

Article

Investigation of Long and Short-Term Water Surface Area Changes in Coastal Ramsar Sites in Turkey with Google Earth Engine

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Abstract: Deltas and lagoons, which contain many flora and fauna, have rich coastal ecological and biological environments, and are wetlands of vital importance for humans. In this study, the current problems in all coastal Ramsar sites in Turkey are summarized, and changes in water surface areas are investigated using Landsat and Sentinel 1/2 satellite images on the Google Earth Engine (GEE) cloud computing platform. Landsat TM and OLI images were used in the long-term analysis, and time series were created by taking annual and July to September averages between 1985 and 2020. In the short-term analysis, monthly averages were determined using Sentinel 2 images between 2016 and 2020. Sentinel-1 Synthetic Aperture Radar (SAR) images were used in the months when optical data were not suitable for use in monthly analysis. The Normalized Difference Water Index (NDWI) was used to extract water surface areas from the optical images. Afterwards, a thresholding process was used for both optical and radar images to determine the changes. The changes were analyzed together with the meteorological data and the information obtained from the management plans and related studies in the literature. Changes in the water surface areas of all coastal Ramsar sites in Turkey were determined from 1985 to 2020 at different rates. There was a decreasing trend in the Goksu and Kızılırmak Deltas, which also have inland wetlands. The decreasing rates from 1985 to 2020 were -24.52% and -2.86% , for annual average water surfaces for the Goksu and Kızılırmak Deltas, respectively, and -21.64% and -6.34% for the dry season averages, respectively. However, Akyatan Lagoon, which also has inland wetlands, showed an increasing trend. Observing the annual average surface area from 1985 to 2020, an increase of 438 ha was seen, corresponding to 7.65%. Every year, there was an increasing trend in the Gediz Delta and Yumurtalık Lagoons, that do not have inland wetlands. The increasing rates from 1985 to 2020 were 46.01% and 17.31% for the annual average surface area, for the Gediz Delta and Yumurtalık Lagoons, respectively, and 38.34% and 21.04% for the dry season average, respectively. The obtained results reveal the importance of using remote sensing methods in formulating strategies for the sustainable management of wetlands.



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1. Introduction

Wetlands are assets that need to be well-defined and managed in terms of conservation–utilization balance, considering their ecological functions and values, as well as their economic value. Globally, wetlands cover approximately 12.8 million km² (8.5%) of the Earth's land area. However, over half of the world's wetlands have been degraded or destroyed in the past century, irreversibly losing their economic and ecological functions [1]. The main reasons for the deterioration and loss of wetlands are: the creation of land due to the increasing need for agricultural land in parallel with the increasing population; meeting the water needs from wetlands; excessive use of groundwater; dams built on the rivers which feed wetlands; weirs; diverting water to different places through canals; air and water

pollution, etc. The Ramsar Convention is the first modern intergovernmental agreement created to raise awareness about the intended use and conservation of natural resources, especially wetlands. The parties of the convention (171 countries) nominate wetlands as internationally essential, and have committed to preserving the ecological character of more than 2300 wetlands of international importance, covering nearly 250 million hectares, which include 13–18% of global wetlands [2]. Turkey became party to the Ramsar Convention in 1994, and 14 wetlands (9 inland and 5 coastal/marine) that provided Ramsar criteria have been recognized as Ramsar Sites. Each Ramsar site meets at least one of the nine criteria [3] related to wetland types, ecological communities, water birds, fish, and other taxa, that signify international importance. In the previous study [4], all inland Ramsar sites in Turkey were examined from 1985 to 2020, and changes in water surface areas were evaluated on the Google Earth Engine (GEE) cloud computing platform, using Landsat satellite images and the Normalized Difference Water Index (NDWI). Data acquired from the closest meteorological stations to each Ramsar Site were evaluated, and in addition to the meteorological effects, the other factors that may have been causing changes in these areas were also investigated. The coastal/marine Ramsar sites, for which temporal change analyses were made in this study, include the Goksu Delta and the Akyatan and Yumurtalık Lagoons, which are located on the Mediterranean coast, the Gediz Delta, located on the Aegean Sea coast, and the Kızılırmak Delta, located on the Black Sea coast of Turkey (Figure 1). The coastal Ramsar Sites are listed in Table 1 with the site numbers, protection areas, wetland types, coordinates, designation dates, and the criteria which they meet.

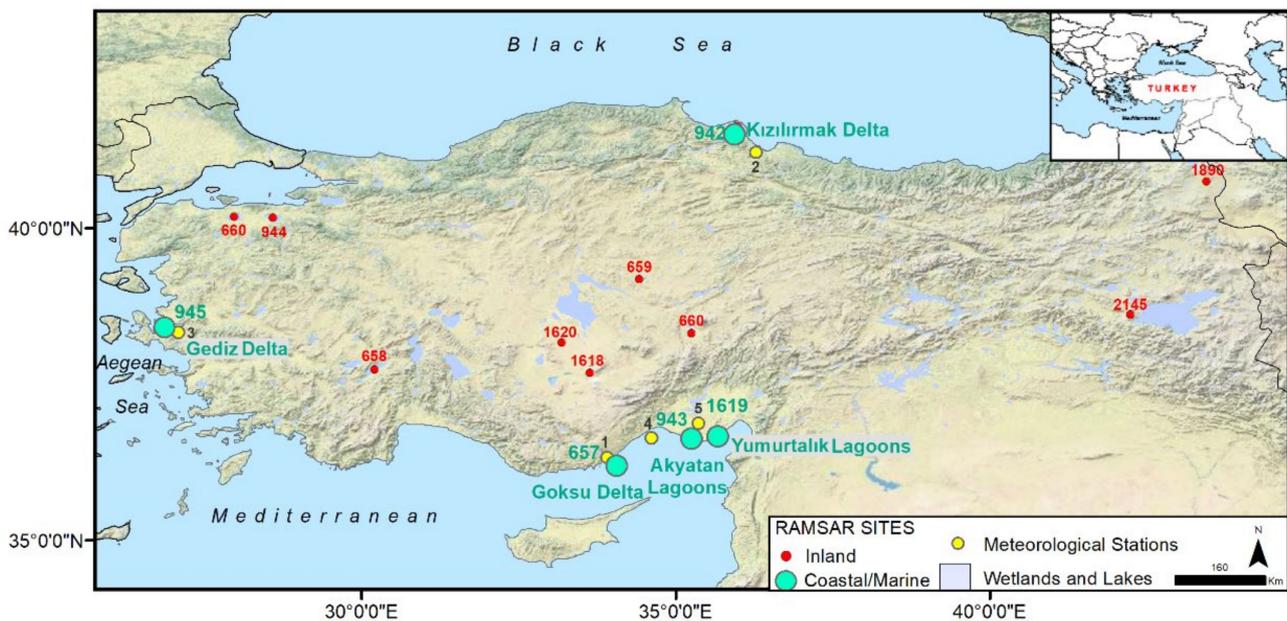


Figure 1. Turkey's Ramsar sites and nearby meteorological stations (for coastal/marine sites).

Table 1. Coastal Ramsar sites of Turkey.

Ramsar Site	Ramsar (Site Number)	Wetland Type *	Ramsar Criteria	Coordinates	Protection Area (ha)	Designation Date
Goksu Delta	657	I + M/C	2,3,4	36°17' N 33°59' E	15,000	13 July 1994
Kızılırmak Delta	942	I + M/C	1,2,3,5,6,7,8	41°38' N 35°59' E	21,700	15 April 1998
Akyatan Lagoon	943	M/C	1,2,3,4,5,6,8	36°37' N 35°15' E	14,700	15 April 1998
Gediz Delta	945	I + M/C	2,3,4,5	38°31' N 26°53' E	14,900	15 April 1998
Yumurtalık Lagoons	1619	M/C	1,2,3,4,5,6,8	36°42' N 35°38' E	19,853	21 July 2005

* I = Inland, M/C = Marine and Coastal.

Deltas and lagoons are ecosystems that protect and improve water quality, produce oxygen, control erosion, dissolve organic materials in water, protect coasts against storms, prevent saltwater from mixing with groundwater, limit the surrounding microclimate area, and treat toxic wastes. Additionally, they provide natural and cultural richness as well as a source of livelihood to the people who live in the surrounding region, and they are often used for recreational activities. Deltas stand out as fertile agricultural areas, while lagoons are habitats for several vital, cultural, and economic uses, from drinking water to fishing, and recreational activities such as swimming, surfing, and skiing [5]. Since coastal wetlands (deltas and lagoons) contain a large number of flora and fauna, and have rich coastal ecological and biological environments, they are of great importance for all living bodies. Therefore, they should be protected and the changes that may occur around them should be continuously monitored. Today, satellite technologies such as Remote Sensing (RS) can be used as an important tool for this purpose. In Turkey, there are various studies on the monitoring of these areas cited in literature. The only study that included all five coastal Ramsar sites was conducted in 2011, using a total of 15 Landsat images, and coastline changes in five coastal Ramsar sites were examined [6]. There are studies covering one or two coastal Ramsar sites, mostly using Landsat images, and analyzing temporal changes: Goksu Delta [7–10]; Kızılırmak Delta [11,12]; Akyatan Lagoon [13,14]; Akyatan and Yumurtalık Lagoons [15,16]; and the Gediz Delta [17–21].

As can be seen, the temporal change studies in Turkey's coastal/marine Ramsar sites are limited to single areas, or the number of images used. This is the first study that covers all coastal Ramsar sites of the country, summarizes their problems, and determines their long- and short-term water surface changes using a large number of images in a cloud computing platform such as Google Earth Engine™ (GEE). GEE provides the infrastructure to rapidly access and process large amounts of Earth Observation data in a systematic and reproducible manner. GEE has a high-throughput (petabyte), analysis-ready data cloud co-located with high-performance parallel computing. The data catalog includes data from various air and satellite-based sensing systems at different wavelengths, both optical and non-optical, environmental variables, weather and climate forecasts, land cover, topographic and socio-economic datasets [22]. From the GEE cloud platform, there are studies in which water surface areas have been extracted from regional to global scale [23–26]. In this study, the annual changes in the coastal Ramsar areas of Turkey in the 1985–2020 (long-term) period and the monthly changes in the 2016–2020 (short-term) period were determined by processing 6672 images on the GEE platform. Since the archive data access date of the Sentinel 2 data used in the short-term analysis is 2016, the start date was taken as 2016, unlike the one considered in the long-term analysis. Changes were analyzed together with meteorological data, various features of the areas, and the factors threatening the area were summarized from the management plans and the related literature review.

2. Materials and Methods

2.1. Materials

In the long-term assessment of Ramsar sites, Landsat 5 TM and 8 OLI satellite images were used, and the water surface areas between 1985 and 2020 were determined separately for the 12-month average and the 1 July–30 September average of each year. Since there were few/no cloudless images for all months in some sites, the averages of July, August and September were also used to determine the trends in the water area change, as well as the 12-month average. These months were preferred, as they were the months with the least amount of precipitation and more cloudless images. Landsat 7 images had data gaps due to a Scan Line Corrector (SLC) error; therefore, the analyzes of the 2012 data set could not be performed.

Sentinel-2 MSI satellite images were used in the short-term evaluation of the Ramsar sites, and water surface areas were determined for each month of the five-year period (2016–2020). Due to the cloudy weather conditions, each month of the year could not be analyzed with Sentinel-2 optic images. Therefore, the water surface areas of the months

without a clear cloudless image were determined by Sentinel-1 SAR images, with ascending tracking mode and VV polarization, utilized to separate water and non-water areas [27]. With the averages of the five years, monthly water surface area graphs were created. The characteristics and number of images of the Landsat and Sentinel 1–2 satellites used are given in Table 2 [28–30].

Table 2. Detailed information of optic and SAR satellite images used.

Satellite	Spectral Resolution (µm)	Spatial Resolution (m)	Radiometric Resolution (Bit)	Temporal Resolution (Day)	Number of Images Used
Landsat 5 TM (1985–2011)	7 Bands (0.45–2.35)	B1,B2,B3,B4,B5,B5, B7: 30 m; B6:120 m;	8	16	2610
Landsat 8 OLI (2013–2020)	9 Bands (0.43–2.51)	B1,B2,B3,B4,B5,B6,B7,B9:30 m; m B8:15 m B10,B11: 30 m; B2, B3,B4,B8:10 m;	16	16	1001
Sentinel-2 MSI (2016–2020)	13 Band	B5, B6,B7,B8A,B11,B12: 20 m; B1,B9,B10: 60 m;	12	5	2369
Sentinel-1 (2016–2020)	C band 5250–5570 MHz	5 m × 20 m (azimuth × range) VV-VH polarizations	10	6	692

Precipitation, evaporation, and air temperature data of the meteorological stations nearby the Coastal Ramsar Sites (Figure 1), between 1985 and 2020, were obtained from the General Directorate of Meteorology. The graphs created using the annual total precipitation, evaporation and average air temperature data of these stations are given next to the long-term water surface area graphs in the results section. Again, monthly average precipitation and evaporation data are given together with the monthly water surface area graphs created for the years 2016–2020.

2.2. Methods

All processing steps carried out in this study, including optical and SAR processing, are given in the flowchart in Figure 2.

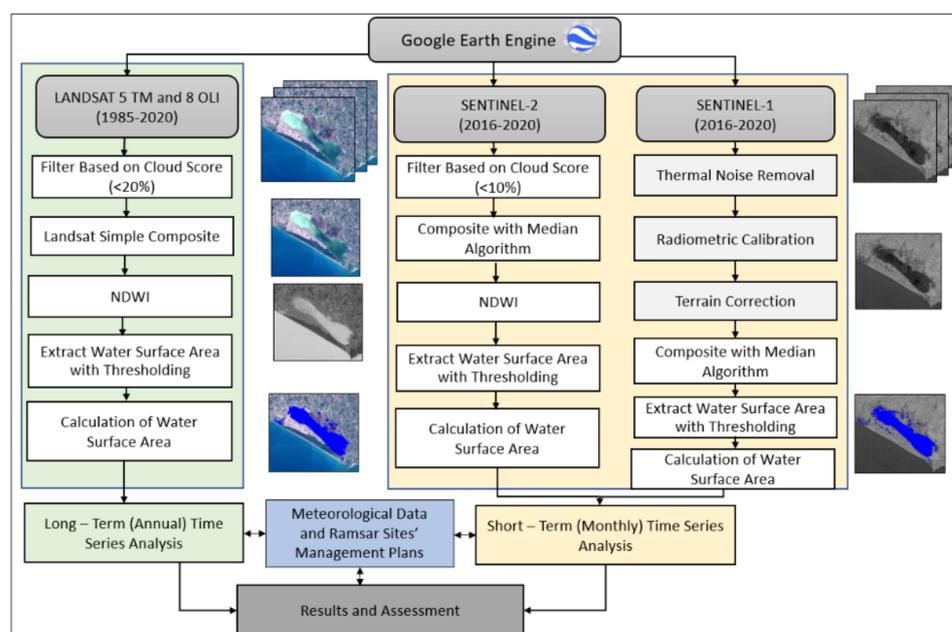


Figure 2. Flowchart of the study of long and short-term water surface changes in coastal Ramsar sites in Turkey with Google Earth Engine.

Before the water surface area extraction, optical satellite images were filtered considering cloud coverage of the scene. The cloud filter was applied as 20% for Landsat images with a temporal resolution of 16 days, and 10% for Sentinel-2 with a temporal resolution of 5 days. Composite images were created yearly in the long-term time series analysis between 1985 and 2020, and monthly in the short-term time series analysis between 2016 and 2020. In the long-term analysis, Landsat satellite images were merged using the Landsat simple composite algorithm. This algorithm designates a cloud score for each pixel, and calculates pixel values by the pixels with the lowest cloud score at each point. However, there is no composite algorithm for the Sentinel images, so the median algorithm was used for the monthly time series analysis. Water extraction methods were applied to the composite images.

Many indices have been developed to take advantage of the unique spectral signature of water compared with other land cover types, with the most used index being NDWI. Many studies comparing other indices show that the NDWI gives better results [31–33]. In addition, it was seen that the best index was NDWI using green and NIR bands in the studies conducted on field studies in wetlands. Therefore, NDWI was used to extract water surface areas in this study. Initially, NDWI was introduced in 1996 to delineate open water features using the green and near-infrared (NIR) bands of Landsat TM [34]. Water features generally have low reflectance in both the visible red and NIR spectrum. In contrast, water has a higher reflectance in the green spectrum (compared with red), resulting in a lower correlation with the NIR band. The results of the index can range from -1 to $+1$ (since it is normalized). As indicated in [34], zero threshold has been proposed for extracting surface water, i.e., all positive NDWI values are classified as water, and negative values are classified as vegetated surfaces and soil areas. The NDWI is expressed as [34]:

$$\text{NDWI} = (\text{Band}_{\text{Green}} - \text{Band}_{\text{NIR}}) / (\text{Band}_{\text{Green}} + \text{Band}_{\text{NIR}}) \quad (1)$$

In this study, the NDWI calculation was performed using the Top of Atmosphere (TOA) values. As spectral bands, band 2 and band 4 for Landsat TM; band 3 and band 5 for Landsat OLI; and band 3 and band 8 for Sentinel 2, were used in the NDWI calculation.

Water surface areas were obtained using SAR images for the months when optical images were not available due to cloud. Sentinel-1 SAR images are served to users in GEE as radiometrically and geometrically corrected. The main preprocessing steps include thermal noise removal, radiometric correction, terrain correction and conversion to decibel values. The preprocessed SAR images used in this study were combined monthly with the median algorithm. Then, water surface area extractions were calculated from the composite images using the histogram-based thresholding method, based on the threshold value in dB units from the image histogram. According to the surface roughness, the backscatter values of water bodies are generally lower than on land. However, windy weather conditions can cause water roughness, but the median algorithm eliminates such water pixels in the monthly data. In other words, values below the threshold value determined from the histogram of the monthly composite SAR image data will show water pixels. Then, the areal extent of the extracted water pixels was calculated.

3. Results and Discussion

The current problems and threats at each coastal Ramsar site were initially summarized. Afterwards, the water surface area changes in the sites were examined annually for a period of 35 years for the long-term analysis, and monthly, taking the averages of the most recent five years, for the short-term analysis.

For long-term analysis, annual water surface areas at each Ramsar site from 1985 to 2020 were determined by NDWI using Landsat images for all months, and the dry season (1 July to 30 October), with the highest cloud-free imagery. The location of each Ramsar site is given by a thematic map (Esri World Imagery is used for a base map) and the water surface areas of 1985 and 2020 are shown on the map. A view of the sites is given in Figures 3, 4, 5, 6 and 7b. The annual water surface areas for the all-months average and

dry season average between 1985 and 2020, and the corresponding meteorological data representing the same terms, are given in Figures 3, 4, 5, 6 and 7c,d.

For short-term analysis, monthly water surface areas at each Ramsar site were determined by applying NDWI to Sentinel 2 optical images between 2016 and 2020, and water surface areas of those that were not eligible were determined with Sentinel 1 SAR images. Average monthly water surface areas were determined by taking the averages of each month for five years. Again, monthly averages of precipitation and evaporation data were calculated between 2016 and 2020, together with the monthly water surface areas as given in Figures 3d, 4, 5, 6 and 7e. The water surface area changes in the five coastal Ramsar sites were evaluated together with meteorological data, management plans, and related publications, and the analyses are given below.

The Goksu Delta is an alluvial delta with intense agricultural activity, and ecological and economic significance. It has a particular reputation for being one of the few remaining areas in the world where sea turtles lay their eggs. In this area, there are significant and intense agricultural activities each month of the year, due to the typical Mediterranean climate of hot and dry summers, and cool and rainy winters [35]. This area is also located on one of the world's important bird migration routes, and especially in cold winter conditions, when the lakes in Central Anatolia freeze, it provides shelter for bird communities of huge numbers [35]. Several small lakes in the delta, usually less than 1 m deep, with limited areas having about 2 m depth, have abundant aquatic vegetation [9]. The factors threatening the Goksu Delta are briefly summarized below [35,36]. Agricultural activities constitute the most important land use in the Goksu Delta, and are the source of income for more than 80% of those living on the delta. As a result of an unconscious, uncontrolled, and intensive use of pesticides and fertilizers, chemical pollution problems have arisen in the area. Untreated domestic and urban industrial sewage carried by the Goksu river threatens the natural life in the wetland. In the past, the streams' directions were changed to gain agricultural land, which caused coastal erosion. There are 328 species of approximately 450 bird species found in the Goksu Delta. Although it is prohibited, hunting causes significant damage to the bird's habitat [35,37,38].

Goksu Delta is given in Figure 3a with coordinates, and the average water surface areas of 1985 and 2020 are shown on the map. A view from the Goksu Delta is given in Figure 3b. The water surface areas of the Goksu Delta, obtained from both the annual average and dry season averages between 1985 and 2020, and the annual total precipitation, total evaporation, and average air temperature data corresponding to the same period, are given in Figure 3c,d. Moreover, the monthly water surface-area change analysis, five-year monthly average water surface areas, precipitation and evaporation data are given in Figure 3e.



(a)



(b)

Figure 3. Cont.

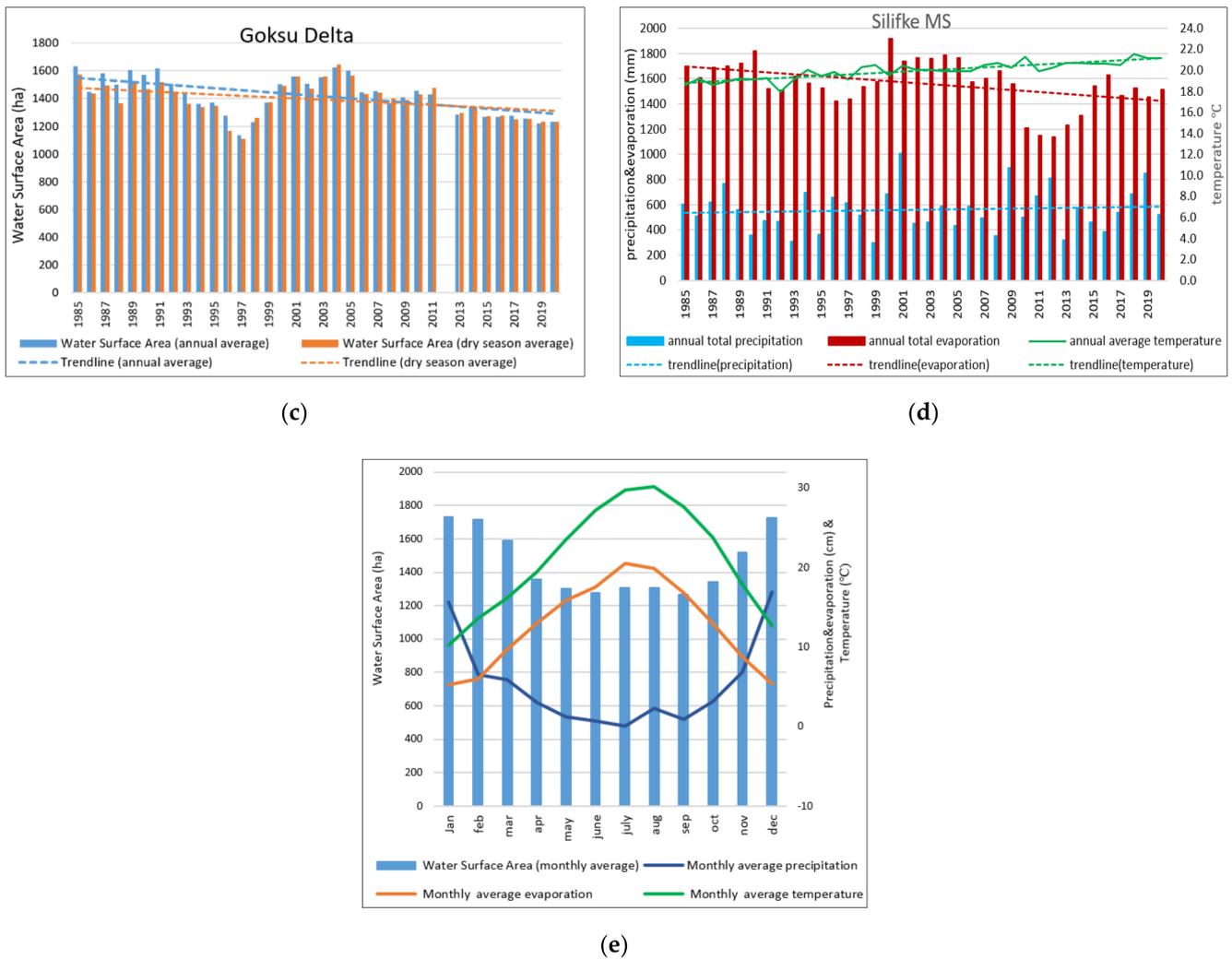


Figure 3. Goksu Delta: (a) Location and 1985 and 2020 Annual Average Water Surface Areas (NDWI > 0); (b) View of the Goksu Delta [39]; (c) 1985–2020 period, Water Surface Areas (Annual Averages and Dry Season Averages); (d) Silifke Meteorological Station Data (Annual Total Precipitation, Total Evaporation, and Average Air Temperature); (e) 2016–2020, Monthly Average Water Surface Areas, Precipitation, Evaporation and Temperature.

When the graph showing the annual water surface areas in Figure 3c was examined, it was seen that there was a decrease both in the annual average and dry season averages. Although there were decreases and increases in some years, the general trend was in a decreasing direction. As expected, the average precipitation during the dry season (1 July–30 September) was much lower than the average for other wet seasons, and therefore lower than the overall annual average (Figure 3c). When the meteorological data was examined (Figure 3d), it was seen that there was no noticeable change in the annual average precipitation trend, but there was a decrease in evaporation, and an increase in air temperature over time. When the average data of 35 years was examined, it was observed that precipitation was 617.93 mm, and evaporation was 1253.54 mm; evaporation was approximately 2.02 times more than precipitation. The decrease in the water surface area in the area is related to the fact that the area includes the inland wetland areas, although the precipitation is in a slightly increasing trend and evaporation performs a decreasing trend. When the change in water surface areas of the Goksu Delta was examined monthly (Figure 3e), it was seen that it reaches the largest water surface areas in January, February and December, when there is high precipitation and minimum evaporation. It was observed that the water surface areas decreased due to increased evaporation and decreased

precipitation, starting from March. The lowest precipitation and the highest evaporation were in July.

The Kızılırmak Delta covers almost all the members of the wetland ecosystems: natural or artificial, permanent or temporary, flowing or stagnant, freshwater, brackish or saline, and includes the sea parts where the water level does not exceed 6 m during tidal periods.

It is a large wetland complex containing swamps, peat, and water-covered areas. The primary environments in this complex are forests (flooded and remnant), lakes (seven large lakes), reeds, wet meadows, dunes, and agricultural lands. The delta, which has a wide variety of habitats, is significant in terms of its biodiversity. The existence of habitats with different ecological characteristics has made the delta rich in terms of plant diversity [36,40]. The ecological risk zone of the Kızılırmak Delta was assessed with effective parameters, and the delta zone close to the water bodies was especially detected as a susceptible and risky site [41]. The factors that threaten the Goksu Delta are also valid for the Kızılırmak Delta: pollution of water by agricultural activities; wastewater discharged into rivers without treatment; improper irrigation and drainage; illegal construction in the area, and hunting.

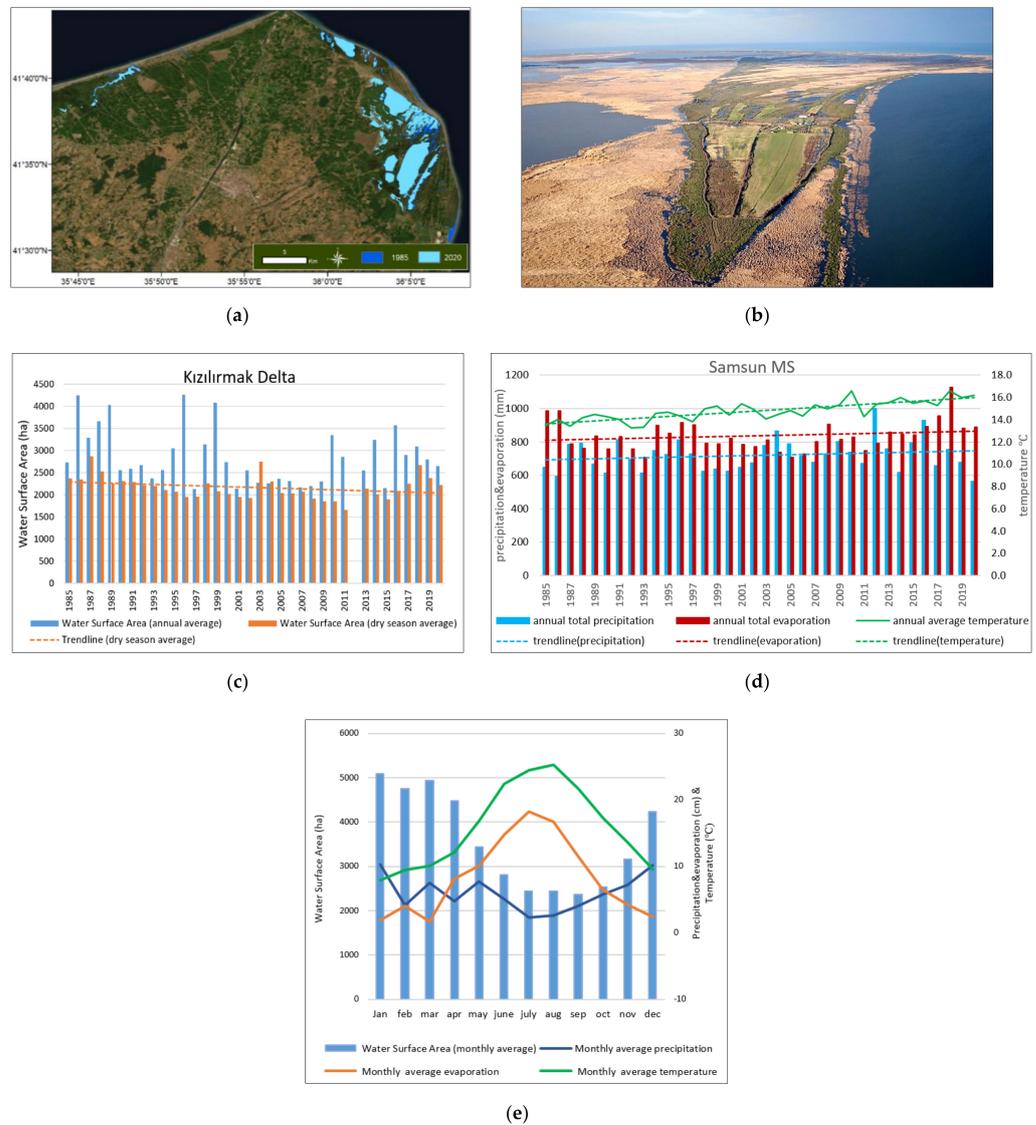


Figure 4. Kızılırmak Delta: (a) Location and 1985 and 2020 Annual Average Water Surface Areas (NDWI > 0); (b) View of Kızılırmak Delta [42]; (c) 1985–2020 Period, Water Surface Areas (Annual Averages and Dry Season Averages); (d) Samsun Meteorological Station Data (Annual Total Precipitation, Total Evaporation, and Average Air Temperature); (e) 2016–2020, Monthly Average Water Surface Areas, Precipitation, Evaporation and Temperature.

Kızılırmak Delta is given in Figure 4a with coordinates, and the average water surface areas of 1985 and 2020 are shown on the map. A view from delta is given in Figure 4b. The water surface areas of the Kızılırmak Delta, obtained from both the annual average and dry season averages between 1985 and 2020, and the annual total precipitation, total evaporation, and average air temperature data corresponding to the same period are given in Figure 4c,d. For the monthly water surface-area change analysis, five-year monthly average water surface areas, precipitation and evaporation data are given in Figure 4e.

When the graph showing the annual water surface areas in Figure 4c was examined, sudden changes were seen in the annual values where the averages of all months were taken. The reason for this fact is that the Ramsar site, located in the Black Sea region of the country, is rainy in many months of the year and, as a result, there were no cloudless image for every month. For this reason, when the dry season average values were considered, there was a decreasing trend from 1985 to 2020.

When the meteorological data were examined (Figure 4d), it was seen that there was an increase in all meteorological parameters. The average data of 35 years were examined; the precipitation was 721.40 mm, which is above the Turkey average (646 mm), and the evaporation was 836.91 mm. The evaporation/precipitation rate was 1.2, which is the lowest rate among other station data.

When the monthly changes in the water surface areas of the Kızılırmak Delta were examined, it was seen that the largest water surface area was reached in January, February and March when precipitation was high, and the water surface area decreased as of April (Figure 4e). In July, August and September, when precipitation was the least, the water surface area decreased to its lowest levels. Again, the highest evaporation occurred in July and August.

The Akyatan Lagoon is an important wetland which hosts a wide variety of habitats. As in the Goksu Delta, many water birds come to this area due to the freezing of the wetlands in Central Anatolia during winter. In addition, due to its location on the migration route, it provides feeding and accommodation opportunities for crowded bird groups of different species during migration. Between Lake Akyatan and the sea, there are Turkey's giant dunes with a width of several kilometers and a height of 20 m. These dunes are one of the most important nesting beaches for the green sea turtle (*Chelonia mydas*), endangered worldwide. Living environments with different ecological characteristics, such as open water surfaces, reeds, fresh and salty marshes, freshwater ponds, ponds, broad dune ecosystems, and beaches, provide shelter for vibrant wildlife from different species, especially water birds. The north of the lake is surrounded by large agricultural areas [36,43]. The depth of Akyatan Lagoon is 1 m on average in the season when the water level rises; on the other hand, in the season when the water level drops, it is 0.5 m on average [44]. In a study carried out between December 2007 and August 2008 to determine the salinity and some pollution levels in the Akyatan Lagoon, the lagoon was defined as a hypersaline lagoon, since the salinity and other parameter values were 1.5–2 times higher than seawater [45]. In another study, it was stated that increased evaporation and decreasing precipitation will cause an increase in salinity, which will negatively affect the groundwater quality [46].

The main threats in the area are uncontrolled pesticides and fertilizers carried to the lagoons through drainage channels, causing pollution and making the lagoons eutrophic. When the drainage channels give intense water, the freshwater carried to the lagoon reduces the lagoon's salinity below its average level, and because the water turns into freshwater, the entry of fish into the lake decreases. The natural areas around the dunes and lagoon are destroyed to open up new agricultural areas. Due to the solid wastes coming from the sea, litter accumulates on the beaches and creates pollution [36,43].

The Akyatan Lagoon is given in Figure 5a with coordinates, and the average water surface areas of 1985 and 2020 are given on the map. A view from delta is given in Figure 5b. Water surface areas of the Akyatan Lagoon, obtained both from the annual average and dry season averages between 1985 and 2020, and the annual total precipitation, total

evaporation, and average air temperature data corresponding to the same period, are given in Figure 5c,d. The monthly water surface-area change analysis, five-year monthly average water surface areas, precipitation and evaporation data are given in Figure 5e.

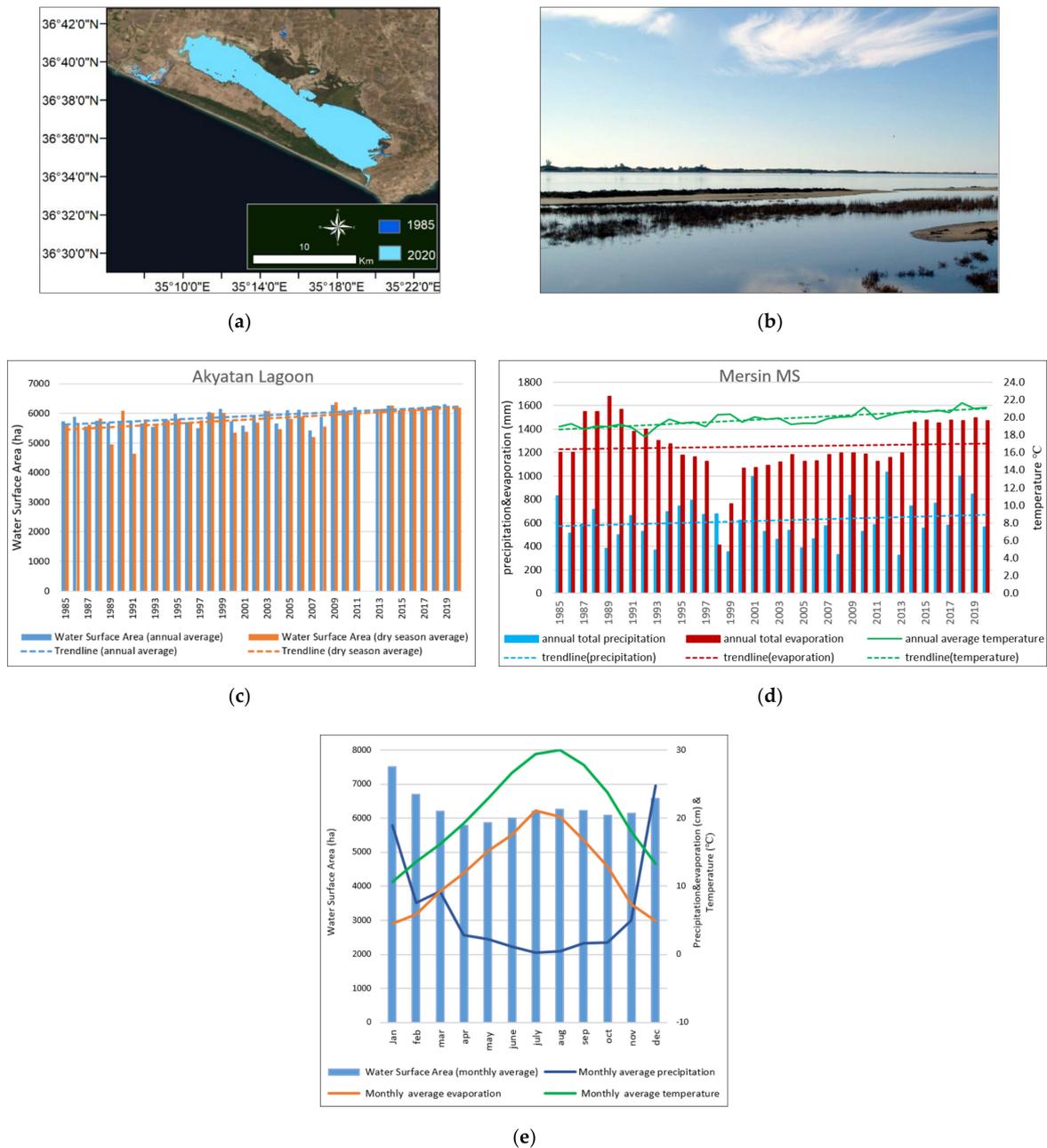


Figure 5. Akyatan Lagoon: (a) Location and 1985 and 2020 Annual Average Water Surface Areas (NDWI > 0); (b) View of Akyatan Lagoon [47]; (c) 1985–2020 Period, Water Surface Areas (Annual Averages and Dry Season Averages); (d) Mersin Meteorological Station Data (Annual Total Precipitation, Total Evaporation, and Average Air Temperature); (e) 2016–2020, Monthly Average Water Surface Areas, Precipitation, Evaporation and Temperature.

When the annual water surface area chart in Figure 5c was analyzed, although there were decreases and increases in some years, the general trend was increasing in the annual average and dry season average. When the meteorological data was examined (Figure 5d), it was seen that there was an increase in all meteorological parameters. When examined, the average data of 35 years showed that the precipitation was 558.26 mm, and the evaporation was 1561.91 mm. The amount of evaporation was 2.7 times the precipitation. When the

water surface areas in the Akyatan Lagoon were examined monthly (Figure 5e), it was seen that the majority of precipitation was in December and January, and the largest water surface areas were detected in these months. The surface area decreased as of February and continued almost similarly. It is known that even if the surface area does not change, the water level drops by half [46]. The months with the least precipitation and the highest evaporation were July and August.

There are four different ecosystems in the Gediz Delta: saltwater ecosystems (salt lands); freshwater ecosystems (reeds); grasslands; and hilly areas. These ecosystems include various habitats such as delta swamps, reeds, creeks, salt flats, freshwater marshes, salt marshes, saline meadows, temporary wet meadows, alluvial islets, agricultural fields, and Mediterranean-type scrubland. It has been determined that the delta hosts a total of 272 bird species, including species that are endangered worldwide, and the bird population varies between 80,000 and 120,000 in the winter period [48]. The Gediz River meets the drinking water needs of both the basin and the Izmir metropolis. Domestic and industrial wastewater are carried to the delta by river, and threaten the ecological life. The Gediz River carries industrial wastewater, and therefore includes a high amount of heavy metals that cause the death of animals [49]. Another study stated that wastewater discharge continued in 2016, as was the case in 2002 [50]. The most critical problems in the Gediz Delta are: water scarcity due to rapid socio-economic development; intensive water demand for agricultural irrigation; and incredibly rapid industrialization in the region. Thus, a high degree of pollution arises from these activities [51]. One of the critical factors threatening the ecological structure is the drought problem experienced in the reeds in freshwater ecosystems in the area, especially in summer. In addition, due to the decrease in water, the settlements turned to groundwater resources to meet their own needs. Excessive water withdrawal from the wells drilled in the plain area causes saline water to intrude on the freshwater areas. Thus, a salinization problem is experienced in drinking water. While salinization causes the deterioration of the ecological structure, it also creates unfavorable environments for agricultural activities [36,51]. Another essential problem in the area is unplanned urbanization. As in other areas, illegal hunting is another problem in the Gediz Delta.

Gediz Delta is given in Figure 6a with coordinates, and the average water surface areas of 1985 and 2020 are given on the map. A view from delta is given in Figure 6b.

The water surface areas of the Gediz Delta, obtained from both the annual average and dry season averages between 1985 and 2020, and the annual total precipitation, total evaporation, and average air temperature data corresponding to the same period are given in Figure 6c,d. In addition, the monthly water surface-area change analysis, five-year monthly average water surface areas, precipitation and evaporation data are presented in Figure 6e.

When the annual water surface area graph in Figure 6c was examined, although there were decreases and increases in some years, the general trend was in the direction of increase. It was realized that the water surface areas of the annual average and dry season were close to each other. When the Izmir Meteorology station data was examined (Figure 6d), it was seen that there was an increase in precipitation, evaporation, and air temperature. The average data of 35 years resulted in precipitation of 695.31 mm, whereas evaporation was 1464.15 mm, indicating that evaporation was about 2.1 times precipitation.

When the water surface areas in the delta were examined on a monthly basis (Figure 6e), it was seen that it had the largest water surface area in July when the precipitation rate was the least and the evaporation was the highest. A high water surface area in June is related to salt production ponds. Çamaltı saltworks, the largest sea saltworks of Turkey, is located in the Gediz Delta plain, and the high water surface area in June is due to the presence of a high amount of seawater in these pools. Salt is produced in September by evaporating water during the summer months. Since the change in the water surface area in the entire area has been examined, and has also become a part of the ecological system in the pools where salt has been produced since 1863, it has been included in the analysis.

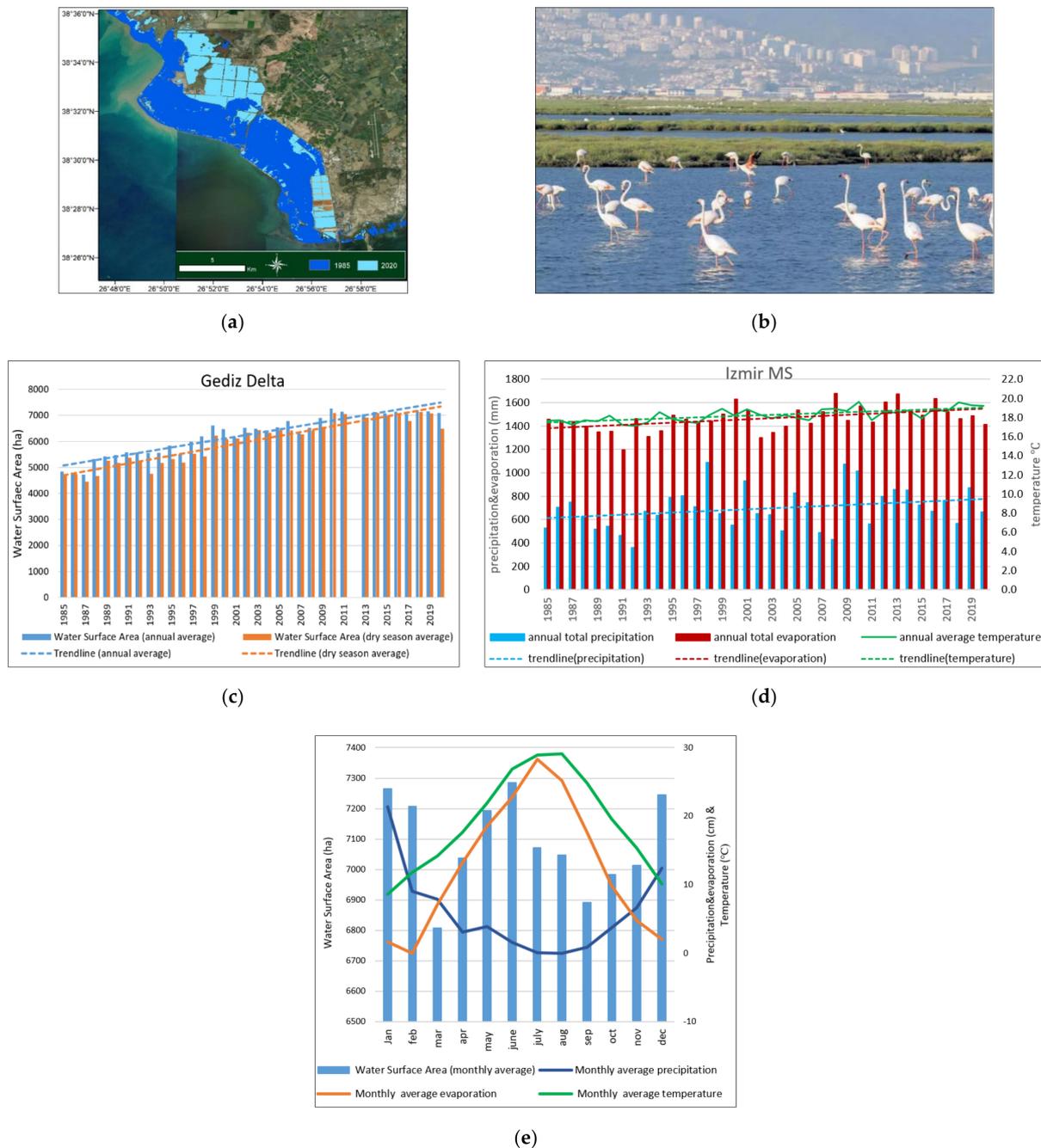


Figure 6. Gediz Delta: (a) Delta Location and 1985 And 2020 Annual Average Water Surface Areas (NDWI > 0); (b) View of Delta [52]. (c) 1985–2020 Period, Water Surface Areas (Annual Averages and Dry Season Averages); (d) Izmir Meteorological Station Data (Annual Total Precipitation, Total Evaporation, and Average Air Temperature); (e) 2016–2020, Monthly Average Water Surface Areas, Precipitation, Evaporation and Temperature.

The Yumurtalık Lagoons are a huge wetland system consisting of many lagoons, fresh and saltwater marshes, reeds, and expansive coastal dunes in connection with the sea. There are two central lagoon systems in the area, and their depth is generally at the level of 1 m, reaching 4 m in some areas. The groundwater level is at or near the surface, and the alluvium made of clay, sand, and gravel has an excellent aquifer characteristic. In the parts close to the sea and lakes, the groundwater is salty, and in the distant parts, it is unsalted or less salty. Birds are at the forefront of the elements that make the area essential. During the observations made in the area, 163 bird species were identified [36,53]. Due

to the dams established on the Ceyhan River, which is the primary water source of the Yumurtalik Lagoons, since 1971, the amount of water feeding the lagoons has started to decrease. The thermal power plant, which is very close to the area, causes the seawater to warm up, becoming hotter in shallow areas such as the lagoon and its surroundings, evaporating rapidly and, in turn, the region’s salinity increases. Excess freshwater entering the agricultural areas is sent to the lagoons through drainage channels. Thus, pesticides and fertilizers used in agricultural areas are transported to the lagoons. Due to such chemicals and extra organic material carried to the lagoons, pollution occurs, and the lagoons become eutrophic. The agricultural activities carried out in the region are supported by the fertile alluvial soils taken from the dunes and, as a result, the natural structure of the dunes has become deteriorated. In addition, the animals that graze heavily on the dunes are destroying them. In this area, as was the case in other areas, the problem of illegal hunting continues [36,53].

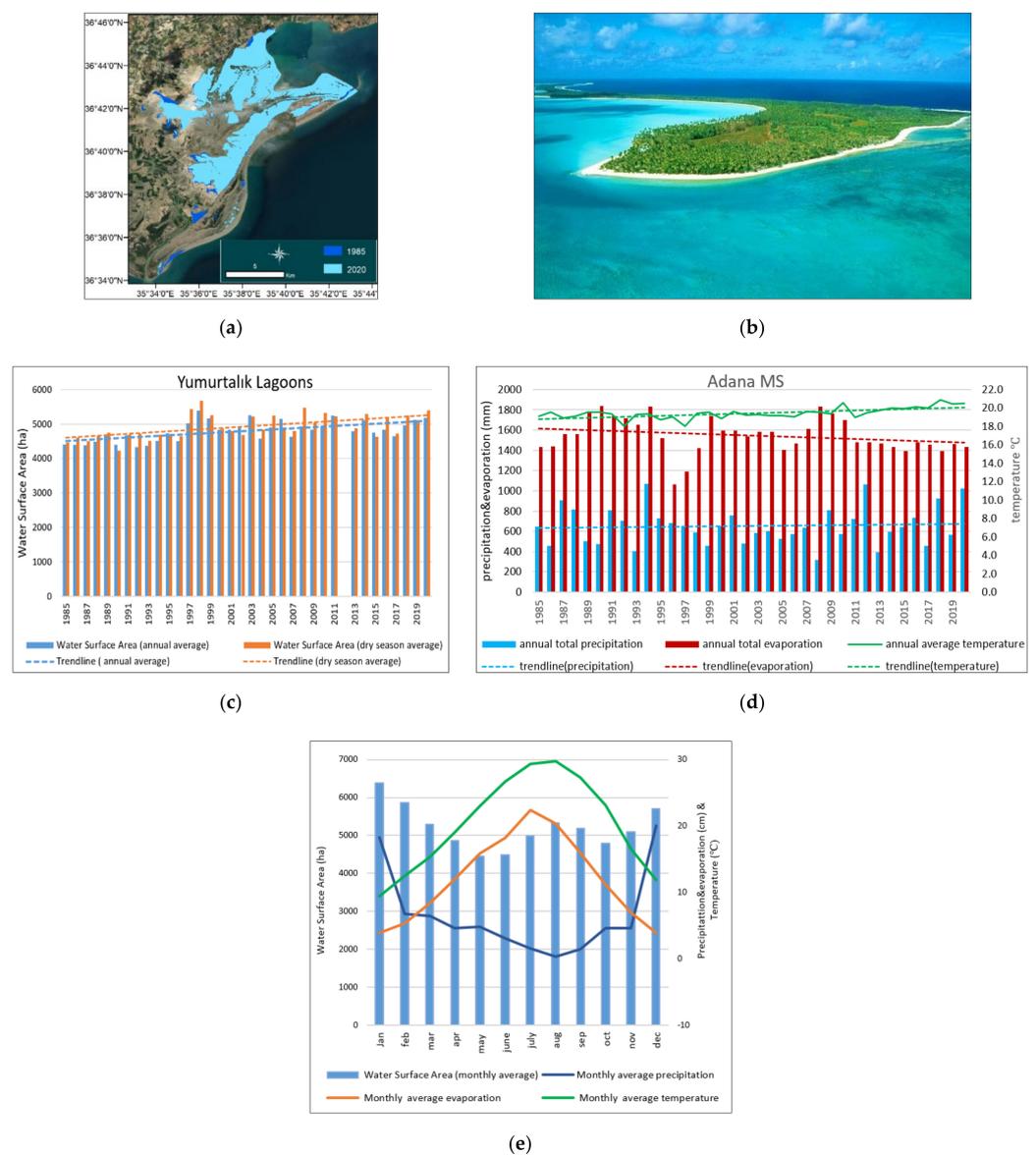


Figure 7. Yumurtalik Lagoons: (a) Lagoons’ Location and 1985 And 2020 Annual Average Water Surface Areas (NDWI > 0); (b) View of Lagoons [54]; (c) 1985–2020 Period, Water Surface Areas (Annual Averages and Dry Season Averages); (d) Adana Meteorological Station Data (Annual Total Precipitation, Total Evaporation, and Average Air Temperature); (e) 2016–2020, Monthly Average Water Surface Areas, Precipitation, Evaporation and Temperature.

The Yumurtalık Lagoons are given in Figure 7a with coordinates, and the average water surface areas of 1985 and 2020 are given on the map. A view of the lagoons is given in Figure 7b. Water surface areas of the Yumurtalık Lagoons, obtained both from the annual average and dry season averages between 1985 and 2020, and the annual total precipitation, total evaporation, and average air temperature data corresponding to the same period are given in Figure 7c,d. In addition, for the monthly water surface-area change analysis, five-year monthly average water surface areas, precipitation and evaporation data are given in Figure 7e.

When the annual water surface area graph in Figure 7c was examined, it was seen that the general trend was increasing in both the annual average and the dry season average. When the Adana Meteorology station data was examined (Figure 7d), it was seen that the trend line did not considerably change, although precipitation values decreased in some years and increased in others. It was observed that there was a decrease in evaporation and an increase in air temperature values. When the average data of 35 years were examined, precipitation was 653.36 mm, evaporation was 1544.96 mm, and it was seen that evaporation was approximately 2.4 times the precipitation.

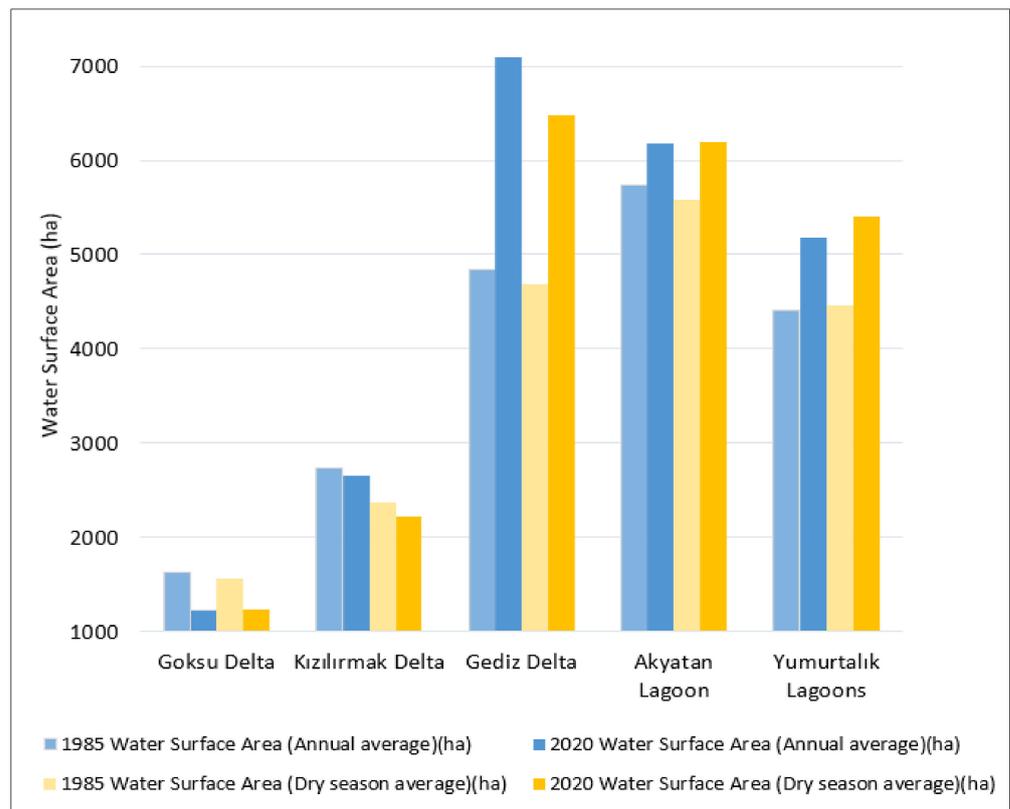
When the water surface areas of the Yumurtalık Lagoons were examined monthly (Figure 7e), it was seen that the water surface area was high in January and February, then decreased until June, and increased again after July. Despite the low precipitation and highest evaporation values in July and August, the water surface area was quite large. Despite the width of the area covered by the water, it is known that the water level decreases in the inland wetland areas during the summer months [36].

In Table 3, annual averages and dry season average water surface areas of all coastal Ramsar sites in 1985 and 2020 are given with water surface area changes from 1985 to 2020. In Figure 8a, the 1985 and 2020 water surface areas are given in hectares, and Figure 8b shows the water surface area changes as percentages.

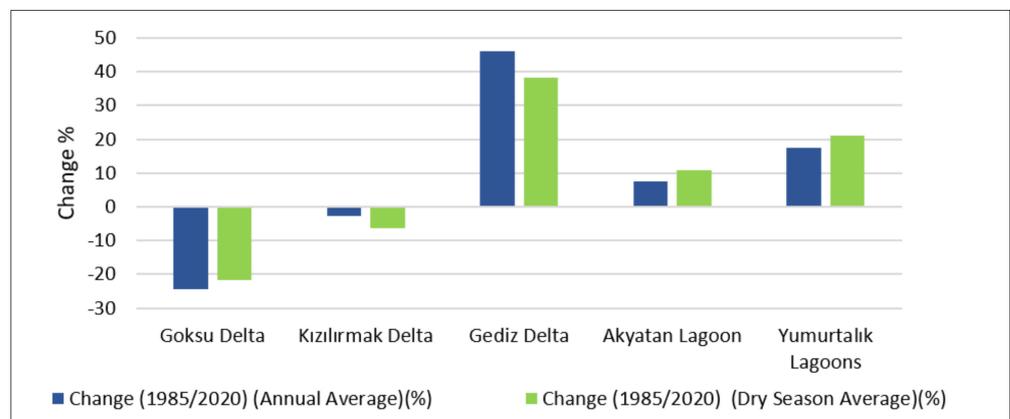
Table 3. Water Surface Areas (Annual and Dry Season Averages) at Turkey’s Coastal Ramsar Sites in 1985 and 2020 and Changes (ha).

Ramsar Site	Wetland Type	1985 Annual Average (ha)	2020 Annual Average (ha)	Change (1985/2020) (ha)	1985 Dry Season Average (ha)	2020 Dry Season Average (ha)	Change (1985/2020) (ha)
Goksu Delta	I + M/C	1634.34	1233.57	−400.77	1572.91	1232.56	−340.35
Kızılırmak Delta	I + M/C	2732.65	2654.41	−78.24	2376.15	2225.44	−150.71
Gediz Delta	M/C	4841.86	7083.92	2242.06	4686.77	6483.85	1797.08
Akyatan Lagoon	I + M/C	5735.89	6174.73	438.84	5583.25	6188.83	605.58
Yumurtalık Lagoons	M/C	4410.58	5174.11	763.53	4463.12	5402.49	939.37
Total (I + M/C wetlands)		10,102.88	10,062.71	−40.17	9532.31	9646.83	114.52
Total (M/C wetlands)		9252.44	12,258.03	3005.59	9149.89	11,886.34	2736.45
All		19,355.32	22,320.74	2965.42	18,682.2	21,533.17	2850.97

When Table 3 and Figure 8 are examined, it can be seen that, in the Goksu Delta, which also has inland wetlands, the water surface area was 1634.34 ha (annual average) and 1572.91 ha (dry season average) in 1985. As it decreased to 1233.57 ha (annual average) and 1232.56 ha (dry season average) in 2020, the change was −25.52% and −21.64%, respectively. In the Kızılırmak Delta, which also has inland wetlands, the decrease in water surface area was −2.86%, according to annual average values and −6.34% according to dry season averages. In the Akyatan Lagoon, which has much less inland wetland area than Goksu and Kızılırmak, there was an increase of 7.65% (annual average) and 10.84% (dry season average). The highest increase was seen in the Gediz Delta, with an annual average of 46.04% and a dry season average of 38.34%. Yumurtalık Lagoons were also increased from 1985 to 2020 17.31% (annual average) and 21.04% (dry season average).



(a)



(b)

Figure 8. (a) Water Surface Areas (Annual and Dry Season Average) at Turkey's Coastal Ramsar Sites in 1985 and 2020 (b) % changes.

As a result, there was a decrease in water surface areas in Goksu and Kızılırmak Deltas, and an increase in the Akyatan and Yumurtalık Lagoons and the Gediz Delta. The decrease in water surface areas in the Goksu and Kızılırmak Deltas can be associated with the fact that these areas also contain inland wetlands. One of the main reasons for the decrease in deltas (only Gediz Delta is exceptional due to salt-producing ponds) including inland wetlands is meteorological factors. However, since the lagoons have a permanent connection with the sea, the flow of water from the sea does not cause a decrease in the water surface in these areas. Considering the total changes of all areas, the water surface area (annual average) which was 19,355.32 ha in 1985 increased by 2965.42 ha and reached 22,320.74 ha in 2020. A study on the inland wetlands of Turkey [5] identified a decrease in

water surface areas in all inland wetlands. As a result, it was seen that there was a decrease in water surface areas in the Goksu and Kızılırmak Deltas, and an increase in the Akyatan and Yumurtalık Lagoons and the Gediz Delta. When meteorological data was evaluated, it was concluded that there was no decrease in precipitation for all Ramsar sites throughout the years, and the trend was slightly upwards. While evaporation amounts increased in the Kızılırmak, Akyatan and Gediz regions, it decreased in the Goksu and Yumurtalık regions. Average air temperatures in all coastal Ramsar sites have slightly increased by 1.8 °C. According to the data of 249 stations throughout Turkey, the increase in air temperature is about 2 °C in the past thirty-five years [55,56]. In this study and the previous study [4], it was observed that an increase of approximately 2 degrees in temperature over a thirty-five-year period causes a decrease in inland wetlands. Climate change studies project that temperatures in Turkey will increase by 0.5 to 3.0 °C by 2050, and 0.5 to 4.0 °C by 2100, with an optimistic scenario (RCP 4.5). According to the pessimistic scenario (RCP 8.5), the expected increase will be higher: by 0.9 to 3.5 °C by 2050, and by 0.9 to 6.3 °C by 2100 [55]. It is inevitable that increases in temperature will adversely affect wetlands.

According to all these findings, it can be said that precipitation and evaporation are related to decreases in the water surface areas. The areas where increase occurs are the areas directly related to the sea.

As a final step, the correlations of annual/monthly total precipitation, total evaporation and average temperature values with annual/monthly water surface areas (WSA) were examined for the years 1985–2020/2016–2020, respectively, and are given in Table 4.

Table 4. Correlations with water surface areas (WSA) and meteorological factors.

Correlation (r)		Goksu Delta WSA	Kızılırmak Delta WSA	Akyatan Lagoon WSA	Gediz Delta WSA	Yumurtalık Lagoons WSA
		Annual Average	Annual Average	Annual Average	Annual Average	Annual Average
Meteorological factors	Precipitation (annual total)	0.01	−0.05	0.07	0.30	−0.05
	Evaporation (annual total)	0.55	0.27	−0.04	0.44	−0.20
	Temperature (annual average)	−0.53	0.03	0.72	0.69	0.27
		Goksu Delta WSA	Kızılırmak Delta WSA	Akyatan Lagoon WSA	Gediz Delta WSA	Yumurtalık Lagoons WSA
		Monthly Average	Monthly Average	Monthly Average	Monthly Average	Monthly Average
Meteorological factors	Precipitation (monthly total)	0.89	0.59	0.70	0.40	0.68
	Evaporation (monthly total)	−0.93	−0.78	−0.57	−0.11	−0.65
	Temperature (monthly average)	−0.93	−0.91	−0.60	−0.19	−0.68

Correlation coefficients in Table 4 are evaluated as: very high ($0.8 \leq r \leq 1.0$), high ($0.6 \leq r \leq 0.79$), moderate ($0.4 \leq r \leq 0.59$), low ($0.2 \leq r \leq 0.39$), very low ($r \leq 0.19$) and no correlation ($r = 0$) (for both positive and negative values) [57].

When the correlation between WSA and the driving meteorological factors was analyzed on an annual basis, it was seen that the temperature had a relatively high correlation compared with the others (except the Kızılırmak Delta and Yumurtalık Lagoons), as expected. Considering the other two factors, the highest correlation (0.55) was seen only in the Goksu Delta, while no correlation was found with other sites.

On the other hand, when the correlations were examined on a monthly basis, it was seen that the results were more significant and explainable. Table 4 shows that the highest correlation with the three factors was obtained in the Goksu Delta, and the correlation at all other Ramsar sites ranged between 0.57 and 0.91 (except for the Gediz Delta—salt production ponds are the main driving force determining the water surface area as previously explained).

There was a high positive correlation between monthly water surface averages and monthly precipitation averages of the Goksu Delta (i.e., WSA is high in rainy months).

However, the very high correlation observed between WSA and both temperature and evaporation was negative (i.e., WSA is smaller in months with higher temperature and evaporation values).

There was a high positive correlation between WSA and precipitation in the Kızılırmak Delta, and the Akyatan and Yumurtalık Lagoons. Although there was a very high negative correlation between WSA and temperature only in the Kızılırmak Delta, there was a high correlation with the other two sites. For evaporation, a high correlation was observed between WSA in the Kızılırmak Delta and Yumurtalık Lagoons, and a moderate correlation was observed in the Akyatan Lagoon.

Among all these areas, different but not surprising results (i.e., moderate correlation for precipitation and very low correlation for both temperature and evaporation) were found in the Gediz Delta compared with other areas due to salt production ponds.

4. Conclusions

Coastal wetlands are dynamic and productive ecosystems located at the intersection of land and sea, providing natural transitions between land and sea. Despite the Ramsar convention and its importance, wetlands are still threatened and continue to decline globally in both area and quality. In this sense, monitoring such ecosystems and identifying spatial changes over time provides valuable data for decision makers. In this context, the importance of remote sensing, which is a useful tool for this purpose, in developing strategies at a national, regional and/or local level has been demonstrated in this study.

Two-dimensional analysis of the changes in water surface areas in all coastal Ramsar sites in Turkey over a 35-year period was performed using total 6672 images (Landsat and Sentinel 1–2) on the GEE platform. It was seen that Landsat satellites, which have been providing data for about 50 years in the creation of long-term time series, are useful and valuable in monitoring wetlands. On the other hand, Sentinel 1–2 satellites have critical advantages over Landsat satellites, such as a higher spatial and temporal resolution and the ability to fill gaps in the time series (Sentinel 1 SAR) due to cloud cover. However, as used in this study, thousands of remotely sensed images (big data) need easy processing and rapid change analysis. In this context, the GEE cloud platform is an effective tool in analyzing wetlands from a regional to a country-wide scale, and efficiently determining their trends, as in many other areas.

The results of the study show that coastal Ramsar sites, including large inland wetlands, decreased in some areas (Goksu Delta -24.52% , Kızılırmak Delta -2.86%), and increased in areas connected to the sea (Gediz Delta 46.01% , Yumurtalık Lagoons 17.31%). The Akyatan Lagoon also had a small inland wetland area (7.65%). When meteorological data were examined, it was seen that there was an increase in temperature due to climate change in Turkey, as expected. In many studies, it was stated that there was an increase of about $2\text{ }^{\circ}\text{C}$ in the past 35–40 years. This increase in temperature causes an increase in evaporation that has adverse effect on shallow wetlands.

Correlation analysis was made between the water surface areas and three meteorological parameters on an annual and monthly basis, and the results obtained on a monthly basis were found to be more significant. The correlation was generally between 0.57 and 0.93 (except for the Gediz Delta).

Since dramatic temperature increases are expected to continue according to climate change projections, it becomes necessary to protect/manage wetlands in a rational way. The primary way to protect these areas is to prepare viable management plans that ensure effective management of the protected areas. In this context, although there are management plans, there is a lack of implementation and legislation in this regard in Turkey. Due to the fact that the needs and demands of the people living in the region are not taken into account while these plans are being prepared, and new technologies such as remote sensing are not used in continuous monitoring, problems regarding the ecological sustainability and rational use of these areas tend to continue during the implementation stage.

In future studies, it is planned to determine the changes in wetland depths and related total water volumes, even if the water surface areas do not change.

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