INVESTIGATION OF THE CHANGES OF LAKE SURFACE TEMPERATURES AND AREAS: CASE STUDY OF BURDUR AND EGIRDIR LAKES, TURKEY

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Commission III, WG III/7

KEY WORDS: Climate Change, Lake Shoreline Extraction, LSWT, Change Detection, NDVI, MNDWI

ABSTRACT:

The world's average surface temperature has been increasing in recent decades. This situation is expected to affect aquatic systems and lakes are one of the most important aquatic systems. The main aims of this study are to examine Lake Surface Water Temperature (LSWT) and area changes of Burdur and Egirdir lakes located in the West Mediterranean Region (TR61) of Turkey for the years 1998, 2008 and 2018 using Landsat satellite images. For this purpose, initially, Normalized Difference Vegetation Index (NDVI) and Modified Normalized Difference Water Index (MNDWI) images were generated and the lake shorelines were extracted by thresholding these images. Then, the LSWT values were obtained by using Landsat thermal images. Finally, the area and LSWT changes of Burdur and Egirdir lakes between the years 1998-2008-2018 and the relationships of these parameters with each other were analysed. The obtained results showed that the lake boundaries could be semi-automatically extracted with overall accuracy values higher than 95%. In 20-year time period it was also observed that the Burdur Lake area decreased significantly, while the Egirdir Lake area decreased slightly. When the LSWT values were analysed, it can be stated that the LSWT values increased in both lakes during this time period. The amount of increase in LSWT values was about 2.2°C for Burdur Lake, while about 1.3°C for Egirdir Lake.

1. INTRODUCTION

The world population growth and the urbanization that it brings with it are increasing rapidly day by day. In 2000, while there were 371 cities with a population of 1 million or more in the world, the number of these cities increased to 548 in 2018 and it is predicted to be 706 in 2030 (United Nations, 2018). Besides, the number of megacities (cities with a population of more than 10 million) on a global scale is expected to increase from 33 to 43 from 2018 to 2030 (United Nations, 2018). The global average temperature and the human impact on this temperature are constantly increasing. Haustein et al. (2017) stated that the rate of human-induced warming may have been accelerating in the last 20 years and is now +0.16°C more than the period 1997-2016. In addition, the instantaneous evaluation of human-induced global warming since the second half of the 19th century shows that human-induced warming now is approximately +1.22°C (Leedham and Allen, 2021).

The average surface temperature has been increasing since the last century in globally and it is expected that especially aquatic systems will be adversely affected by future climate change (EPA, 2014). The water temperatures are increasing significantly in lakes in different parts of the world (O'Reilly et al., 2015) and the warming trend of lakes is expected to have serious consequences for aquatic ecology (O'Neil et al., 2012; Paerl and Paul, 2012). Lakes, make up 1.8% of the global land surface (Messager et al., 2016) and these large water bodies affect the ecosystems around them. Lakes are affected by both climate change and human factors and it is important to

examine the changes of lakes over time for climate studies. For this reason, many studies have been done on lakes (Liu et al., 2015; Liu et al., 2019; Sharma et al., 2015; Wan et al., 2017). Studies of water surface temperature using traditional methods are expensive and time consuming. On the contrary, this process can be done faster and less costly using remote sensing data. The Landsat images are one of the most frequently used data in LST studies. The Lake Surface Water Temperature (LSWT), which is a key parameter for lacustrine systems, can be obtained using thermal and multispectral bands of Landsat imageries.

The Land Use Land Cover (LULC) change detection has gained more importance for climate studies because it is known that there is a relationship between LULC pattern and Land Surface Temperature (LST) (Chen et al., 2006). Deep learning, classification or various indexes can be used to the LULC determination and change detection studies. Different land classes can be determined by applying threshold values to the indices (Chen et al., 2006). There are studies that use Normalized Different Vegetation Index (NDVI) and Modified Normalized Water Index (MNDWI) to detect the open water surfaces (Acharya et al., 2019; Rokni et al., 2014; Sarp and Ozcelik, 2017; Wen et al., 2021).

The objectives of this study are to examine the effects of climate and human factors on lake areas and LSWT values, and to reveal the temporal change using remote sensing data. For this purpose, we investigated the relationship between the lake areas and the LSWT values for Burdur and Egirdir Lakes in West Mediterranean Region (TR61) of Turkey. The remotely sensed

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data used in this study are Landsat 5 TM satellite images acquired on 24th August 1998 and 19th August 2008 and Landsat 8 OLI/TIRS satellite image acquired on 19th August 2018. Firstly, for three years (1998, 2008 and 2018) the lake areas were extracted using only the NDVI and MNDWI images. Then, the LSWT values were calculated using the Landsat images. Finally, the LSWT and area changes and their relationship between each other were analysed for Burdur and Egirdir lakes.

2. STUDY AREA AND DATA

In this study, Burdur and Egirdir Lakes, which are the biggest lakes of West Mediterranean Region (TR61), are selected as study areas (Figure 1). Burdur Lake is one of the deepest lakes in Turkey, it is shrinking dramatically in recent years. In addition, Burdur Lake is one of the 13 Ramsar sites in Turkey. Egirdir Lake is the second largest freshwater lake of Turkey. In addition to being a natural drinking water basin, it is an internationally important wetland in terms of biodiversity values. For these reasons, Burdur and Egirdir Lakes were selected for this study.

The process that started with the first Landsat satellite in 1972 continued with the launch of the Landsat 8 OLI / TIRS satellite in 2013. Landsat images are frequently preferred in environmental studies because they can be obtained free of charge and their temporal resolution is high. Landsat 5 TM has 6 multispectral and one thermal band. In addition, the Landsat 8 OLI/TIRS images contains 8 multispectral, 1 panchromatic and 2 thermal bands. The radiometric resolutions of Landsat 5 and Landsat 8 satellite images are 8 and 12 bits, respectively (Landsat 8 is served as 16 bits).
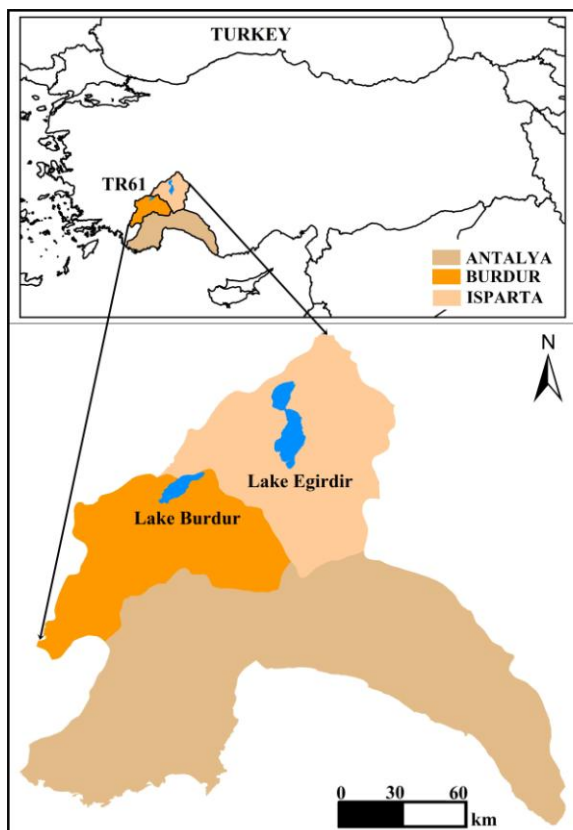

Figure 1. The locations of Burdur and Egirdir Lakes in West Mediterranean Region (TR61) of Turkey.

The Green, Red, NIR, SWIR and Thermal bands of Landsat satellite images were used in this study. The spatial resolutions of the multispectral bands are 30m for both Landsat 5 TM and Landsat 8 OLI/TIRS satellites. On the other hand, the spatial resolutions of thermal bands are 120m and 100m for Landsat 5 TM and Landsat 8 OLI/TIRS satellites, respectively. However, these bands were obtained as resampled to 30m for both satellites.

3. METHODOLOGY

The methods used in the study can be examined under three main headings: (i) detection of the lakes' areas using NDVI and MNDWI images and extraction of the lakes' shorelines, (ii) determination of LSWT values of lake areas and (iii) accuracy assessment. Fig.2 shows the steps of the study methodology.
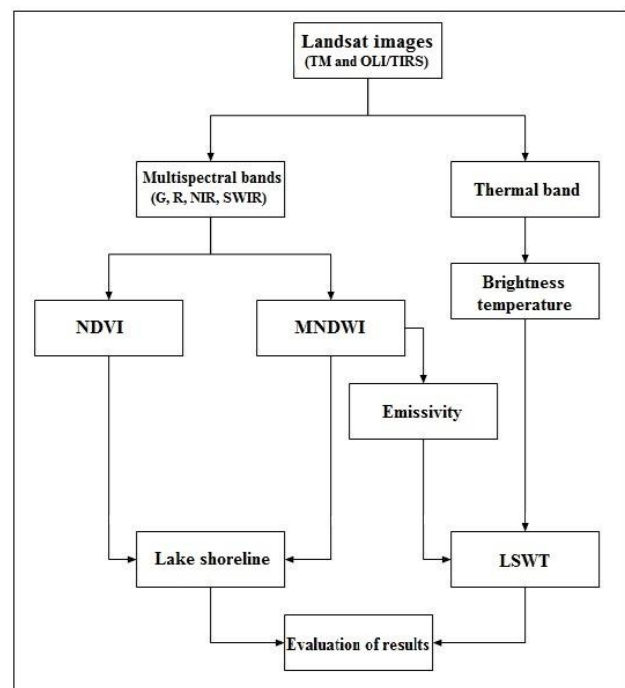

Figure 2. The flowchart of the methodology.

3.1 Extraction of lakes' shorelines

Various indices are used to predict LULC pattern from satellite images. In addition, different land cover classes can be defined by using more than one index together (Chen et al., 2006; Guha et al., 2018; Ranagalage et al., 2017). The NDVI was developed by Rouse et al. (1974) and it is the most frequently used index to estimate the proportion of vegetation in the image, as well as providing information about the water in the area. In the resultant NDVI images, pixel values vary between -1 and 1, and generally, water areas take values below 0. The MNDWI has been modified by (Xu, 2006) and it provides information on the presence of open water in the area. In this study, it is aimed to determine the lake areas with high accuracy by using NDVI and MNDWI images together. Lake shorelines were extracted by applying threshold values to NDVI and MNDWI data. The threshold values to apply NDVI and MNDWI images were determined by trial and error. Then, the lake areas were extracted using these threshold values (DN < NDVI$_{thr}$ and DN > MNDWI$_{thr}$), the lake surface areas were calculated and

lakes'shorelines were extracted. The NDVI and MNDWI data were generated using equation 1 and 2.

$$NDVI = (NIR-Red)/(NIR+Red) \qquad (1)$$

$$MNDWI = (Green- SWIR)/(Green + SWIR) \qquad (2)$$

where   NIR, Red, Green and SWIR are Near Infrared, Red, Green and Short-wave Infrared bands of Landsat images, respectively.

3.2 The LSWT determination

After extracting lake areas, the LSWT data for both lakes were computed using the thermal bands of Landsat 5 TM and Landsat 8 OLI/TIRS satellite images. In Landsat 5 TM there is only one thermal band: the 6th band was used for LSWT determination. On the other hand, in Landsat 8 OLI/TIRS there are two thermal bands, the 10th and 11th bands. However, only the 10th band was used in this study, due to the fact that it was recommended to work with TIRS Band 10 data as a single thermal band (USGS, 2013). For this process, firstly, the brightness temperature values were calculated using the formulas on the USGS website (USGS, 2021). Then LSWT values were computed using the NDVI threshold method (Sobrino et al., 2008, 2004; Sobrino and Raissouni, 2000) and the emissivity corrected land surface temperature values were calculated (Artis and Carnahan, 1982; Weng et al., 2004). The basic equations used in LSWT estimation are as follows (Eq. 3-7):

$$L_b = (L_{min} + (L_{max} - L_{min})) * DN/Q_{CalMax}, \qquad (3)$$

where L_b = the spectral radiance value in watts/m^2*sr*μm, L_{min} and L_{max}, minimum and maximum spectral radiance forthermal band,
Q_{CalMax} = maximum quantized and calibrated standard product pixel values (DN),

$$T_B = K_2 / (\ln (K_1/L_b + 1)) \qquad (4)$$

where T_B = Brightness temperature, K_1 and K_2 are Band-specific thermal conversion constant from the metadata (K_1 = 607.76 and K_2 = 1260.56 for Landsat 5 TM), (K_1 = 774.89 and K_2 =1321.08 for Landsat 8 OLI/TIRS),

$$LSWT = T_B / (1+(Λ*T_B/\alpha) * \ln(\varepsilon)) \qquad (5)$$

where   LSWT is Lake Surface Water Temperature,
ε_λ= emissivity (Sobrino et al., 2008, 2004; Sobrino and Raissouni, 2000),
Λ = average wavelength of band,
$\alpha = 1.438 * 10^{-2}$mK

$$\varepsilon_\lambda = \begin{array}{l} \varepsilon_{s\lambda} \\ \varepsilon_{s\lambda}+(\varepsilon_{v\lambda}- \varepsilon_{s\lambda})*P_v \\ \varepsilon_{v\lambda} \end{array} \left\{ \begin{array}{l} NDVI < NDVI_s \\ NDVI_s \leq NDVI \leq NDVI_v \\ NDVI > NDVI_v \end{array} \right. \qquad (6)$$

where $\varepsilon_{s\lambda}$ = 0.980-0.042*R $\varepsilon_{v\lambda}$ = 0.99
$NDVI_s$ = 0.2 and
$NDVI_v$ = 0.5 (Sobrino et al., 2008).
P_v (Carlson and Ripley, 1997) is vegetation proportion and it is calculated using the following equation;

$$P_v = ((NDVI-NDVI_S)/(NDVI_V-NDVI_S))^2 \qquad (7)$$

3.3 Accuracy assessment

The accuracy assessment of the extracted lakes' areas was performed by comparing the manually digitized boundaries with the obtained boundaries using NDVI and MNDWI images. On the other hand, the validity of computed LSWT values was conducted by using MODIS Land Surface Temperature and Emissivity (LST/Emissivity) based LSWT data.

4. RESULTS AND DISCUSSION

The obtained lake areas and boundaries for Burdur and Egirdir Lakes are given in Figure 3 and 4, respectively and the overall accuracies are given in Table 1. The obtained results indicate that using NDVI and MNDWI indices the lake boundaries can be extracted quite successfully. The overall accuracy values are computed above 95% for both lakes and for the years 1998, 2008 and 2018 (Table 1).
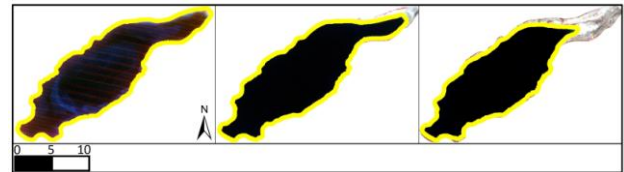

Figure 3. Burdur Lake areas and shorelines (yellow polygons) for the years 1998, 2008 and 2018, respectively, from left to right.
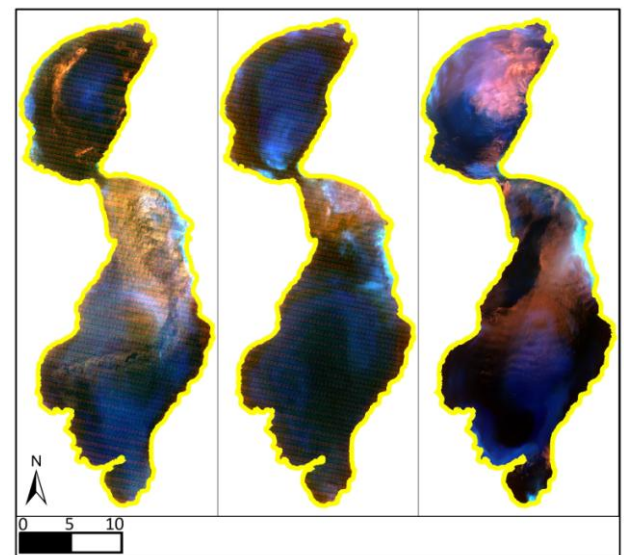

Figure 4. Egirdir Lake areas and shorelines (yellow polygons) for the years 1998, 2008 and 2018, respectively, from left to right.

Years	Lake area detection accuracy (%)	
	Burdur	Egirdir
1998	99.22	96.88
2008	99.13	96.09
2018	99.42	95.98

Table 1. The overall accuracy values of extracted lake areas for the years 1998, 2008 and 2018.

The computed lake areas for the years 1998, 2008 and 2018 are given in Table 2. The Burdur lake area, which was 161.81 km^2 in 1998, decreased to 144.98 km^2 in 2008 and 127.31 km^2 in 2018. It was observed that within the 20-year time period the Burdur Lake area has decreased about 34 km^2. In other words, the lake area has dried about 21% in 20 years. For the Egirdir Lake, it was observed that the area decreased slightly (about 4 km^2) within the 20-year time period. The decrease ratio is less than 1% for this lake.

Years	Lake area (km^2)	
	Burdur	Egirdir
1998	161.81	454.19
2008	144.98	451.38
2018	127.31	450.20

Table 2. The lake areas for the years 1998, 2008 and 2018.

The obtained LSWT maps for the Burdur and Egirdir Lakes are given in Figure 5 and 6, respectively.
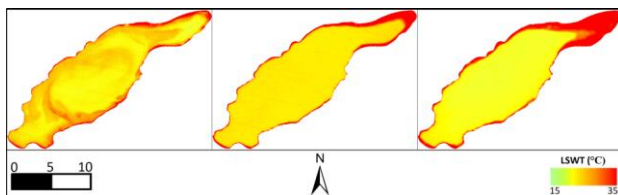

Figure 5. The Burdur Lake LSWT maps for the years 1998, 2008 and 2018, respectively, from left to right.
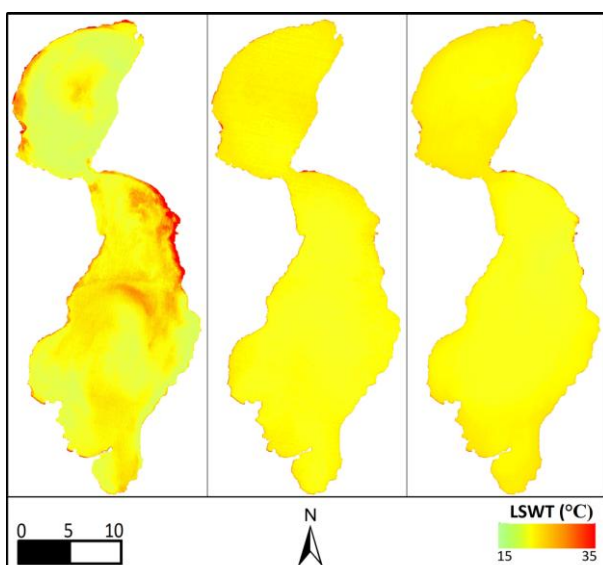

Figure 6. The Egirdir Lake LSWT maps for the years 1998, 2008 and 2018, respectively, from left to right.

The obtained mean LSWT values for the Burdur and Egirdir lakes are given in Table 3. The obtained results show that the water temperatures in both lakes increased between the years 1998 and 2018 (Table 3). The increase is about 2.2°C in Burdur Lake, while 1.3°C in Egirdir Lake.

Years	The mean LSWT values (°C)	
	Burdur	Egirdir
1998	24.12	23.24
2008	25.34	24.31
2018	26.34	24.55

Table 3. The mean LSWT values for the years 1998, 2008 and 2018.

To validate the temperature values, the MODIS LSWT values were calculated using the rescaling factor (0.02) (Wan, 2013). Then, correlation analysis was performed using Landsat-based LSWT and MODIS-based LSWT values and the correlation value was found over 0.85.

When the minimum, maximum and average LSWT values were examined, it was seen that all three values increased from 1998 to 2008 for Egirdir and Burdur lakes (Fig. 7). On the other hand, from 2008 to 2018, the min and max values decreased in Egirdir lake, but the average LSWT value increased. In Burdur Lake, while the maximum LSWT decreased, the minimum and average LSWT values increased by approximately 1°C.
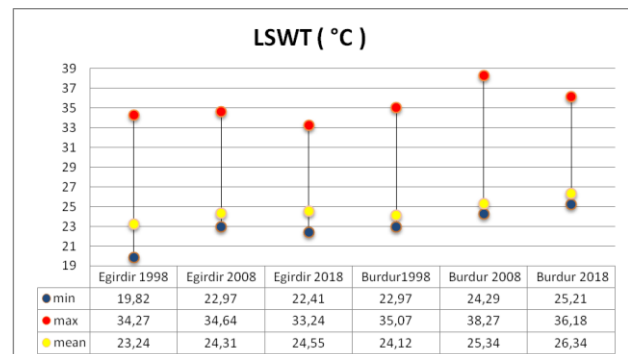

Figure 7. Egirdir and Burdur lakes min-max and mean LSWT graphs for the years 1998, 2008 and 2018, respectively.

When the obtained results were analysed, as expected a strong relationship between lake water temperatures and lake surface areas was observed. The LSWT values increased as the lake area decreased. The increase in LSWT values for both lakes can be attributed to the increase in global surface temperature. However, when the Egirdir Lake and Burdur Lake are evaluated together, it is seen that the situation cannot be explained solely by climatic effects. When the Burdur Lake area-LSWT exchange relationship is examined, it can be said that human activities also contribute to this situation. Davraz et al. (2019) analysed hydrological, climatic and human activities for Burdur Lake and they stated that the change in lake levels may be due to the human influences rather than climatic factors. Lake Egirdir is used as a source of drinking water and domestic waste water discharged around the lake without treatment reaches Egirdir Lake through the rivers feeding the lake (T.C. ORMAN VE SU ISLERI BAKANLIGI, 2017). However, when Burdur and Egirdir lakes are compared, Egirdir lake is almost 3 times the size of Burdur lake area and is not as close to the city centre as Burdur Lake. This situation may have caused Lake Egirdir to be less affected by human factors than Lake Burdur.

5. CONCLUSION

Lakes are affected by both climate change and human factors. For this reason, it is important to examine the changes of lakes over time. In this study, it was aimed to examine the area and the surface water temperature changes for Burdur and Egirdir lakes in the TR61 region for the years 1998, 2008 and 2018. For this purpose, the lake areas were extracted semi-automatically by thresholding NDVI and MNDWI indices. Then the LSWT values were calculated for detected lake areas. Thus, the 20-year changes of Burdur and Egirdir lakes between 1998-2018 were monitored.

The results showed that lake shorelines can be extracted quite accurately using NDVI and MNDWI indices. Furthermore, the results indicate that the Burdur Lake area has been shrinking dramatically. The Burdur Lake area, which was approximately 161 km^2 in 1998, decreased by 127 km^2 by 2018. In other words, Burdur Lake surface area has dried more than 20% in 20 years. In same time period, the LSWT value increased 2.2°C. The Egirdir Lake is the largest lake in the region and the lake area has shrunk by less than 4 km^2 in 20-year time period. This amount of shrink is not significant when compared to the error limits of the study and the rate of shrink of the Burdur lake area. On the other hand, the LSWT values of Egirdir lake increased by more than 1.3°C in 20-year time period. When the relationship between the lake area and the LSWT change is examined, it is seen that the LSWT values increase as the lake area gets smaller. In addition, it has been observed that there is a relationship between the amount of reduction of the lake surface areas and the increase of LSWT values. As a result, the study indicated that the effects of climate change and/or the human factors on lakes can be detected using remote sensing.

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