

MONITORING THE CHANGES OF LAKE ULUABAT RAMSAR SITE AND ITS SURROUNDINGS IN THE 1985-2021 PERIOD USING RS AND GIS METHODS

Tuğba ÜSTÜN TOPAL^{1*} Tuğba MEMİŞOĞLU BAYKAL²

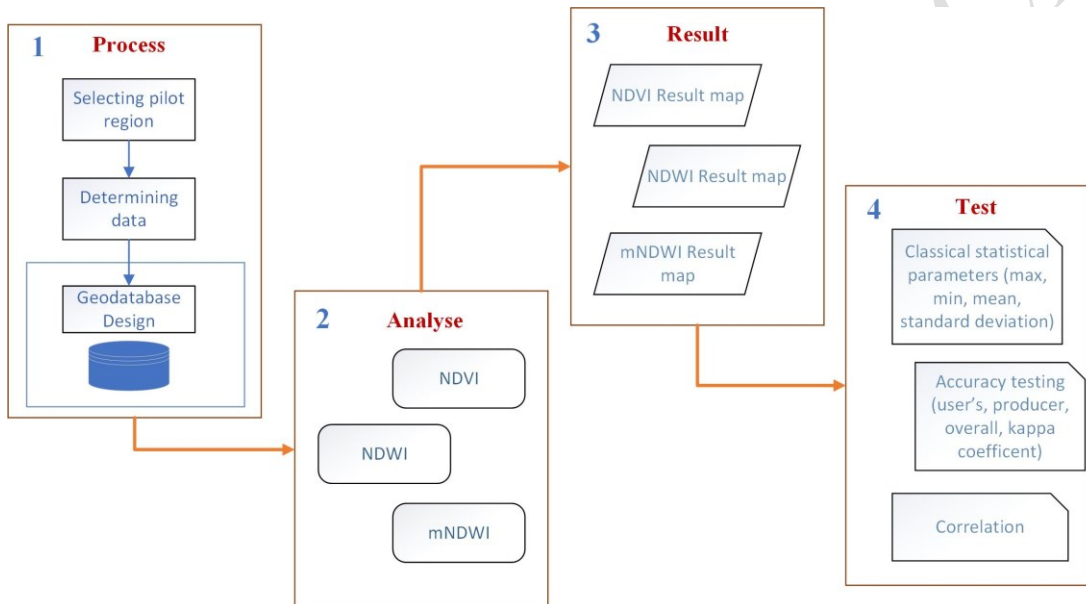
¹Department of Landscape Architecture, Faculty of Fine Arts, Design and Architecture, Tekirdağ Namık Kemal University, 59030, Tekirdağ, Türkiye

²Department of Geomatics Engineering, Faculty of Engineering, Artvin Çoruh University, 08100, Artvin, Türkiye

*Corresponding author: T. Üstün Topal

E-mail: tugbaustun61@gmail.com tel: +902822502933

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

28 images (Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI/TIRS) as RS data. The resulting changes
29 were monitored and the success of the indices in determining these areas and the relations of the
30 indices with each other were questioned by Accuracy index, Kappa coefficient, and Correlation
31 analyses. The results show 36-year long-term changes and reveal a 13.06% shrinkage of Uluabat Lake
32 wetland and surrounding water areas with the highest kappa coefficients for mNDWI as 0.83, 0.90,
33 0.93, 0.97, respectively, over the years studied.

34 **Key Words:** NDVI, NDWI, mNDWI, Remote sensing, GIS, Lake Uluabat, Bursa.

35

36 1. INTRODUCTION

37 Wetlands, which have an important place for life, have many environmental, social, economic and
38 recreational functions (providing habitat, providing environmental sustainability, providing
39 production and information, etc.) (Halls, 1997; Yağmur and Musaoğlu, 2020; Faruque et al., 2022).

40 However, the world's water resources and water bodies are turning into ecosystems that are gradually
41 shrinking and disappearing due to both climate change and human activities. As a matter of fact,
42 wetlands with shallow water depths and large areas are among the water bodies that are most affected
43 by climate change (Chang et al., 2017; Musaoğlu et al., 2020). However, wetlands are also
44 deteriorating due to many reasons such as agricultural transformation to meet the increasing
45 population and food demand, developing residential areas, digging for irrigation, drying, filling,
46 drainage, pollution, excessive resource consumption (Mozumder et al., 2014; Akdeniz et al., 2015;
47 Yagmur and Musaoğlu, 2020; Mukherjee and Pal, 2021).

48 With the understanding of the necessity of taking some measures against these deteriorations,
49 wetlands have become the focus of international protection activities since the early 1970s (Fletcher,
50 2011). In this way, Ramsar Convention, one of the oldest multilateral environmental agreements was
51 signed in 1971 in Ramsar, Iran, with the aim of protecting wetlands. The purpose of the contract are
52 regulation of the water regimes of the regions where wetlands are located, providing shelter for
53 characteristic plant and animal communities, especially waterfowl, preventing movements that may

54 cause loss of wetlands as they constitute economic, cultural, scientific and recreational resources,
55 recognizing that wetlands are an international resource due to the crossing of borders as a result of
56 seasonal migrations of waterfowl and therefore the protection of wetlands and their dependent plant
57 and animal communities. In addition, with the agreement, it is aimed to ensure the rational use of
58 wetlands while protecting them with the goal of sustainable development around the world
59 (Çağırankaya and Meriç, 2013; Demirel, 2005; Anonymous 2021a).

60 Despite the existence of legislation to protect wetlands, degradation in wetlands occurs more rapidly
61 than in other ecosystems (Mozumder et al., 2014). So much so that 50% of the wetlands in the
62 Mediterranean region have disappeared since 1970 (Anonymous, 2022a). However, the degradation
63 and destruction of wetlands, one of the most productive and important ecosystems in the world, is a
64 serious threat to biodiversity (Ekumah et al., 2020; Ashok et al., 2021; Paul and Pal, 2020). In this
65 context, habitat monitoring, evaluation and conservation activities are critical to support the
66 conservation of biodiversity (Ludwig et al., 2019; Teng et al., 2021). For this reason, it is necessary
67 to determine the changes caused by climate change and human activities in wetlands and to determine
68 the effects of these changes on the environment and society. In this context, mapping is very important
69 for the protection, planning and management of wetlands (Ashok et al., 2021; Mallick et al., 2021).

70 Türkiye, which signed the Ramsar Convention in 1994, has very favorable and rich wetlands in terms
71 of biodiversity. 14 of the 93 wetlands in Türkiye are designated as Ramsar Sites. The total surface
72 area of the areas currently designated as Ramsar sites in Türkiye is 184,487 ha. (Anonymous,
73 2021a,b). However, wetlands are under pressure in Türkiye as well as in the rest of the world. Lake
74 Uluabat Ramsar Site is one of the important wetlands of Türkiye, which is also under pressure. As a
75 matter of fact, the Uluabat Wetland Workshop and the final report held on February 5, 2022 showed
76 that there is an urgent need to develop better protection measures (Anonymous, 2022b).

77 The fact that water management decisions require the use of modern methods (Chalkidis et al., 2016)
78 has made Remote sensing (RS) and geographic information systems (GIS) have become one of the
79 widely used tools that provide significant potential and information to assess the status of wetland

80 ecosystems, at the point where the developments in science and technology have come, especially in
81 the last few decades (Eid et al., 2020a; Musaoğlu et al., 2020; Brinkhoff et al., 2022). RS-GIS-based
82 techniques have been adopted because they allow effective temporal evaluation through satellite
83 images, as well as being efficient in terms of labor and cost (Maleki et al., 2016; Mukherjee and Pal,
84 2021; Li et al., 2021). Areas covered by water can be determined by water index equations based on
85 the ratio of bands in multi-band satellite images (McFeeters, 1996; Xu, 2006). There are many studies
86 in the literature to accurately determine the changes in water-land surfaces using spectral indices
87 (Ashok et al., 2021; Mozumder et al., 2014; Fitoka et al., 2020; Eid et al., 2020b; Mukherjee and Pal,
88 2021; Paul and Pal, 2020; Bhatnagar et al., 2020; Debanshi and Pal, 2020; Ludwig et al., 2019; Szabo
89 et al., 2016; Rokni et al., 2014).

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

101 **2. MATERIALS AND METHODS**

102 *2.1. Methodology*

103 The study consists of 9 stages:

- 104 i. Selecting the study area
- 105 ii. Determining the characteristics of the study area

- 106 iii. Obtaining Landsat satellite images of 1985, 2000, 2015 and 2021 from the United States
- 107 Geological Survey (USGS) Earth Explorer
- 108 iv. Organizing the obtained data in ArcGIS 10.8 program and creating the geodatabase
- 109 v. Defining the edited data in the WGS 84- 35N projection system and making it ready for
- 110 analysis
- 111 vi. Performing analysis by calculating NDVI, NDWI and mNDWI
- 112 vii. Mapping the results obtained
- 113 viii. Testing and evaluation of results from indexes
- 114 ix. Conclusions and recommendations

115 2.2. Study area

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

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

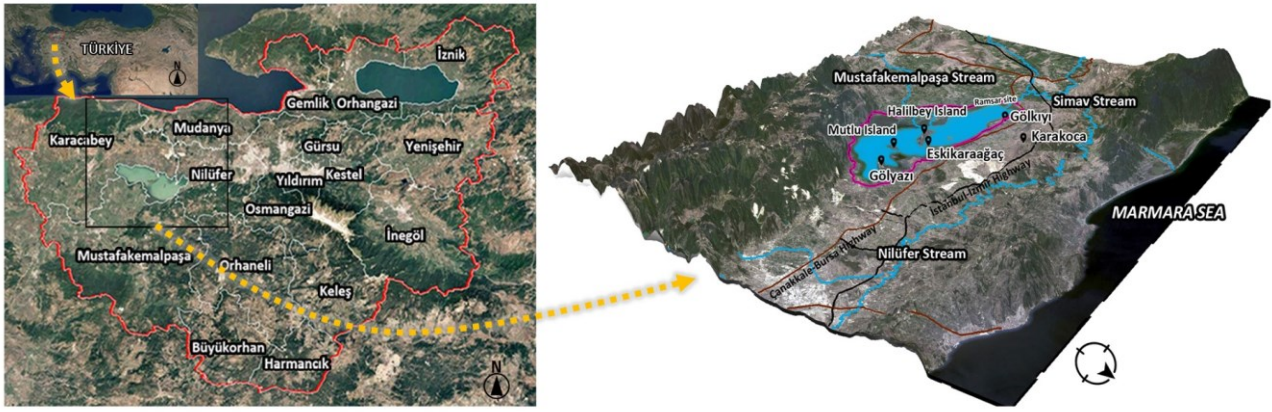


Figure 1. Study area

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 (Hacısalıhoğlu et al., 2016; Anonymous, 2021c).

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

| Criteria | Explanation |
|--|--|
| Criterion 2: <i>A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities</i> | Among them, <i>Hirudo medicinalis</i> (The medicinal leech) is listed in UICN as near threatened, <i>Pelecanus crispus</i> (Dalmatian pelican) is a vulnerable species living in the Uluabat Lake. Also, <i>Sagittaria sagittifolia</i> and <i>Stachys palustris</i> are vulnerable plant species also found in the region. |
| Criterion 4: <i>“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.”</i> | <i>Lutra lutra</i> (otter) is an internationally protected mammal species. The area is the most important breeding ground for <i>Phalacrocorax pygmeus</i> in Türkiye. It is also a nesting, wintering and breeding ground for many birds. <i>Pelecanus crispus</i> , <i>Aythya nyroca</i> and <i>Microcarbo pygmaeus</i> 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 spawning ground for many fishes. 21 fish species live in this lake. |

143

144 When the herbaceous plant taxa around the lake were evaluated, it is reported that the endemism rate
145 of Lake Uluabat is very high as 36.14% (Akdeniz et al., 2015). Almost all the shores of the lake are
146 covered with underwater plants (Hacısalıhoğlu et al., 2016). Lake Uluabat Wetland has plant species
147 included in the “LC-Least Concern” category in the Red List of the The International Union for
148 Conservation of Nature (IUCN). *Nymphaea alba* (water lily), *Ceratophyllum demersum* (hornwort),
149 *Butomus umbellatus* (flowering rush) are among the species in the lake ecosystem. Species found in
150 the lakeshore ecosystem include *Phragmites australis* (reed), *Typha domingensis* (southern cattail),
151 *Tamarix smyrnensis* (tamarisk). Some bird species found in the area are on the IUCN red list. These
152 are *Pelecanus crispus* (great crested grebe) in the "VU-Vulnerable" category, *Aythya nyroca*
153 (ferruginous duck), *Microcarbo pygmaeus* (pygmy cormorant catalan) in the "NT-Near Threatened"
154 category, and *Chlidonias hybrida* (the whiskered tern), *Ardeola ralloides* (the squacco heron),
155 *Platalea leucorodia* (Eurasian spoonbill catalan), *Nycticorax nycticorax* (the black-crowned night
156 heron) in the "LC-Least Concern" category (Anonymous, 2022c). Among the mammal species
157 detected around the lake, there are *Canis aureus* (the golden jackal), *Vulpes vulpes* (the red fox),
158 *Meles meles* (badger) ve *Lepus capensis* (the cape hare), as well as the *Lutra lutra* (otter), which is
159 endangered in the IUCN red list and has international protection status (Akšana and Bulut, 2021).
160 In addition, the lake provides many ecosystem service components such as water supply, food supply,
161 spiritual and inspirational properties, and potential for recreation and tourism (Table 2).

162

163

164

165

166 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 |

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

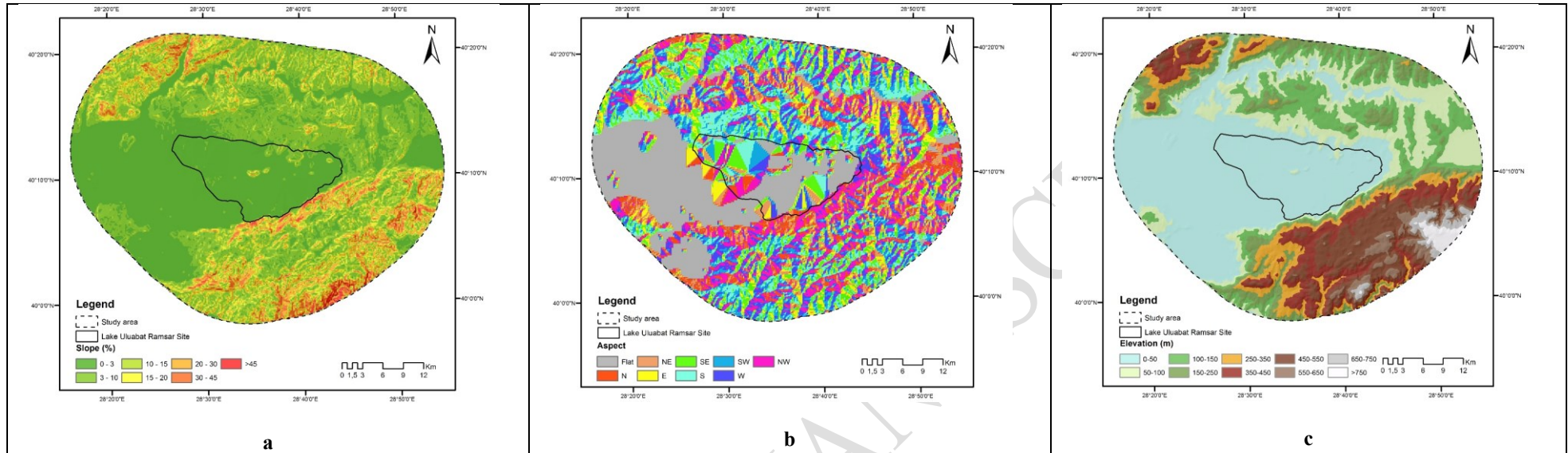
168 2.2.2. Topographic and climatic features of the study area

169
 170 This stage of the study is the definition of the physical and climatic properties of the selected study
 171 area. At this point, topographic maps of the region (elevation, slope and aspect) were produced.
 172 According to the results of the slope analysis, 38,25% of the study area has a slope of 0-3%, and these
 173 areas cover 69,352 ha. Areas with a slope of 3-10% cover 52.007 ha. Areas with a slope of >45 in the
 174 study area have the lowest percentage with 0.54% and 984 ha. it covers. As the slope percentages
 175 increase, the ha. occupied by these areas appears to be decreasing. In the study area, in general, the
 176 areas in the west and northwest parts are flat and have almost flat slopes, while the south and
 177 southwest parts have a slope of more than 45% (Figure 2a, Table 3a). The aspect map of the study
 178 area is divided into 9 classes as flat areas, intermediate directions and cardinal directions. The results
 179 show that flat areas are more common than other areas. It is seen that the other areas distribute in
 180 close proportions to each other. Accordingly, flat areas cover 35,652 ha and these areas constitute
 181 19.66% of the study area (Figure 2b, Table 3b). The height map from the generated maps is divided

182 into 10 classes. According to the results, areas of 0-50 m are 68,161 ha and cover 37.59% of the
183 study area. The maximum elevation of the land is 920 m. (Figure 2c, Table 3c).

184 Considering the long-term climatic data for Bursa province, the average temperature between 1928-
185 2021 is 14.6°C annually. The average monthly precipitation amount was recorded as 709.5 mm
186 (Anonymous, 2021d). It has been noted that the average temperature tends to increase, especially
187 between 1985 and 2020 (Demir, 2020; Dervişoğlu, 2021). According to the long term average
188 precipitation data in the same period, it has been noted that the precipitation varies between 500-1400
189 mm. This difference shows that Bursa does not have a homogeneous climate structure and the air
190 masses that Bursa is affected by vary according to years (Demir, 2020). Dervişoğlu (2021) reported
191 the average annual precipitation for Ulubat Lake as 707.13 mm and the average annual evaporation
192 as 1149.62 mm for 1985-2020. Accordingly, the evaporation/precipitation ratio is calculated as 1.63.

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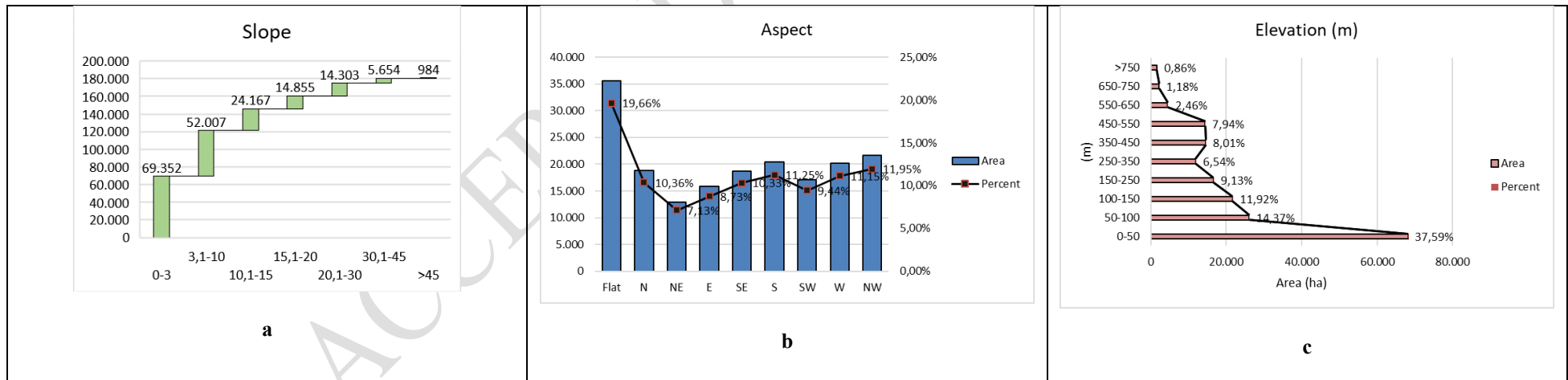


193

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

194

Table 3. Statistical results of topographic maps



195

196 *2.3. Data*

197 As can be seen, Uluabat Lake Ramsar Site, which forms an important ecosystem with the effect of
198 many components it contains and has a great biological diversity, constitutes the main material of the
199 research. Landsat series satellite images were used to determine the change of Uluabat Lake Ramsar
200 site and its surroundings by years with remote sensing techniques. Such temporal changes in lakes
201 can be calculated using Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper
202 Plus (ETM+) and The Operational Land Imager (OLI) images (Ashok et al., 2021; Eid et al., 2020b).
203 The images downloaded for use in the study belong to the years 1985, 2000, 2015 and 2021. Images
204 with less than 10% cloudiness were selected in order to obtain more accurate results. In order to avoid
205 confusion due to the differences arising from seasonal water situation changes, the images of the
206 summer months of July and August were selected. In addition, the data is Level 2 and atmospheric
207 and radiometric calibrations have been made. Therefore, no preprocessing was required in terms of
208 atmospheric and radiometric correction before the analysis. The features of the satellite images used
209 in the study are given in Table 4.

210 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 |

211

212 *2.4. Method*

213 *2.4.1. NDVI*

214 Considering the literature, it is seen that various spectral measurements and indices are used to
215 understand and predict the condition of vegetation both qualitatively and quantitatively (Eid et al.,

216 2020a). Among these, the most widely applied index in environmental and climate change research
217 is NDVI (Normalized Difference Vegetation Index) (Eid et al., 2020b).

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

222
223 Calculation formula of NDVI (Rouse et al., 1973; Tucker and Seller, 1986) (eq.(1)).
224

$$225 \quad \text{NDVI} = (\text{NIR}-\text{Red}) / (\text{NIR}+\text{Red}) \quad (1)$$

226
227 Water and wet surfaces show strong absorption in the near infrared (NIR) spectrum (Ludwig et al.,
228 2019). NIR and Red represent spectral reflectance values obtained in the near-infrared and red part
229 of the electromagnetic spectrum, respectively. NDVI values range from -1 to +1. NDVI values from
230 -1 to 0 indicate no vegetation, while values close to +1 indicate the highest green vegetation density
231 (Ekumah et al., 2020).

232 233 2.4.2. NDWI

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

238
239 Calculation formula of NDWI (McFeeters, 1996): (eq.(2)).

$$240
241 \quad \text{NDWI} = (\text{Green}-\text{NIR}) / (\text{Green}+\text{NIR}) \quad (2)$$

242

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

246 247 2.4.3. *mNDWI*

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

254
255 Calculation formula of mNDWI (Xu, 2006; Szabó et al., 2016): (eq.(3)).

$$256$$
$$257 \mathbf{mNDWI = (Green-SWIR) / (Green+SWIR)} \quad \mathbf{(3)}$$
$$258$$

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

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

264 265 2.5. *NDVI, NDWI and mNDWI Analyses Criterias*

266

267 NDVI defines values from -1.0 to 1.0, where negative values are mainly formed from clouds, water
268 and snow, and values close to zero are primarily formed from rocks and bare soil. Very small values
269 (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand or snow. Moderate values
270 (from 0.2 to 0.3) represent shrubs and meadows, while large values (from 0.6 to 0.8) indicate

271 temperate and tropical forests (Anonymous, 2022e). Based on this, the class ranges determined for
272 the study are shown in Table 5. Values below 0 for NDWI and mNDWI indicate areas without water,
273 values above 0 indicate areas with water.

274 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 |

279 2.6. Testing NDVI, NDWI and mNDWI

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

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

288 The method used in this study is discussed as follows:

- 289 1. A total of 60 sampling points were selected for the study area. Analyzes were performed using
290 the ArcGIS program.
- 291 2. High resolution images were used as reference data to verify and adjust the Random sampling
292 points, and then ground reference points were established.
- 293 3. Ground reference points were added above the dewatering results to verify the accuracy of
294 each random sampling point.
- 295 4. The accuracy of each method was evaluated by applying four evaluation indices. For this
296 purpose, the confusion matrix was created (Table 6). By comparing the extracted water and

297 non-water points with the reference data, four types of pixels were obtained (Acharya et al.,
 298 2018):

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

303 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 |

304
 305 Based on four pixels, Producer's accuracy, User's accuracy, the overall accuracy (OA), and kappa
 306 coefficient (kappa) were used to assess the accuracy of the produced maps (Jiang et al., 2021;
 307 Lombana and Martinez-Grana, 2022). These are:

308
 309
$$\text{Producer's accuracy} = \frac{TP}{TP+FN} \quad (4)$$

310
 311
$$\text{User's accuracy} = \frac{TP}{TP+FP} \quad (5)$$

312
 313
$$\text{Overall accuracy} = \frac{TP+TN}{T} \quad (6)$$

314
 315
$$\text{Kappa coefficient} = \frac{T(TP+TN) - ((TP+FP)(TP+FN) + (FN+TN)(FP+TN))}{T^2 - ((TP+FP)(TP+FN) + (FN+TN)(FP+TN))} \quad (7)$$

316
 317
 318 **3. FINDINGS**

319
 320 *3.1. Determining the NDVI, NDWI and mNDWI results and examining the change over the years*

321
 322 At this stage of the study, NDVI, NDWI and mNDWI calculations were made using satellite images
 323 for the years 1985, 2000, 2015 and 2021, respectively. As a result of the calculations, the change of
 324 vegetation and water areas for the study area by years was mapped. All index results show that the
 325 water body in Lake Uluabat has gradually decreased from 1985 until 2021 (Figure 3).

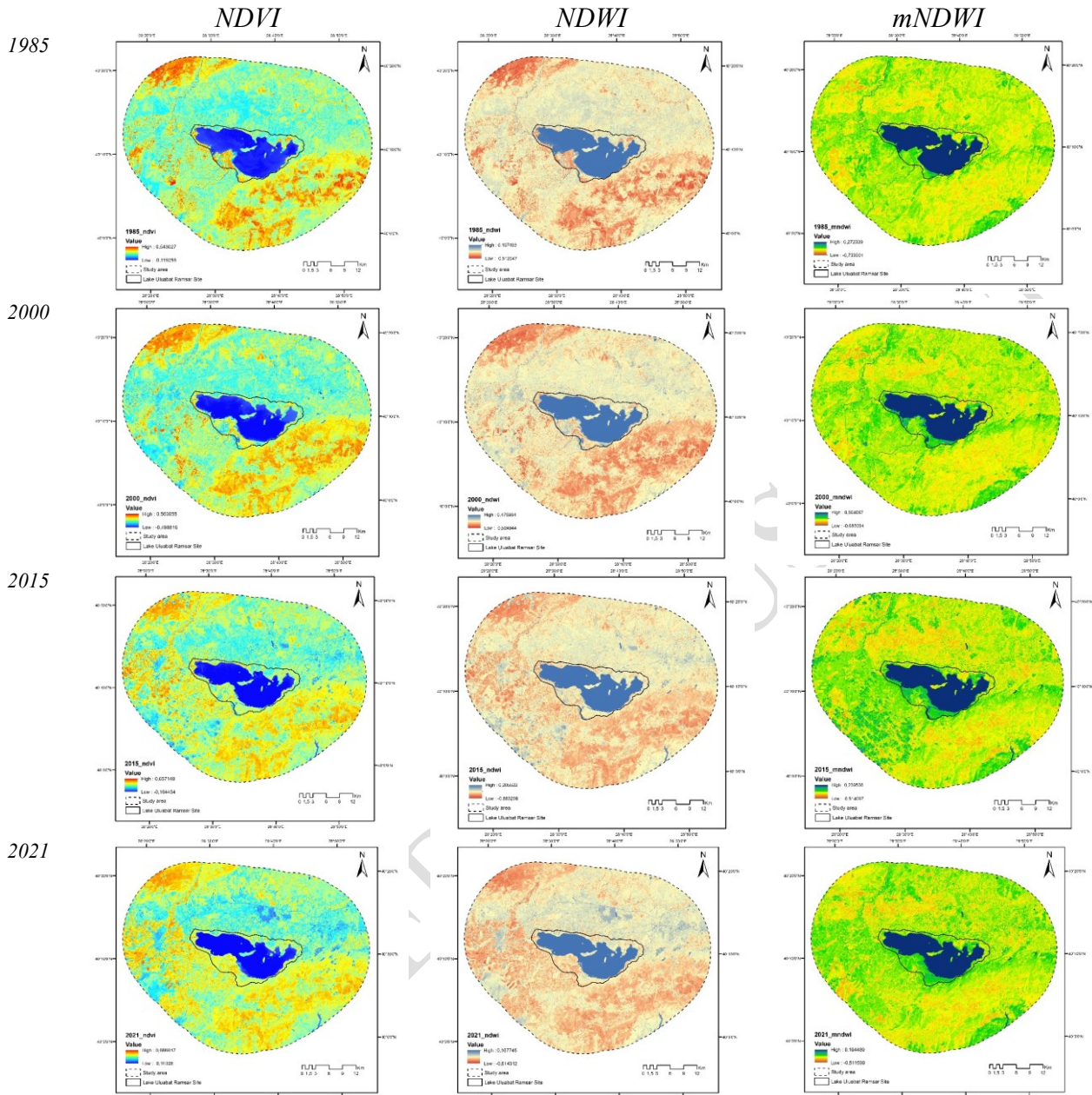


Figure 3. Changes of NDVI, NDWI and mNDWI over the years

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

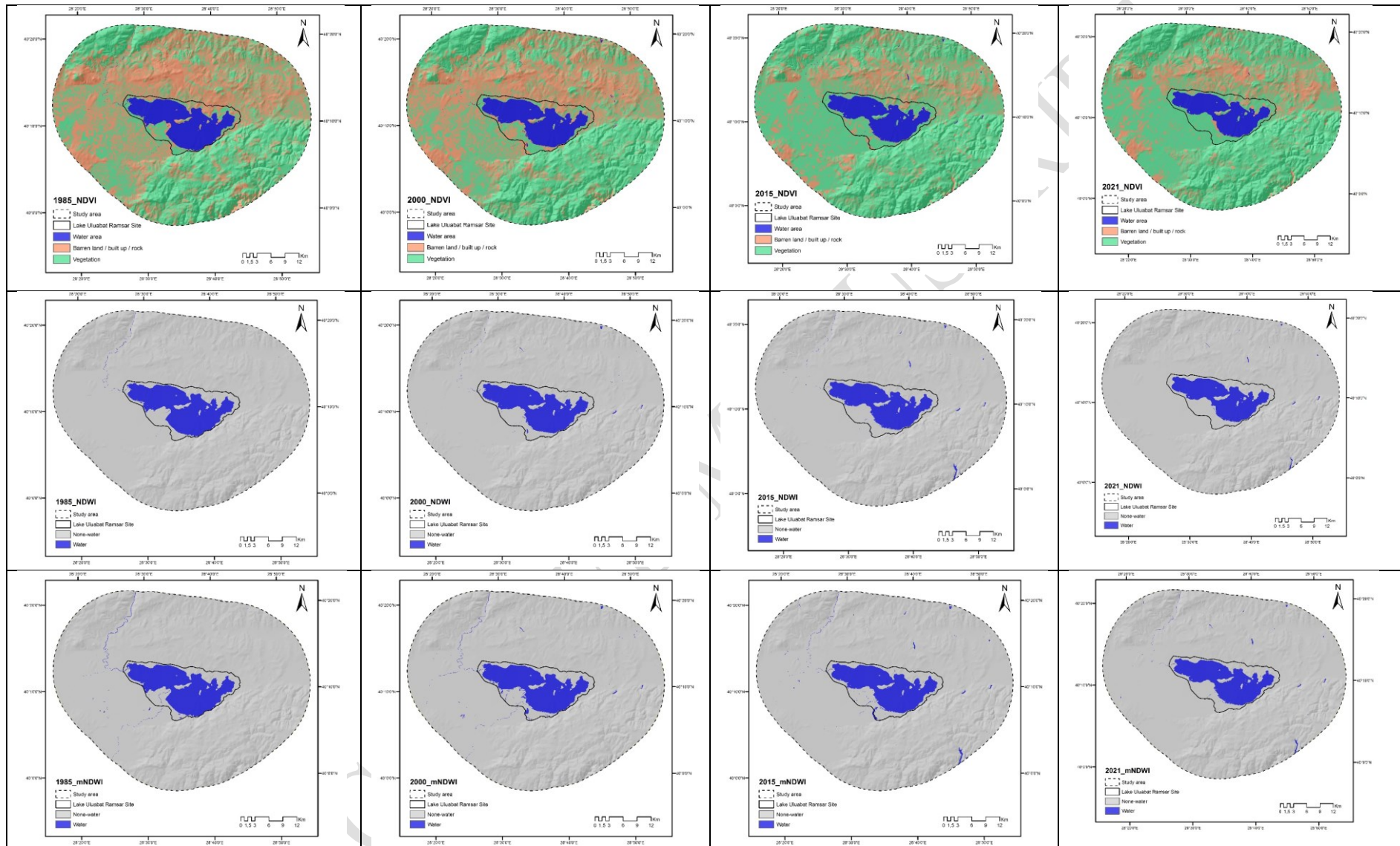
In order to better interpret the results obtained from the NDVI, NDWI and mNDWI index calculations, the images were reclassified according to the criteria and value ranges previously determined in the method (Figure 4). Then, the changes over the years were compared in terms of area and percentage (Table 7). NDVI results show that between 1985 and 2021, water areas decreased

337 by 15.85%, with a loss of 1.953 ha. On the other hand, it is seen that the areas classified as barren
 338 land/built up/rock decreased by 48.93%. It can be said that comprehensive handling of the
 339 classification both as a type of land use and a range of values is effective in the emergence of this
 340 situation. Considering the change in vegetation areas, it is seen that it increased by 42.53%. Pettorelli
 341 (2013) stated that NDVI values ranging from 0.2 to 0.5 represent shrubs, grasslands or aging plants
 342 (Ashok et al., 2021). Accordingly, the NDVI results in our study were close to each other for all the
 343 years examined, but the highest was measured as 0.666617, suggests that the growth of vegetation
 344 and the increase in leaf widths reveal the index values of Uluabat Lake and its surroundings, rather
 345 than the presence of dense and/or very dense vegetation in the area (Figure 4, Table 7). When the
 346 NDWI results are considered, it is seen that the water areas have decreased by 12.84% by losing 1.632
 347 ha, while the none-water areas have increased by 0.97%. When the mNDWI results are taken into
 348 consideration, it is seen that the water areas decreased by 13.06% by losing 1,734 ha, while the none-
 349 water areas increased by 1.03%.

350 When the changes in 1985, 2000, 2015 and 2021 are examined in detail, respectively, it is a
 351 remarkable result that all index results show the decrease in water areas. MNDWI considers the
 352 maximum area as the water area according to the other two indexes each year. It is seen that NDVI
 353 and NDWI show close values for water areas. However, the greatest change in water areas between
 354 1985-2021 was measured by the NDVI index (Figure 5). The results in which the change in the
 355 boundaries of the Lake Uluabat are handled in more detail can be seen in Figure 6.

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

| | | 1985 | 1985-2000 | 2000 | 2000-2015 | 2015 | 2015-2021 | 2021 | 1985-2021 |
|--------------|-------------------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|-----------|-----------------------|
| <i>NDVI</i> | Type | Area (ha) | Percentage change (%) | Area (ha) | Percentage change (%) | Area (ha) | Percentage change (%) | Area (ha) | Percentage change (%) |
| | 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% |
| <i>NDWI</i> | 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% |
| <i>mNDWI</i> | 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% |



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

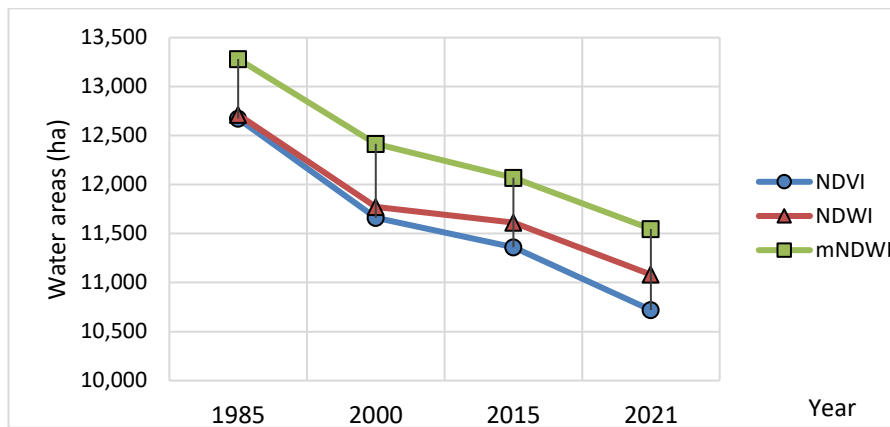


Figure 5. Changes of different indexes for the Uluabat Lake Ramsar Site and its surroundings's water areas during the period between 1985 and 2021.

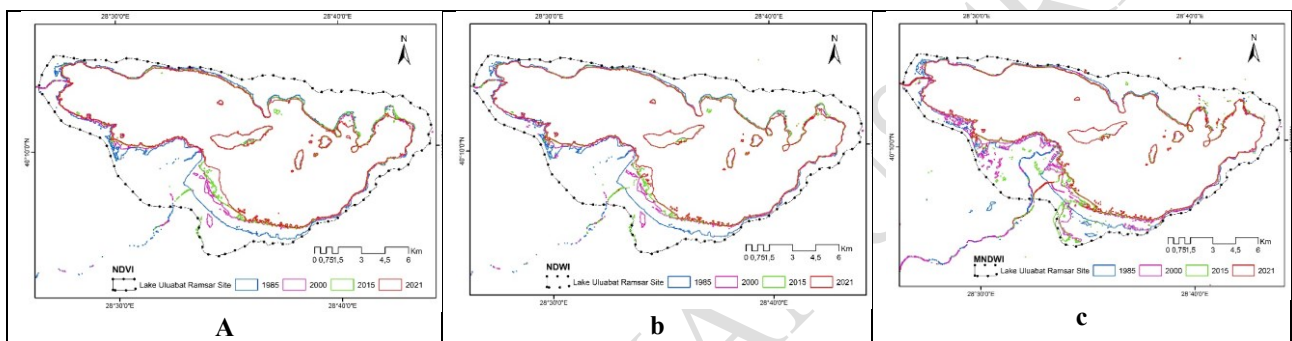


Figure 6. Change in the water surface area over the years (a: NDVI, b:NDWI, c:mNDWI)

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.

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.

380 Table 8. Maximum, minimum, mean and standard deviation (σ) values for NDVI, NDWI and
 381 mNDWI indexes considered in the study
 382

| | | 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 |

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

390 Table 9. Producer's Accuracy, User's Accuracy, Overall Accuracy and Kappa coefficient results for
 391 the NDVI, NDWI and mNDWI indexes considered in the study
 392

| | | 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

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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).

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Table 10. Correlation between NDVI, NDWI, and mNDWI

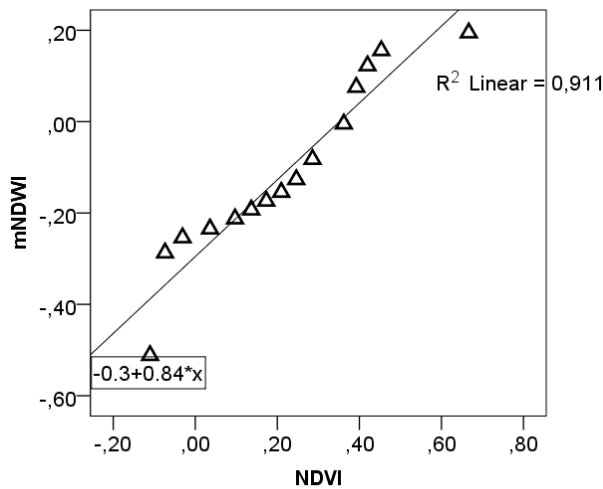
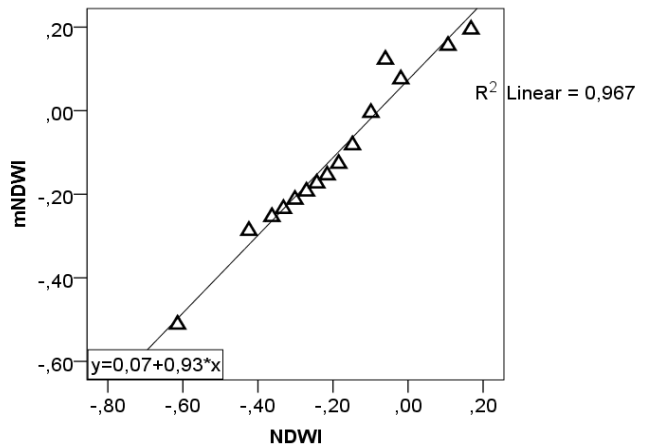
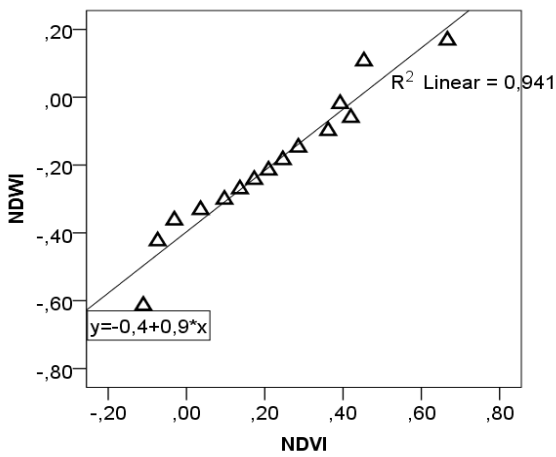
| | | NDVI | NDWI | MNDWI |
|-------|-----------|------|-------|-------|
| NDVI | Pearson r | 1 | ,970* | ,955* |
| | P | | ,000 | ,000 |
| NDWI | Pearson r | | 1 | ,983* |
| | P | | | ,000 |
| MNDWI | Pearson r | | | 1 |

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

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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%.



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

414 **4. DISCUSSION**

415 NDVI, NDWI and mNDWI results showed the wetland loss of Uluabat Lake. In addition to global
 416 climate change, human activities are also effective in the emergence of these results in Uluabat Lake.
 417 As a matter of fact, water is drawn from Uluabat Lake with pumps and used for irrigation. The use of
 418 water for agricultural purposes affects the water level. According to the data of Directorate General
 419 for State Hydraulic Works (DSI) 1st Regional Directorate (2020), the volume of the lake is 840,000
 420 hm³, its irrigation area is 6.344 ha and the amount of water withdrawn from the lake is 19.000
 421 hm³/year (Anonymous, 2020). In addition, the mixing of chemicals such as boron and chromium into
 422 the lake as a result of the activities of settlements, industries, coal and mining facilities in the basin
 423 and the transport of fertilizers and pesticides used in agriculture to the lake with drainage water causes
 424 water pollution in the lake. Wastewater treatment plants are both insufficient and not adequately

425 operated. The erosion problem in the surrounding forests causes the lake to fill up. During the
426 forbidden seasons and excessive amounts of fishing, introducing alien fish species, unplanned use of
427 recreation and tourism areas, superstructure projects such as highway power plant adversely affect
428 the lake life. Numerous studies conducted in the lake basin confirm that water pollution, sediment
429 accumulation, eutrophication, species decline, and heavy metal pollution continue in the lake
430 (Salihoğlu ve Karaer, 2010; Hacısalihoğlu et al., 2016; Hacısalihoğlu ve Karaer, 2020; Dervisoğlu,
431 2021). This increase in pollution in the area and the inability to protect the area effectively despite
432 being declared a Ramsar area threatens the lake and its environment from an ecological point of view.

433 On the other hand, the results of our study support the results of previous studies in terms of the
434 reduction of water areas. Aksoy and Ozsoy (2002) examined the change of Lake Uluabat Ramsar Site
435 and its surroundings between 1984-1998 and calculated that the lake area decreased by 12%. Saçın
436 (2010) found that Lake Uluabat shrank by 8.5% between 2000 and 2005. The researcher determined
437 that the most changes in the shoreline of the lake occurred in the southern parts of the lake. Tağıl
438 (2004) examined the change between 1975 and 2000 and concluded that the water surface has
439 decreased, the area covered by the reeds and open soil surfaces has increased, the presence of a rapid
440 landfall process in the lake has been detected, and the landfall threatens especially the south of the
441 region. This change in the southern parts is in line with the results of our study in which the change
442 was observed between the years 1985-2021 (Figure 6). These results reveal that the lake is being lost
443 year by year. Accordingly, water withdrawal from the lake, precipitation and evaporation status,
444 sediment accumulation, and alluvial accumulation can be listed among the causes of water loss
445 observed in the lake.

446 Within the scope of the method used in the study, the studies in the literature showed results specific
447 to each study area. Studies have confirmed that not all indexes show the same accuracy for every
448 field. Among the indexes used, mNDWI provided results with higher accuracy in some studies (Szabo
449 et al., 2016; Lombana and Martinez-Grana, 2022), while it showed lower accuracy in some studies

450 (Rokni et al., 2014; Acharya et al., 2018). In this study, in line with the method followed, the results
451 of the index were compared and statistical analyzes were carried out.

452 **5. CONCLUSION AND RECOMMENDATIONS**

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

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

469 General recommendations regarding the study can be listed as follows: 1) Our study was carried out
470 with images between the years 1985-2021. If images from previous years could be included, the scope
471 of the study could be expanded. 2) Wetlands are fed by seasonal precipitation and flood waters, so
472 the body of water in these areas looks different every year and at different seasons of the year.
473 Therefore, it will be important to monitor changes for different seasons as well. 3) Making future
474 predictions and creating scenarios for wetlands using computer technologies can lead to important

475 results for the future of wetlands. 4) In our study, mNDWI was found to be successful with higher
476 accuracy in wetland mapping. Therefore, mNDWI can be used as a reliable wetland determination
477 method in this region.

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482 Directorate of Nature Conservation And National Parks for providing open source for wetlands of
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