ISSN: 2148-9173 Vol: 9 Issue:2 June 2022

International Journal of Environment and Geoinformatics (IJEGEO) is an international, multidisciplinary, peer reviewed, open access journal.

Spatio-Temporal Assessment of the Shrinking Lake Burdur, Turkey

Adalet DERVISOGLU, Nur YAGMUR, Ertuğ FIRATLI, Nebiye MUSAOĞLU, Ayşegül TANIK

Abstracting and Indexing: TR DIZIN, DOAJ, Index Copernicus, OAJI, Scientific Indexing Services, International Scientific Indexing, Journal Factor, Google Scholar, Ulrich's Periodicals Directory, WorldCat, DRJI, ResearchBib, SOBIAD

International Journal of Environment and Geoinformatics 9(2): 169- 176 (2022)

Research Article

Spatio-Temporal Assessment of the Shrinking Lake Burdur, Turkey

Adalet Dervişoğlu[1, *], Nur Yağmur[1, 2], Ertuğ Fıratlı[3], Nebiye Musaoğlu[1], Ayşegül Tanık[3]

[1] Istanbul Technical University, Faculty of Civil Engineering, Department of Geomatics Engineering, Istanbul, TURKIYE
[2] Gebze Technical University Faculty of Engineering, Department of Geomatics Engineering, Kocaeli, TURKIYE
[3] Istanbul Technical University, Faculty of Civil Engineering, Department of Environmental Engineering, Istanbul, TURKIYE

* Corresponding author: Adalet Dervişoğlu
E-mail: adervisoglu@itu.edu.tr

Received 06.06.2019
Accepted 14.03.2022

How to cite: Dervişoğlu et al., (2022). Spatio-Temporal Assessment of the Shrinking Lake Burdur, Turkey, *International Journal of Environment and Geoinformatics (IJEGEO)*, 9(2): 169-176. doi. 10.30897/ijegeo. 1078781

Abstract

Water resources in the world are becoming scarce due to both natural climatic conditions under the effect of climate change and human-induced activities. The population is rising day-by-day leading to a steady decrease in water resources, which in turn, highly disturbs the natural ecological functions of the vulnerable systems. Lakes can be addressed as important water bodies that are under the effect of shrinkage in different parts of the world, and if no remedial measures are taken, they will disappear in the near future. Lake Burdur in Turkey is among such lakes that lose its water volume over time. This study was performed via a group of interdisciplinary scientists to analyze the spatial and temporal changes in the water surface area in the long-term (1985-2020) and in the short-term (2016-2020) with the aim of putting forth the areal changes. Remote sensing technology was utilized for this purpose. Landsat imagery and Sentinel 2 images were utilized for the long and short-term assessments, respectively. Meteorological conditions during the inspection terms were obtained from the State Meteorological Service to determine the dominating reason(s) of area changes over time. Natural conditions and anthropogenic activities are linked with the findings. Resultantly, water withdrawals from the dams and reservoirs built in the region and from the streams feeding the lake for irrigation purposes during the dry season representing the human-induced activities dominate over the natural causes of climate change as is the case in most of the water bodies of the world. This outcome was also confirmed by a detailed analysis of the agricultural areas in the basin through satellite images and by field trips made at site.

Keywords: Anthropogenic Activities, Lake Burdur, Change Analysis, Landsat, Natural Conditions, NDWI, Sentinel 2.

Introduction

Decrease of water resources both in quality and quantity and struggle in accessing water is among the most critical issues that have recently become hot topics worldwide regarding water issues. While the demand for water increases every year due to increasing population, global warming, and worldwide drought, the most important freshwater resources, namely lakes and wetlands, are decreasing according to the reports that have been issued by relevant organizations, especially the United Nations (UN) and UNESCO (UNWWDR, 2020; Njagi et al., 2022).

Due to global warming, rising temperatures intensify evaporation, which then reduces water depths and surface areas in lakes (Lionello, et al. 2017; Ülker et al., 2018). Endorheic lakes without an outflow are particularly vulnerable to climate change as their water levels are determined by the delicate balance between precipitation and discharge into the lake and evaporation from the lake surface. In this study, Lake Burdur located in the Burdur Basin of Turkey that is a typical endorheic lake that cannot be used for domestic and agricultural purposes due to its salty, brackish, and arsenic-containing water characteristics was chosen as the case study area to investigate the effects of global warming and/or anthropogenic factors on a water body that is not used as a water resource by humans (Orhan et al., 2017).. The dynamics of Lake Burdur were determined via multitemporal Landsat and Sentinel-2 satellite imagery to analyze its spatio-temporal changes with related land use/land cover (LULC) and meteorological data. To discover the impacts of natural (climate change) and anthropogenic (human-induced) activities on lake surface area, possible factors that might induce variations in the lake were further examined, including annual mean temperature, annual precipitation, annual evaporation, and temporal LULC change. The temporal dynamics of surface water of the lake extended from 1985 to 2020 through analyzing annual Landsat imagery, and by Sentinel- 2 imagery seasonally between 2016 and 2020.

There are several techniques in the related literature that describe surface water extraction for calculating areal changes; these are categorized into four basic types, namely; thematic classification, linear non-interference, single-band thresholding, spectral water indices (Feyisa et al., 2014; Kedirkan, 2019). An easy and effective way to extract the water surface area is to use water indices calculated from two or more bands to determine the differences between water and non-water areas. Many indices have been developed and used to extract surface water areas such as Normalized difference water index (NDWI), Modified Normalized Difference Water Index (MNDWI), Water Ratio Index (WRI), Simple Water Index (SWI), Normalized Difference Moisture Index (NDM) and Automatic Water Extraction Index (AWEI). Studies comparing the well-known indices indicate that the Normalized Difference Water Index (NDWI) gives better results than the other indices (Rokni et al., 2014; Zhou et al., 2017; Acharya et al., 2018).

Mishra et al. (2019) studied the long-to-short-term dynamics of shoreline situations along the coast of Puri district, Odisha, in India during the past 25 years (1990–2015) using open-source multi-temporal satellite images of Landsat TM, ETM+, and OLI by applying NDWI coupled with statistical methods. Similarly, Landsat 8 OLI and Sentinel-2 MSI images and NDWI were used to monitor seasonal surface water bodies in the Western Cape region of South Africa by Bhaga et al. (2020). NDWI was also applied to Landsat and Sentinel images by Yagmur et al. (2020) in which 18 natural lakes in Turkey's Konya Closed Basin were examined with various other features. In the Google Earth Engine (GEE) cloud platform, there are some studies in which water surface areas from regional scale to global scale are extracted using NDWI. The maximal and minimal water extent in the year of 1990, 2000, 2010 and 2017 in the Middle Yangtze River Basin of China were calculated on the GEE platform by processing 2343 scenes of Landsat images (Wang et al., 2018). About 75000 scenes of Landsat images were processed to investigate the long-term changes of open-surface water bodies in the Yangtze River Basin in China from 1984 to 2018 by Deng et al. (2019). In another study again from Asia, the surface water dynamics were estimated from February 2017 to November 2019 with Sentinel-2 and Landsat 8 images in the Yangtze River which is the longest river in Asia and the third in the world by Yang et al. (2020). NDWI was most recently applied to Landsat and Sentinel images using the GEE platform to determine the water surface change between 1985 and 2020 at the 14 Ramsar Sites in Turkey (Dervisoglu, 2021; Dervisoglu, 2022). Moreover, Firatli et al. (2022) investigated the changes over a 35-year period in Turkey's natural lakes with a surface area greater than 20 km^2 using NDWI in the GEE.

Study Area

Lake Burdur, which is located in Turkey, is within the closed basin of Burdur and is one of the deepest lakes (almost 100 m) formed as a result of a tectonic depression filled with water. Location of Lake Burdur is given in Figure 1 on the digital elevation model (DEM) created from the AsterGdem global elevation model. A few small streams along with Bozçay in the southwest of the lake that are fed by groundwater and precipitation feed the lake. The direct precipitation rate of the lake is around 40%, the rate of water coming from the rivers is about 55%, and the rate of other resources is almost 5% according to State Water Works (DSI, 2016). Since 1974, dams and reservoirs in various volumes have been built for almost all of the streams feeding the lake for domestic use and agricultural irrigation, and thus, feeding of the lake has decreased significantly over time (Sener et al., 2005; Davraz et al., 2019).

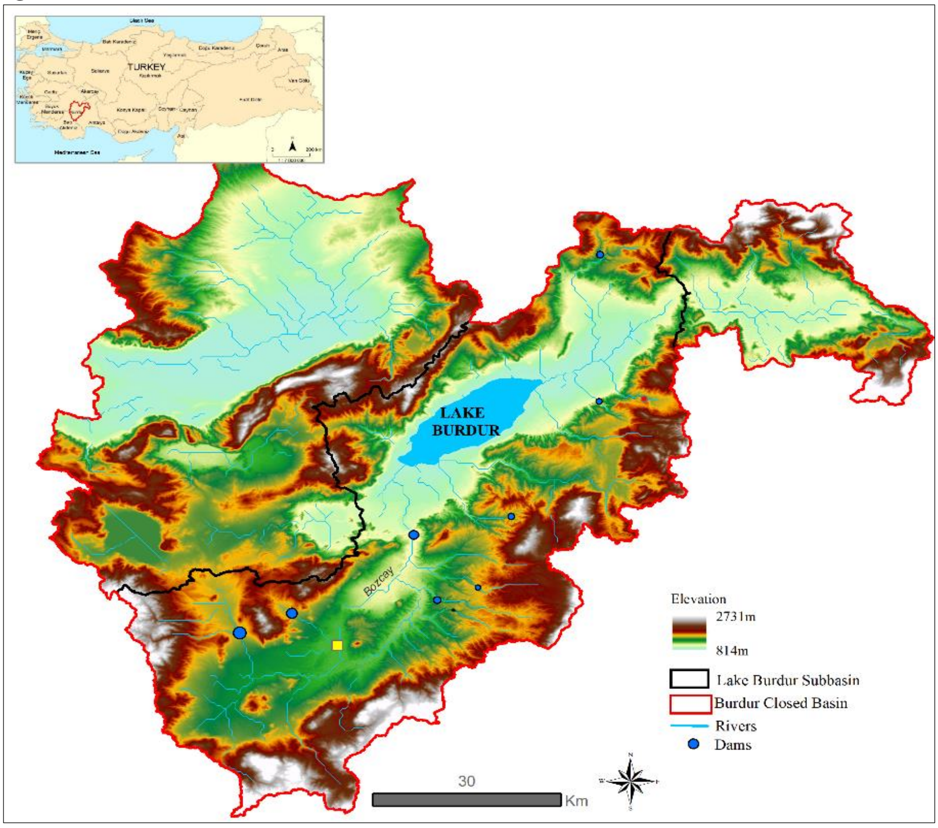


Fig. 1 DEM of Burdur Closed Basin and location of Lake Burdur

The water level of the lake was 840.50 m, depth 59.53 m, surface area 125.8 km^2 and its volume was calculated as 3945 hm^3 according to measurements done in October 2018. The lake has a length of 23.60 km and width of 8.16 km. It reached to its maximum water level (857.5 m) in 1970 with a surface area of 215.7 km^2 and a volume of 6.826 hm^3 in this period. In July 2018, the water level was measured as 840.5 m. When the bathymetry map of the lake prepared in given in Figure 2 is examined, it is seen that the lake is shallower in the northeastern part and deeper in the southeastern part (Lake Burdur Management Plan, 2018).

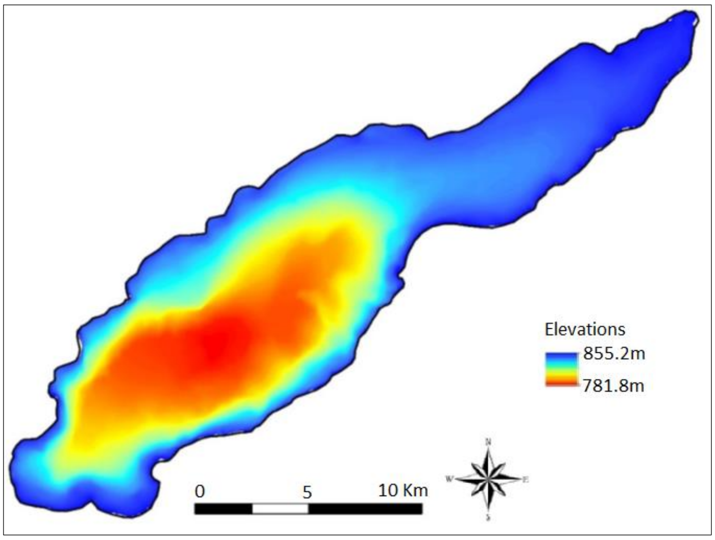


Fig. 2 Bathymetry map of Lake Burdur prepared in 1975 (Lake Burdur Management Plan, 2018)

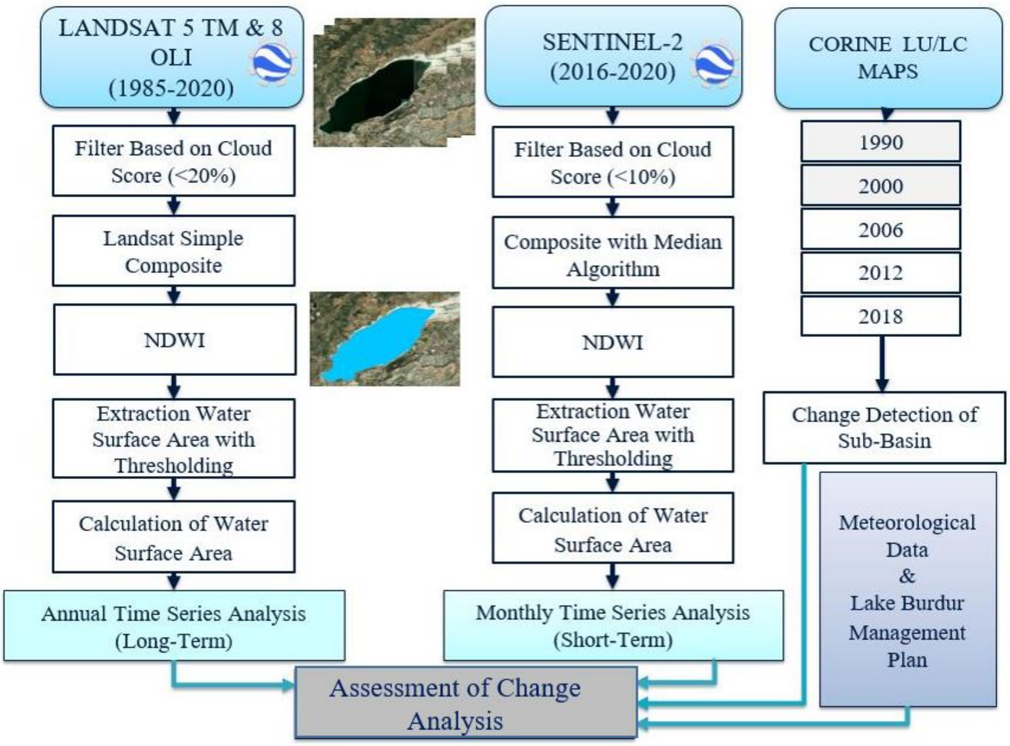


Fig. 3 Methodology flowchart of the study

Materials and Methods

In this study, water surface area changes in Lake Burdur between 1985 and 2020 were determined on GEE platform using Landsat satellite images and Sentinel-2 Multispectral instrument (MSI). GEE provides the infrastructure to rapidly access and process large volumes of satellite imagery in a systematic and reproducible manner. It has a high-performance, high-throughput (petabyte), analysis-ready data cloud. The data catalog includes data from various weather 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 (Gorelic et al., 2017).

Changes were analyzed by using LULC information and meteorological data obtained from the Turkish State Meteorological Service. For the long-term analyses, Landsat 5 TM and Landsat 8 OLI satellite images (Url-1) during 1985–2020 were used. For short-term assessment that included the months from March to October to observe the seasonal changes and variations, Sentinel-2 MSI imageries (Url-2) during 2016-2020 were used. The satellite images together with their features are given in Table 1.

All processing steps carried out in this study are given in the methodology flowchart given in Figure 3. In GEE, optical satellite images were filtered considering the cloud coverage of the scene before the water surface area extraction. The cloud filter was applied at 20% for Landsat images with less image count, and 10% for Sentinel-2. In the long-term analysis, Landsat satellite images were combined using the Landsat simple composite algorithm. This algorithm determines a cloud score for each pixel and calculates pixel values with the pixels with the lowest cloud score at each point. Since there is no unified algorithm for Sentinel-2 images, the median algorithm was used for monthly time series analysis. To extract water surface areas, NDWI were applied to the composite images.

Table 1 Information on the satellite imageries used

Satellite	Spectral Resolution (μm)	Spatial Resolution (m)	Radiometric Resolution (bit)	Temporal Resolution (day)
Landsat 5 TM (1985-2011)	7 Bands (0.45-2.35)	B1-B5, B7:30 m	8	16
Landsat 8 OLI (2013-2020)	9 Bands (0.43-2.29)	B1-B7, B9:30m	16	15
Sentinel-2 MSI (2016-2020)	13 Band (0.48-2.51)	B2-B4, B8 :10m B5-B7, B8A, B11, B12: 20m B1, B9, B10:60m	12	5

To determine the water surface, NDWI was applied to the satellite images. NDWI uses the green and near-infrared bands of satellite imagery, and the resulting values range from -1 to +1, with values greater than zero indicating water (McFeeters, 1996). The NDWI is expressed as:

$$NDWI=(Band_{Green}-Band_{NIR})/(Band_{Green}+Band_{NIR}) \quad (Eq.1)$$

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.

In addition, LULC of the Lake Burdur Sub-basin was examined with open access Environmental Information Coordination (CORINE) data which is the LULC data produced by computer- aided visual interpretation method over satellite images. CORINE has been included in the European Space Agency programs since 1994 and has provided LULC maps of 39 countries with five main classes and 44 subclasses (Url-3). Turkey is one of these countries and has LULC maps of 1990, 2000, 2006, 2012, and 2018 *(*Url-4).

Results and discussion

For the long-term analysis, NDWI was applied to the Landsat images (144 images) acquired in March, April, and May when the water was at its highest level. The long-term annual surface water area of Lake Burdur is shown in Fig. 4a. When the graph is examined, a decreasing trend is seen from 1985 to 2020. The water surface area diminished by 8214.93 ha that almost accounts to approximately 39.6% within the inspection period of 35 years. On the other hand, meteorological data regarding the annual averages of temperature, precipitation and evaporation representing the lake and its basin during the specified term are gathered from the meteorological service. The related data is displayed in Fig. 4b. When the meteorological parameters are examined, it is seen that precipitation decreased in some years, but there is no noticeable decrease or increasing trend. The trend is almost linear without considerable fluctuations within time. Temperature values have been steadily increasing as expected. In 1985, the average temperature was 12.7℃, while in 2020, it ascended to 14.3℃. The temperature increase in 35 years was about 1.6℃ which points out the reality that there exists a highly significant warming trend over time as a result of climate change. Evaporation values also tend to increase in parallel to increasing temperature. Annual evaporation amounts were about three times more than the average annual precipitation values. The satellite view of the water surface areas at every five-year interval over the 35 years is illustrated in Fig. 5. One can easily observe the continuous reduction in water area from these images.

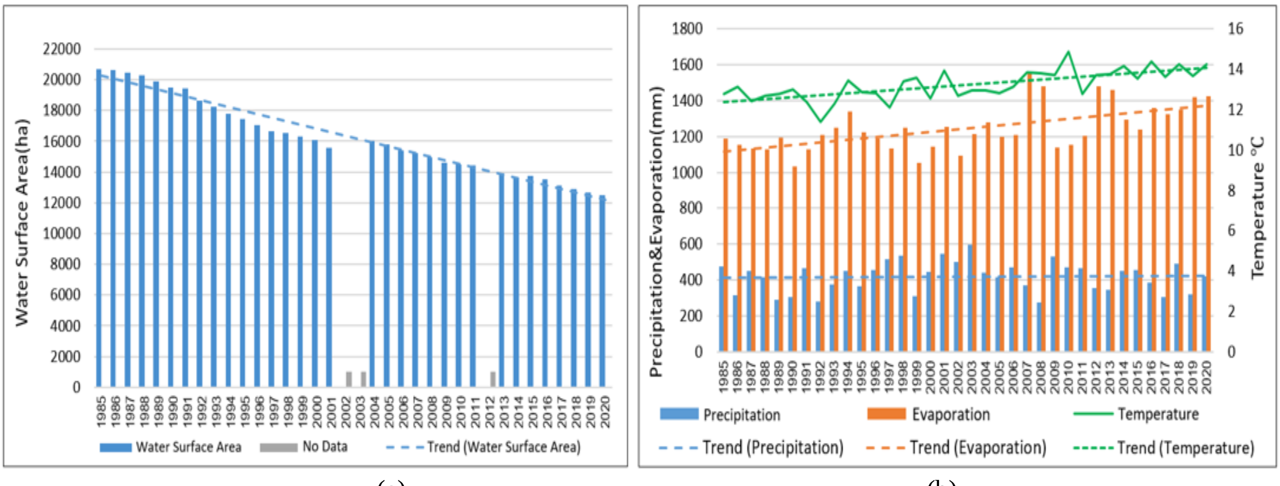


Fig. 4 (a) Annual average water surface areas of Lake Burdur, b) Annual meteorological data over time representing the lake and its basin

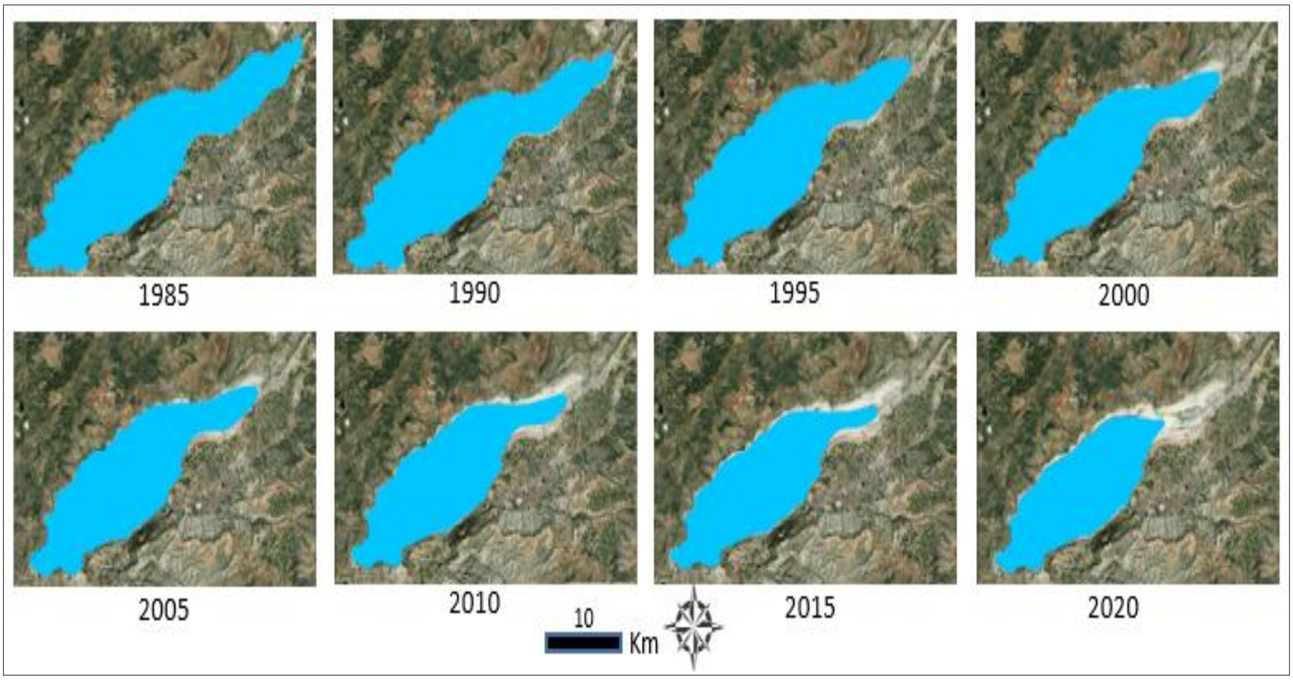
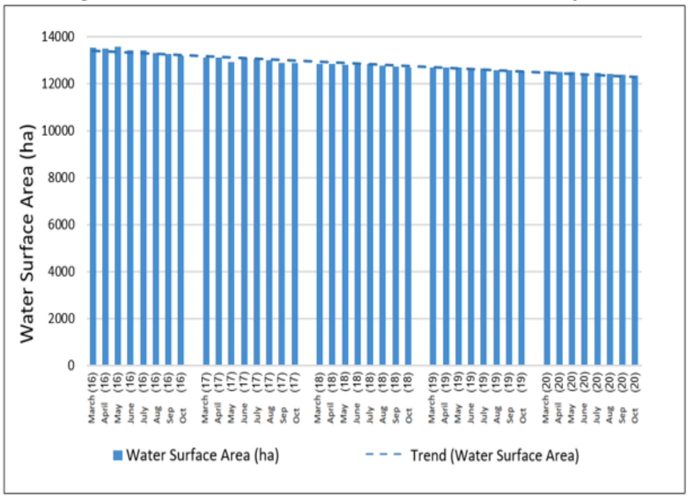


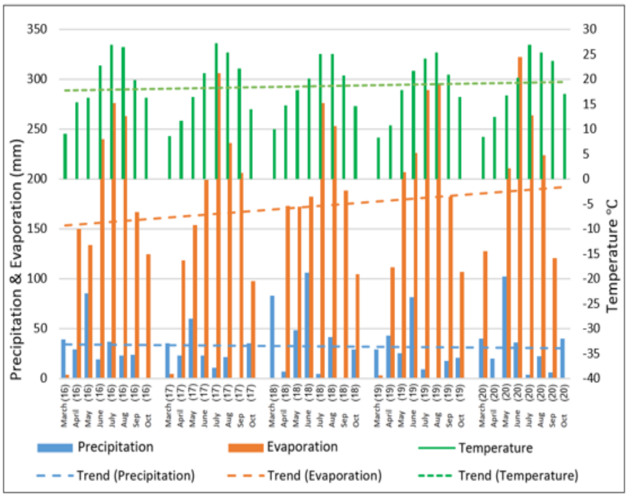
Fig. 5. Satellite images of the Lake Burdur over time showing the water surface areal changes

For the analysis of monthly changes in Lake Burdur, 1054 Sentinel- 2 images with less than 10% cloud ratio between 2016-2020 were used on the GEE platform. NDWI results from March to October for the years 2016- 2020 are given in Fig. 6a, and the monthly average meteorological data of Burdur Meteorological Station are presented in Fig. 6b. When Fig.6 is examined, it is seen that the decrease in the water surface area of Lake Burdur continues despite the increased precipitation in spring. While the precipitation did not affect the water surface area as it did not fluctuate noticeably in the consecutive months over the 5-year interval, it is seen that the evaporation values were quite high especially in July. While the evaporation trend presented an increase, there occurred no significant change in the precipitation pattern. Temperature as expected exerted a slight increase within the short-term inspection period. It is important to note that from March to October within the chosen 5 years, there is a decreasing trend indicating that together with the effect of higher temperatures and higher evaporation, it is the irrigation season in the region. Therefore, in order to understand whether human-induced activities also contribute to this decreasing trend, further analyses were conducted.

Since the water collected in the reservoirs and dams built on the rivers feeding the lake has been mostly used in agriculture for irrigation purposes, the changes in agricultural areas between 1990 and 2018 were also examined to understand whether there has been a positive increase in the arable land that required irrigation. Using the CORINE data set, the agricultural lands were initially divided into irrigated and non-irrigated agricultural land as shown in Fig. 7 (a). When areas are compared as of the year 2018, non-irrigated arable land decreased by about 3%, while the irrigated land steadily increased by about 22% with respect to 1990. It is clear that non-irrigated land has been transformed into irrigated land. In the last 16 years, the cultivation of alfalfa, which needs more water, increased while the cultivation of wheat, which requires less water, decreased. There is no doubt that there is a correlation between increased water consumption in agriculture and the decreasing water mass of the lake that dominates over the natural effects of climate change. The change in both non-irrigated and irrigated agricultural land for 1990, 2000, 2006, 2012, and 2018 are demonstrated in Fig.7(b). Water from the dams and streams reaching the lake has been withdrawn for irrigation purposes mostly during the dry period that extended from March to October. That outcome has been confirmed during the site visits realized during the dry season (July 1999 and July 2020) through the mutual discussions held with the farmers and the other local authorities. The continuous shrinkage of the lake is as understood from this study is the result of the dams built along the rivers (that used to feed the lake in the old days) for irrigation purposes. Thus, the lake loses its resources and tries to be fed only by precipitation. As such, the natural flow of the streams is cut by human-built units of dams and reservoirs. Moreover, the farmers of the basin tend to withdraw irrigation water from the streams. Of course, the population of the world is increasing day-by- day which necessitates to produce more food; which in turn, forces to use more water with the application of old conventional irrigation systems. However, the key idea is to leave the old techniques aside and try to use innovative agricultural methods not only covering irrigation techniques; but also including crop type, crop rotation, and scheduling coupled with good agricultural practices to achieve more product yield with the same area and water usage.

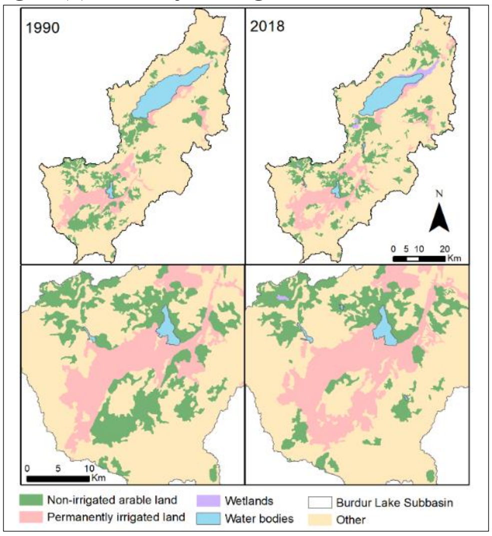


(a)

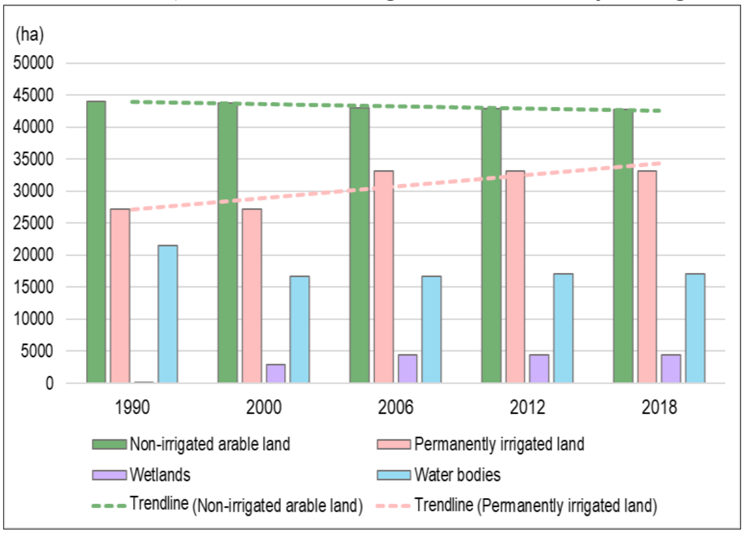


(b)

Fig. 6 (a) Monthly average water surface areas of Burdur Lake, b) Burdur Meteorological station monthly average data



(a)



(b)

Fig. 7 (a) CORINE maps of Burdur Lake Sub-basin (b) Changes in agricultural land between 1990 and 2018.

Conclusions and recommendations

The aim of this study was to determine the change of water surface area of Lake Burdur in 35 years with a long-term analysis, to focus on seasonal changes with short-term analyzes, and to reveal the relationship of changes with meteorological data representing the natural conditions and with human-induced activities like supplying irrigation water from the dams and streams feeding the lake.

Lake Burdur lost its most crucial water source with dams and reservoirs (almost 20) of various sizes which were built for domestic use and especially agricultural irrigation from 1974 to 2016. While there is no increase in precipitation, rising temperatures in the region due to the global warming increase the evaporation trend and keep shrinking of the lake day-by-day. One can state that both human-induced activities and climatic conditions cause the shrinkage of the lake within years; however, the anthropogenic factors dominate over the natural climatic conditions.

The results show that remote sensing has been an important technological tool in monitoring and detecting the temporal and spatial water surface changes, and thus, is regarded as an effective instrument in extracting valuable numerical and visual information. This detailed data may be further used to make different scenario analyses and queries by the scientists to obtain extended information to the decision-makers and planners at both the local and national scales. The practitioners have already been furnished with such data; however, it is important to display the findings in the visualized form as well for the politicians who are in charge of the management of such vulnerable water bodies.

The methodology of this specific study does not only aim the demonstration and analysis of spatial-temporal changes in a lake system; but, also intends to provide a methodology covering the basic steps to be followed and data requirement during another study on a different lake system that suffers from quantity problems over time. This study, apart from developing a methodology to observe spatial and temporal changes over time, emphasizes the utility of modern technological tools of remote sensing to put forth valuable numerical data and analysis over large areas.

Moreover, such studies need a multidisciplinary team involving especially environmental, geomatics, agricultural engineers and hydrologists to contribute better to planners and decision-makers.

Acknowledgements

The authors would like to express thanks to Istanbul Technical University (ITU), Scientific Research Project Funding for their financial support to ITU BAP Project number MGA-2019-41917.

References

Acharya, T. D., Subedi, A., Lee, D. H. (2018). Evaluation of water indices for surface water extraction in a Landsat 8 scene of Nepal. *Sensors*,18(8), 2580.

Bhaga, T. D., Dube, T., Shoko, C. (2020). Satellite monitoring of surface water variability in the drought prone Western Cape, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 102914.

Davraz, A., Sener, E., and Sener, S. (2019). Evaluation of climate and human effects on the hydrology and water quality of Burdur Lake, Turkey. *Journal of African Earth Sciences*, 158, 103569.

Deng, Y., Jiang, W., Tang, Z., Ling, Z., Wu, Z. (2019). Long-term changes of open-surface water bodies in the Yangtze River Basin based on the Google Earth Engine Cloud Platform. *Remote Sensing*,11(19), 2213.

Dervisoglu, A. (2021). Analysis of the temporal changes of inland Ramsar Sites in Turkey using Google Earth Engine. *ISPRS International Journal of Geo-Information*, 10(8), 521.

Dervisoglu, A. (2022). Investigation of long and short-term water surface area changes in coastal Ramsar Sites in Turkey with Google Earth Engine. *ISPRS International Journal of Geo-Information*, 11(1), 46.

DSI (2016). General Directorate for State Water Works, Master Plan, Ankara.

Feyisa, G. L., Meilby, H., Fensholt, R., Proud, S. R. (2014). Automated water extraction index: a new technique for surface water mapping using Landsat imagery. *Remote Sensing of Environment*, 140: 23-35.

Firatlı, E., Dervisoglu, A., Yagmur, N., Musaoglu,N., Tanik, A. (2022). Spatio-temporal assessment of natural lakes in Turkey. *Earth Science Informatics,* doi.org/10.1007/s12145-022-00778-8.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R. (2017). Google Earth Engine: planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202:18-27.

Kedirkan, N. (2019). Water surface Changes of Lakes in the Central Rift Valley of Ethiopia . International Journal of Environment and Geoinformatics, 6(3), 264-267, doi. 10.30897/ijegeo.544770.

Lake Burdur Management Plan (2018). Wetland Revised Plan for 2019-2023. Republic of Türkiye Ministry of Agriculture and Forestry, Ankara.

Lionello, P. et al.; (2017). Climate variability and change in the Mediterranean region, *Global Planet. Change*, 151, 1-3; doi.10.1016/j.gloplacha. 2017. 04.005

McFeeters, S. K. (1996). The use of the normalized difference water index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7): 1425-1432.

Mishra, M., Chand, P., Pattnaik, N., Kattel, D. B., Panda, G. K., Mohanti, M., Baruah, U. D., Chandniha, D. K., Achari, S., Mohanty, T. (2019). Response of long-to short-term changes of the Puri coastline of Odisha (India) to natural and anthropogenic factors: a remote sensing and statistical assessment. *Environmental Earth Sciences*, 78(11), 338.

Njagi, S., Lejju, J., Nkurunungi, J. (2022). Historical Perspectives of Land Use and Land Cover Change in the Sanga-Lake Mburo former Pastoral Rangeland Ecosystem, Uganda, *International Journal of Environment and Geoinformatics*, 9(2), 94-107, doi. 10. 30897/ijegeo.998420

Orhan, O., Yalvaç, S., Ekercin, S. (2017). Investigation of Climate Change Impact on Salt Lake by Statistical Methods, *International Journal of*

Environment and Geoinformatics, 4(1), 54-62, doi. 10.30897/ijegeo. 306493.

Rokni, K., Ahmad, A., Selamat, A., Hazini, S. (2014). Water feature extraction and change detection using multitemporal Landsat imagery. *Remote Sensing*, 6(5), 4173-4189.

Sener, E., Davraz, A., Ismailov, T. (2005). Investigation of Burdur lake coastal change with satellite images. *In*: Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment. Medcoast-2005, Kusadası, Turkey.

Ülker, D., Ergüven, O., Gazioğlu, C. (2018). Socio-economic impacts in a Changing Climate: Case Study Syria. *International Journal of Environment and Geoinformatics*, 5(1), 84-93, doi.10. 30897/ ijegeo.406273

UNWWDR. (2020). The United Nations World Water Development Report 2020: Water and climate Change. UNESCO World Water Assessment Programme, 219p.

Url-1:https://www.usgs.gov/core-science-systems/

Url-2:https://sentinel.esa.int/web/sentinel/

Url-3:https://land.copernicus.eu/

Url-4: https://corine.tarimorman.gov.tr/corineportal/

Wang, C., Jia, M., Chen, N., Wang, W. (2018). Long-term surface water dynamics analysis based on Landsat imagery and the Google Earth Engine platform: A case study in the middle Yangtze River Basin. *Remote Sensing*, 10(10):1635.

Yagmur, N., Tanik, A., Tuzcu, A., Musaoglu, N., Erten, E., Bilgilioglu, B. (2020). Opportunities provided by remote sensing data for watershed management: example of Konya Closed Basin. *International Journal of Engineering and Geosciences (IJEG)*, 5(3): 120-129.

Yang, X., Chen, Y., Wang, J. (2020). Combined use of Sentinel-2 and Landsat 8 to monitor water surface area dynamics using Google Earth Engine. *Remote Sensing Letter*s, 11(7):687-696.

Zhou, Y., Dong, J., Xiao, X., Xiao, T., Yang, Z., Zhao, G., Qin, Y. (2017). Open surface water mapping algorithms: A comparison of water-related spectral indices. *Water*, 9(4), 256.