent analyses and interpretations. Future research may explore alternative approaches, such as incorporating ancillary data or expert knowledge, to improve classification accuracy and provide a better understanding of the dynamics between settlements and agricultural areas in land use change studies.

To compare the land use/cover changes observed between 1984 and 1998, as reported in the study conducted by Aksoy and Özcan in 2002, with the changes between 2002 and 2022, both similarities and differences were observed in the transformation of the Uluabat Lake Ramsar Site over time. Between 1984 and 1998, the land cover classes exhibited varying degrees of change. Settlements and roads, Maquis, Agricultural lands, Orchards, Mixed Marshlands, Reeds, Water lilies and reed, burned reeds, Shrub and trees, Islands, Uluabat Lake, Mustafakemalpaşa River, and Uluabat River were the identified land use/cover classes in the study.

Comparing the percentage changes during these two periods, some similarities can be observed. For instance, the land cover classes of other areas (Settlements and Agricultural areas etc.) lands showed positive percentage changes in both timeframes. Settlements and roads increased from 0.17% in 1984 to 0.26% in 1998, and Agricultural lands increased from 13.01% in 1984 to 16.85% in 1998. However, there were also notable differences in the land use/cover changes between the two study periods. For instance, the Reed and Swamp Areas experienced a significant increased from 3.56% in 1984 to 8.42% in 1998, while in the later study period (2002-2022), the same category showed a higher increase from 2737.9 hectares to 4370.7 hectares, representing a 59.63% change. Similarly, the Lake area exhibited a different trend between the two study periods. In the 1984-1998 study, the Lake percentage remained relatively stable, ranging from 59.61% in 1993 to 58.03% in 1998. However, in the 2002-2022 study, the Lake area experienced a notable decrease, from 66.10% in 2002 to 58.03% in 2022, indicating a negative change of -15.88%.

4. Discussion

Comparing the present study with similar international research, diverse wetland dynamics were observed reflecting region-specific ecological responses to environmental pressures. In the Lake Abaya-Chamo study, between 1990–2019, wetland/swamp areas declined by 11.4% (700 ha), 16% (867 ha), and 31.3% (1,424 ha) across three periods. Settlements and water bodies increased, indicating habitat shifts. Comparatively, in this study from 2002-2022 showed a 59.63% increase in Reed and Swamp Areas, a 35.64% decrease in Shrubs and Forests, and a 74.65% rise in Other Areas. These contrasting trends underscore the varied ecological responses in different wetlands, influenced by regional factors like siltation and population growth (Zekarias et al., 2021).

The Gua Musang study, using Landsat 8 OLI images (2017-2019), identified minimal LULC changes, with deforestation at 5.95%, forest area changes at 5.57%, and water bodies covering only 0.36%. Contrastingly, the present study (2002-2022) showed a 59.63% increase in Reed and Swamp Areas, a 15.88% decrease in Lake area, and a 74.65% increase in Other Areas, indicating more substantial changes over a longer period. These studies highlight the variability in ecosystem responses to different environmental pressures and timescales (Rahman et al., 2022).

The Harike wetland study in India (1989-2010) used a change matrix for post-classification detection, showing significant transformations in land cover. Key changes included the conversion of waterbody areas to Wetland II and other categories and shifts within wetland categories. Comparatively, the present study (2002-2022) observed a 59.63% increase in Reed and Swamp Areas, a significant decrease in Lake area (-15.88%), and an increase in Other Areas (74.65%). These contrasting results highlight different patterns of ecological change in these two wetland ecosystems (Mabwoga, 2014).

These comparisons highlight the dynamic nature of land use/cover changes in the Uluabat Lake Ramsar Site over different time periods. While both studies provide insights into the alterations occurring within the region, the later study (2002-2022) offers a more recent perspective on the land use/cover changes, capturing the transformations in a more current timeframe.

The analysis of land use/cover changes in the Uluabat Lake Ramsar Site is crucial for understanding the impact of human activities, ecological dynamics, and climate change on the wetland ecosystem. It emphasizes the need for sustainable land management practices, conservation efforts, and policy interventions to ensure the preservation of this important ecological site.

5. Conclusion

In conclusion, this study, employing advanced RS and GIS technologies, offers an in-depth analysis of land cover changes in the Uluabat Lake wetlands over a span of two decades. The results reveal a marked decline in natural habitats, including shrubs, forests and lakes, alongside a notable increase in areas designated for reed and swamps and other areas (agriculture and settlements). These changes are indicative of significant human encroachment and impact on these delicate wetland ecosystems. The study emphasizes the critical need for an integrated and sustainable approach to wetland management. This includes engaging local communities, government bodies, and non-governmental organizations in concerted efforts to raise awareness and implement effective conservation strategies. Such collaboration is essential for mitigating further environmental degradation and ensuring the preservation of biodiversity. The presented methodology, leveraging the capabilities of Landsat 7 ETM and Landsat 9 OLI/TIRS satellite imagery, has enabled a detailed and precise analysis of spatial changes. However, it is important to acknowledge the limitations of this study, with a need for further validation and assessment to fully ascertain the accuracy and reliability of the findings. Ultimately, this research provides valuable insights and data for policymakers and conservationists and underscores the urgent necessity of adopting sustainable environmental practices and fostering collaborative efforts in The Uluabat Lake wetland. These are imperative not only for maintaining the ecological balance and health of wetland habitats but also for supporting the overall well-being of local communities and promoting sustainable development. The Uluabat Lake wetlands, like many similar ecosystems, are at a critical juncture; therefore, it is important to ensure their future viability and the broader ecological and socio-economic benefits they can continue to provide.

Ethics Committee Approval: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept: İ.T., B.G.; Design: B.G., İ.T.; Supervision: B.G.; Resources: İ.T., E.K.; Data Collection: B.G., E.K.; Analysis: B.G., E.K.; Literature Search: B.G., E.K., İ.T.; Writing Manuscript: B.G., E.K., İ.T.; Critical Review: İ.T., B.G.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Cite this paper as: Kılınçarslan, E., Gencal, B., Taş, İ. 2024. Assessing Two Decades of Land Use/Land Cover Changes in the Uluabat Lake Ramsar Site using Satellite Imagery, *European Journal of Forest Engineering*, 10(2):100-111.

References

Aksoy, E. and Özsoy, G. 2002. Investigation of multi-temporal land use/cover and shoreline changes of the Uluabat Lake Ramsar Site using RS and GIS. In Proceedings of the International Conference on Sustainable Land Use and Management, 10: 13.

Albalawi, E.K. 2023. Comparing pixel-based to object-based image classifications for assessing LULC change in an arid environment of northern west Saudi Arabia. *The Egyptian Journal of Environmental Change*, 15(1):55-76. https://doi.org/10.21608/ejec.2023.286642.

Anadolu Agency, 2023. "Türkiye'de 105 sulak alan bulunuyor." https://www.aa.com.tr/tr/yesilhat/dogal-yasam/turkiyede-105-sulak-alan-bulunuyor/1819657 coronavirus/2175200 (2021), Accessed 1st June 2023

Bai, Y., Jiang, B., Alatalo, J. M., Chen, Z., Wang, X., Xu, W. 2016. Impacts of land management on ecosystem service delivery in the Baiyangdian river basin. *Environmental Earth Sciences*, 75(3). https://doi.org/10.1007/s12665-015-4831-7.

Bandara, B., Silva, R., Dayawansa, N. 2019. Analysis of forest cover loss in the forest complex: a remotely sensed change detection and fragmentation analysis. *Tropical Agricultural Research*, 30(4):81. https://doi.org/10.4038/tar.v30i4.8330.

Bermoy, M.M., Cacayan, V.O., Carido, J.C., Apdohan, A.G., Cacayan, A.O. 2023. Prediction of future land use land cover (lulc) and assessment of its impact on the water supply availability of Butuan city-taguibo river watershed and forest reserve (trwfr), philippines. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-4/W6-2022, 81-86. https://doi.org/10.5194/isprs-archives-xlviii-4-w6-2022-81-2023.

Biswas, T., Pal, S.C., Saha, A., Ruidas, D., Islam, A.R.M.T., Shit, M. 2023. Hydro-chemical assessment of groundwater pollutant and corresponding health risk in the Ganges delta, Indo-Bangladesh region. *Journal of Cleaner Production*, 382:135229.

Burian, S.J., Brown, M.J., McPherson, T.N. 2002. Evaluation of land use/land cover datasets for urban watershed modeling. *Water Science and Technology,* 45(9):269-276. https://doi.org/10.2166/wst.2002.0256.

Butt, A., Shabbir, R., Ahmad, S.S., Aziz, N. 2015. Land use change mapping and analysis using remote sensing and GIS: a case study of Simly watershed, Islamabad, Pakistan. *Egyptian Journal of Remote Sensing and Space Science*, 18(2):251–259. https://doi.org/10.1016/j.ejrs.2015.07.003.

Çağırankaya, S.S. and Meriç, B.T. 2013. Turkey's Important Wetlands: Ramsar Sites. Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Nature Conservation and National Parks. Ankara, Turkey.

Cetin, M. 2009. A satellite-based assessment of the impact of urban expansion around a lagoon. *International journal of Environmental Science and Technology*, 6(4):579–590. https://doi.org/10.1007/BF03326098.

Cohen, J. 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*. 20(1):37–46. doi:10.1177/001316446002000104.

Congalton, R. G., Green, K. (2009). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices (Second Edition). CRC Press Taylor & Francis Group.

Corner, R. J., Dewan, A. M., Chakma, S. 2014. Chapter 5 monitoring and prediction of land-use and land-cover (LULC) change. In A. M. Dewan & R. J. Corner (Eds.), Dhaka megacity: geospatial perspectives on urbanisation, environment and health (pp.75–97). Dordrecht: Springer http://www.springer.com/series/10180. Accessed 30 Jan 2020.

Demirel, Ö. 2005. Doğa koruma ve milli parklar. Karadeniz Teknik Üniversitesi. Rektörlüğü Genel Yayın No. 219, 424, Trabzon.

Deng, J. S., Wang, K., Hong, Y., Qi, J.G. 2009. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. *Landscape and Urban Planning*, 92(3–4):187–198. https://doi.org/10.1016/j.landurbplan.2009.05.001.

Deng, L., Liu, G., Shangguan, Z. 2014. Land-use conversion and changing soil carbon stocks in China's 'grain-for-green' program: a synthesis. *Global Change Biology*, 20(11):3544-3556. https://doi.org 10.1111/gcb.12508.

Djimadoumngar, K. N. and Adegoke, J. 2018. Satellite-Based Assessment of Land Use and Land Cover (LULC) Changes around Lake Fitri, Republic of Chad. *Journal of Sustainable Development,* 11(5): 71.

FAO, 2011. FAOSTAT. Food and Agriculture Organization of the United Nations.

Fletcher S., Kawabe M., Rewhorn S. 2011. Wetland conservation and sustainable coastal governance in Japan and England. *Marine pollution bulletin,* 62(5):956–962.

Gardner, R., Finlayson, M. 2018. Global Wetland outlook: state of the world's wetlands and their services to people. Ramsar Convention Secretariat, 2018, Stetson University College of Law Research Paper No. 2020-5. Available at https://ssrn.com/abstract=3261606.

Gencal, B., Taş, İ., Akay, A.E. 2018. Spatiotemporal Change Detection of the Linden Forests in Bursa, Turkey. *European Journal of Forest Engineering*, 4(2):50-55.

Gunathilaka, M., Halwatura, D., Manawadu, L., Munasinghe, D. 2022. Application of satellite remote sensing and dapsi(w)r(m) framework as a tool to assess land use impacts on urban lakes in Sri Lanka. *Environment and Urbanization Asia,* 13(2):218-231. https://doi.org/10.1177/09754253221120606.

Habte, D.G., Belliethathan, S., Ayenew, T. 2021. Evaluation of the status of land use/land cover change using remote sensing and GIS in Jewha Watershed, Northeastern Ethiopia. *SN Applied Sciences*, 3:1-10.

Hacısalihoğlu S., Karaer F., Katip A. 2016. Applications of geographic information system (GIS) analysis of lake Uluabat. *Environmental Monitoring and Assessment*, 188(6):1–14.

Hacısalihoğlu, S. and Karaer, F. 2016. Relationships of heavy metals in water and surface sediment with different chemical fractions in Lake Uluabat, turkey. *Polish Journal of Environmental Studies*, 25(5):1937-1946. https://doi.org/10.15244/pjoes/62908.

Hacısalihoğlu, S. and Karaer, F. 2018. Evaluation of water quality in eutrophic shallow lakes: case study on Lake Uluabat, Turkey. *International Journal of Agriculture Environment and Food Sciences*, 2(1):18-28. https://doi.org/10.31015/jaefs.18004.

Hacısalihoğlu, S., Karaer, F., Katip, A. 2016. Applications of geographic information system (gis) analysis of Lake Uluabat. *Environmental Monitoring and Assessment*, 188(6). https://doi.org/10.1007/s10661-016-5332-1.

Hadeel, A. S., Jabbar, M. T., Chen, X. 2011. Remote sensing and gis application in the detection of environmental degradation indicators. *Geo-Spatial Information Science,* 14(1):39-47. https://doi.org/10.1007/s11806-011-0441-z.

Hishe, S., Bewket, W., Nyssen, J., Lyimo, J. 2020. Analysing past land use land cover change and CA-Markov-based future modelling in the Middle Suluh Valley, Northern Ethiopia. *Geocarto International*, 35(3):225–255. https://doi.org/10.1080/10106049.2018.1516241.

Ikiel, C., Ustaoglu, B., Dutucu, A.A., Kilic, D.E. 2013. Remote sensing and GIS-based integrated analysis of land cover change in Duzce plain and its surroundings (northwestern Turkey). *Environmental Monitoring and Assessment*, 185(2):1699–1709. https://doi.org/ 10.1007/ s10661-012-2661-6.

İşçen, C., Emiroğlu, Ö., İlhan, S., Arslan, N., Yılmaz, V., Ahıska, S. 2007. Application of multivariate statistical techniques in the assessment of surface water quality in Uluabat Lake, Turkey. *Environmental Monitoring and Assessment,* 144(1-3):269-276. https://doi.org/10.1007/s10661-007-9989-3.

Islam, A.R.M.T., Kabir, M.M., Faruk, S., Al Jahin, J., Bodrud-Doza, M., Didar-ul-Alam, M., ... and Choudhury, T.R. 2021. Sustainable groundwater quality in southeast coastal Bangladesh: co-dispersions, sources, and probabilistic health risk assessment. Environment, Development and Sustainability, 1-30.

Kadhim, N.A., Hussein, A.K., Jaber, A.S., Abojassim, A.A. 2020. Land Use and Land Cover Change Detection Using Satellite Images for The Kufa District. Najaf, Iraq.

Katip, A. and Karaer, F. 2013. Research on the non-point pollution loads in the lake Uluabat basin. *Journal of Environmental Protection*, 04(07):29-37. https://doi.org/10.4236/jep.2013.47a004.

Lambin, É., Geist, H., Lepers, E. 2003. Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources,* 28(1):205-241. https://doi.org/10.1146/annurev. energy.28.050302.105459.

Li, S., Yang, H., Lacayo, M., Liu, J., Lei, G. 2018. Impacts of land-use and land-cover changes on water yield: a case study in jing-jin-ji, china. Sustainability, 10(4), 960. https://doi.org/10.3390/su10040960.

Mabwoga, S.O. and Thukral, A. K. 2014. Characterization of change in the Harike wetland, a Ramsar site in India, using landsat satellite data. *SpringerPlus,* 3(1):1-11.

Mahaxay, M., Arunpraparut, W., Trisurat, Y., Tangtham, N. 2016. Calibration of hydrological streamflow modeling using Modis. *Journal of Geological Resource and Engineering,* 4(1). https://doi.org/10.17265/2328-2193/2015.01.007.

Mao, D., Wang, Z., Wang, Y., Choi, C., Jia, M., Jackson, M., … and Fuller, R. 2021. Remote observations in china's ramsar sites: wetland dynamics, anthropogenic threats, and implications for sustainable development goals. Journal of Remote Sensing, 2021(10):1-13. https://doi.org/ 10.34133/2021/ 9849343.

Muche, M., Yemata, G., Molla, E., Adnew, W., Muasya, A.M. 2023. Land use and land cover changes and their impact on ecosystem service values in the north-eastern highlands of Ethiopia. *PLOS ONE* 18(9): e0289962.
https://doi.org/10.1371/journal.pone.0289962

Nielsen, A., Trolle, D., Søndergaard, M., Lauridsen, T., Bjerring, R., Olesen, J., … and Jeppesen, E. 2012. Watershed land use effects on lake water quality in Denmark. *Ecological Applications*, 22(4):1187-1200. https://doi.org/10.1890/11-1831.1.

Özesmi, U. and Özesmi, S. 2003. A participatory approach to ecosystem conservation: fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. *Environmental Management*, 31(4):518-531. https://doi.org/10.1007/s00267-002-2841-1.

Ozsoy, G., Aksoy, E., Dirim, M., Tümsavaş, Z. 2012. Determination of soil erosion risk in the Mustafakemalpasa river basin, turkey, using the revised universal soil loss equation, geographic information system, and remote sensing. *Environmental Management*, 50(4):679-694. https://doi.org/10.1007/s00267-012-9904-8.

Pal, S. C., Ruidas, D., Saha, A., Islam, A. R. M. T., Chowdhuri, I. 2022. Application of novel data-mining technique-based nitrate concentration susceptibility prediction approach for coastal aquifers in India. Journal of Cleaner Production, 131205.

Rahman, S.H.A.A., Shukri, M.A.H.M., Ab Latip, A.S., Abd Latif, Z. 2022. Land use and land cover change analysis using satellite images in Gua Musang, Kelantan. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1019, No. 1, p. 012025). IOP Publishing.

Rahmi, K.I.N., Ali, A., Maghribi, A.A., Aldiansyah, S., Atiqi, R. 2022. Monitoring of land use land cover change using google earth engine in urban area: Kendari city 2000-2021. IOP Conference Series: *Earth and Environmental Science*, 950(1):012081. https://doi.org/10.1088/1755-1315/950/1/012081.

Rizwan, M., Zhang, W., Abbas, Z., Guo, F., Gwiazdzinski, L. 2022. Spatiotemporal change analysis and prediction of future land use and land cover changes using qgis molusce plugin and remote sensing big data: a case study of Linyi, China. *Land*, 11(3):419. https://doi.org/10.3390/land11030419.

Ruidas, D., Pal, S. C., Chowdhuri, I., Saha, A., Biswas, T., Islam, A. R. M. T., Shit, M. 2023. Hydrogeochemical evaluation for human health risk assessment from contamination of coastal groundwater aquifers of Indo-Bangladesh Ramsar site. Journal of Cleaner Production, 399, 136647.

Saana B.Y., Sixtus F., Samuel A.S., Godfred M., Napoleon K.T. 2016. Assessment of the quality of groundwater for drinking purposes in the Upper West and Northern regions of Ghana. SpringerPlus. 5. 10.1186/s40064-016-3676-1.

Saharan, M.A., Vyas, N.K., Borana, S.L., Yadav, S.K. 2018. Classification and assessment of the land use – land cover changes in Jodhpur city using remote sensing technologies. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-5, 767-771. https:// doi.org/10.5194/isprs-archives-xlii-5-767-2018.

Sajikumar, N. and Remya, R. 2015. Impact of land cover and land use change on runoff characteristics. *Journal* *of Environmental Management*, 161:460-468. https://doi.org/10.1016/j.jenvman.2014.12.041.

Sarzana, T., Maltese, A., Capolupo, A., Tarantino, E. 2020. Post-processing of pixel and object-based land cover classifications of very high spatial resolution images. In Computational Science and Its Applications–ICCSA 2020: 20th International Conference, Cagliari, Italy, July 1–4, 2020, Proceedings, Part IV 20 (pp. 797-812). Springer International Publishing.

Shen, Y., Chapelle, F.H., Strom, E.W., Benner, R. 2015. Origins and bioavailability of dissolved organic matter in groundwater. *Biogeochemistry*, 122:61-78.

Symeonakis, E., Calvo-Cases, A., Arnau-Rosalén, E. 2007. Land use change and land degradation in Southeastern Mediterranean Spain. *Environmental Management*, 40(1):80-94. https://doi.org/10.1007/s00267-004-0059-0.

Tu, T., Baykal, M.T. 2023. Monitoring the changes of Lake Uluabat Ramsar site and its surroundings in the 1985-2021 period using RS and GIS methods.

Tyagi, S., Sharma, B., Singh, P., Dobhal, R. 2013. Water quality assessment in terms of water quality index. *American Journal of Water Resources*, 1(3):34-38.

UNESCO 2012. Shaping the Education of Tomorrow: 2012 Full-Length Report on the UN Decade of Education for Sustainable Development. Simplified Chinese Version, 20. http://unesdoc.unesco.org/images/0021/ 002166/216606c.pdf.

UNESCO 2015. SDG4-Education 2030, Incheon Declaration (ID) and Framework for Action. For the Implementation of Sustainable Development Goal 4, Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All, ED-2016/WS/28.

Welch, G. and Welch, H., 1998. Breeding Bird Survey of Uluabat Lake, DHKD,1998.

Verma, S., Agrawal, S., Dutta, K. 2021. Satellite imagery driven assessment of land use land cover, urbanization and surface temperature pattern dynamics over tropical megacities. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVI-4/W6-2021, 313-320. https://doi.org/10.5194/isprs-archives-xlvi-4-w6-2021-313-2021.

Vollmer, D., Regan, H.M., Andelman, S.J. 2016. Assessing the sustainability of freshwater systems: A critical review of composite indicators. *Ambio*, 45:765-780.

Vollmer, Derek, and Adrienne Grêt-Regamey. 2013. Rivers as Municipal Infrastructure: Demand for Environmental Services in Informal Settlements along an Indonesian River. *Global Environmental Change*, 23 (6):1542–55.

World Bank Group. 2016. Valuing water resources in Turkey: A methodological overview and case study. World Bank.

Zaitunah, A., Ahmad, A., Pasaribu, I. 2022. Lands cover dynamics of siais lake catchment area, tapanuli selatan district, indonesia. Iop *Conference Series Earth and Environmental Science*, 1116(1):012084. https://doi.org/10.1088/1755-1315/1116/1/012084.

Zekarias, T., Govindu, V., Kebede, Y., Gelaw, A. 2021. Geospatial analysis of wetland land use/land cover dynamics on Lake Abaya-chamo, Southern Rift-valley of Ethiopia... https://doi.org/10.21203/rs.3.rs-407287/v2.

Zeng, Q., Bridgewater, P., Cai, L., Yun, J., Lei, G. 2014. Perspectives on zonation in ramsar sites, and other protected areas: making sense of the tower of babel. *Open Journal of Ecology*, 04(13):788-796. https://doi.org/10.4236/oje.2014.413067.