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A study of the effect of changes in the area of Maharlu Lake on climatic parameters of Shiraz and its surrounding areas

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Abstract

Remote sensing is increasingly used in studies of periodic changes of land use and land surface temperature (LST) calculations. In this paper, the effect of change in the area of Maharlu Lake on climatic elements, land surface temperature and vegetation cover in the areas surrounding the lake were studied. To this end, the ETM + & TM sensor data of LANDSAT satellite on May 22, 1987, May 17, 2000, March 20, 1999 and March 18, 2009 were used. The findings suggested that the average percentage of vegetation index in the 10-km buffer of the lake in 1987 (wet year) compared to 2000 (dry year) had dropped by 15% in the same month. In March 1999 and 2009, however, only a 3 percent decline was recorded. The minimum, average and maximum LST in the periphery of the lake registered an increase on the same dates during the wet period, but the temperature pattern was identical in both periods. Most climatic elements increased in dry years compared to that of the wet years. Also, comparing the statistical features of climatic elements in synoptic stations of Shiraz at the time of capturing images and for the long-term average (1956-2012) suggested a relatively lower increase in temperature during wet years compared to the average long-term period. In most of the years when the precipitation was below average (300 mm), the lake dried in May. In contrast, in years when the precipitation was more than 400 mm, the lake received abundant rainfall in all months. The heavy dependence of the lake on rainfall, the small size of the catchment and the seasonality of rivers flowing into the lake make conditions extremely sensitive, critical and rainfall-dependent.

Keywords: Remote sensing, Satellite data, LST, NDVI, Maharlu Lake, Shiraz

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Introduction

In most areas, lakes are considered as natural rain gauge. Obviously, rainfall throughout the world is subject to extreme temporal and spatial variations. Under these conditions, lakes with their unique characteristics provide appropriate natural phenomena for precise estimation of precipitation fluctuations in an area. Therefore, lakes can be considered as the old rain gauges, with the fluctuations of their surface water indicating oscillation in precipitation of an area (Jahanbakhsh, 2010: 50). Therefore, timely and accurate study of land surface and vegetation characteristics, especially lakes and their surrounding areas, is of utmost importance to gain deeper insight into the interactions between human and natural phenomena and to adopt appropriate measures. To identify these changes, remote sensing data has been widely used in recent decades as primary sources of information. Vegetation change has effects on the surface energy balance in an area. Thus, monitoring these changes will contribute to assessing the energy balance in different regions. Land surface temperature (LST) is a key parameter in environmental studies, especially drought monitoring. Given constraints in estimating the surface temperature in large scales, thermal remote sensing provides a suitable method for this purpose with relatively high precision (Jahanbakhsh *et al.*, 2011: 20), with infrared radiation and physical models offering a powerful means of calculating the LST (Hejazi zadeh *et al.*, 2013: 33).

Many researchers have utilized remote sensing data to investigate the effects of changes in vegetation and land use on LST (Lu and Weng, 2006; Amiri *et al.*, 2009; Wen *et al.*, 2011; Xiao *et al.*, 2005; Jiang and Tian, 2010). In the same vein, some studies have monitored changes in the shorelines of lakes and wetlands using satellite images (Guariglia *et al.*, 2006; Trumpickas *et al.*, 2009; Karaburun and Demirci, 2010; Singh *et al.* al, 2012; Sima et al, 2013; Duan *et al.*, 2013; Sima and Tajrishy, 2013).

Deng *et al.* (2018) also studied the relationship between LST, NDVI and land use changes in karst areas. In their research, Landsat 8 data was used to explore how LST and NDVI were related to land use change. The results indicated that the temperature was directly associated with the height and type of land surface. Ning et al (2017) investigated the relationship between LST and land use. To do so, they examined the effect of land use changes on LST using Landsat 5 and Landsat 8 images of Yellow River delta. Six Landsat images covering two periods (1986 and 2015) were selected and the LST was computed using split window technique. The results showed a mutual relationship between LST and vegetation index, with LST in coastal areas being significantly affected by the local seawater temperature and climatic conditions.

Most studies on variations of coastal lines in Iran have chiefly focused on Lake Urmia (e.g. Ale Sheikh *et al.* (2005); Rasouli *et al.* (2008); Shayan and Jannati (2007); Rasouli and Abbasian (2009); Jalili *et al.* (2011), and the northern coasts of Gulf of Oman and the Persian Gulf (e.g. Gharib Reza and Motamed (2004); Ziayian *et al.* (2010); Naeemi *et al.* (2010); Ranjbar and Iranmanesh (2011). Other related studies include Mahsafar *et al.*, 2010 and Mohammadi Yegane *et al.*, 2013. The role and impact of urbanization on climate parameters have also been explored in a number of studies (e.g. Feng and Petzold, 1988; Karl *et al.*, 1988; Karl and Jones, 1989; Ghazanfari *et al.*, (2009).

In this paper, the Maharlu Lake was used as a case study to investigate the possible impact of extent and area of the lake water on climatic elements, especially humidity, LST and percentage of vegetation index in the periphery of the lake .

Materials and Methods

Data and methods

Study area

Lake Maharlu is located 7 km to the southeast of Shiraz between 29 degrees 18 minutes to 29 degrees 33 minutes northern latitudes and 52 and 42 minutes to 52 degrees 58 minutes eastern longitudes. The lake covers an area of 257.7 m2. The study area comprises Maharlu Lake and its surrounding areas with a total area of more than 243 m2, which constitutes the eleventh water zone of in Iran in terms of vastness (Figure 1).

This basin is surrounded by Bakhtegan Lake in the north, and Ghare Aqaj watershed in the south and west, which encompasses three sub-basins of Sarvestan, Goshangan and the western Basin of Maharlu. The Maharlu Lake has been formed in a synclinal subsidence and Sarvestan fault runs through it (Ghahroodytali *et al.*, 2011: 23). The Hormuz Series belonging to the Cambrian age are the oldest stones in the basin, and the newest stones belong to the Quaternary age (Khaksar *et al.*, 2006: 1). There are about 10 major springs and a number of small fountains on the edge of the lake, which are often seen in the western part of the lake. The direction of groundwater flow in the alluvial plain of Shiraz is towards the Maharlu Lake (Fayazi *et al.*, 2007: 2). The effects of various air masses, considerable elevation of the basin, elongation and relative vastness of the basin have contributed to the climatic variation in the region. The precipitation is more than 500 ml in the north and northwest of the basin and less than 500 mm in the east and 258 mm in Sarvestan (Zomorodian *et al.*, 2012: 51).

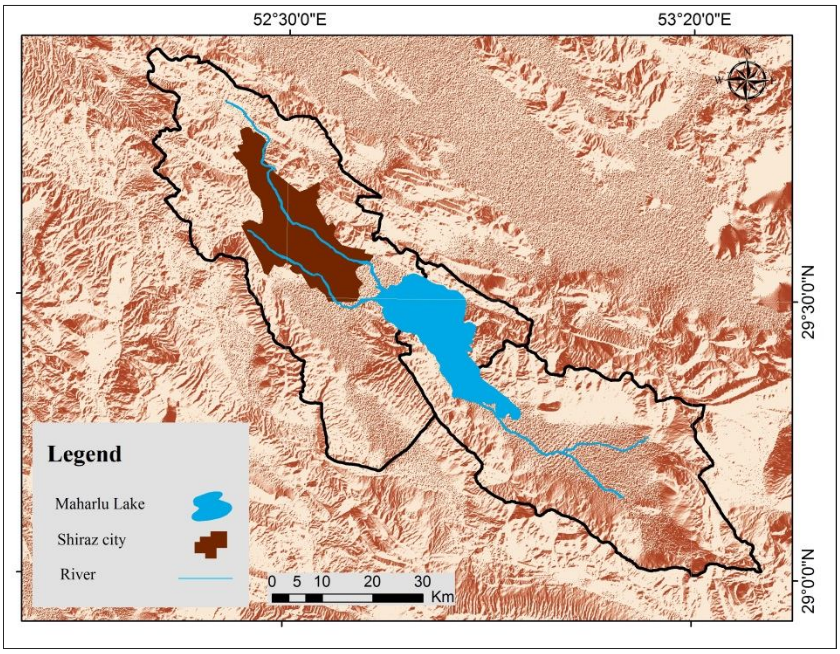

Figure 1. Geographic location of the study area

Remotely sensed data

To calculate Normalized Difference Vegetation Index (NDVI), and LST, and other relevant computations, the study area was plotted based on a 10-km buffer. The data used in this study consisted of 4 Landsat Satellite images, which given the constraints of receiving satellite images and the necessity of simultaneous utilization of the images, were selected in two periods - the end of winter and the end of rainfall in the early June – during wet and dry years of 1987, 2000, 1999, and 2009 from the website of the United States Geological Survey (USGS). The spatial resolution was 30 m for bands 1 to 5 and 7 of TM and + ETM sensors, 60 m for band 6 (thermal) and 15 m for band 8 (panchromatic) of ETM+. Moreover, climatic parameters (minimum, average and maximum temperature, dry and wet temperatures, dew point and evaporation rate, minimum LST and minimum, average and maximum humidity) of Shiraz synoptic station during the period 1956-2012 were employed. The properties of these images are shown in Table (1). The False Color Composites (FCC) are also depicted in Figure 2.

Table 1. List of satellite images collected for the study area

Data	Row- Path	Satellite	Sensor
1987/5/22	162-40	Landsat 5	TM
2000/5/17	162-40	Landsat 7	ETM
1999/3/20	162-40	Landsat 5	TM
2009/3/18	162-40	Landsat 5	TM

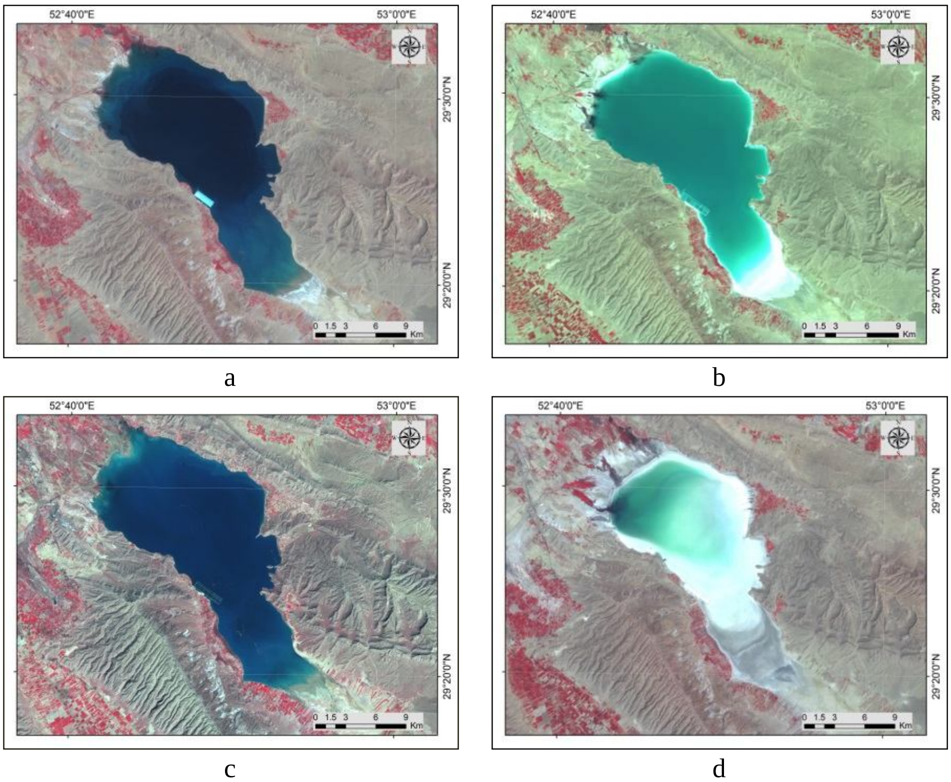

Figure 2. False color composites (RGB 432) of Maharlu Lake during (A: 1987, B: 2000 and C: 1999, D: 2009)

Normalized different Vegetation Index analysis (NDVI)

Vegetation index (VI) is an arithmetic disparity between pixel values in two or more spectral bands of the same imagery. Given the discrepancy in the reflectance of features over different wavelength ranges, it allows enhancing vegetation by subtracting one spectral band from another. The spectral data from the sensor is generally accessible as the normalized difference vegetation index (NDVI). It is calculated from reflectance factors in the near-infrared (NIR) and red regions of the electromagnetic spectrum.

NDVI parameter was estimated based on Landsat red (band 3) and infrared (band 4) wavelengths as presented in Eq. (1):

$$\text{NDVI} = \frac{\text{(Band 4) NIR} - \text{(Band 3) R}}{\text{(Band 4) NIR} + \text{(Band 3) R}} \qquad (1)$$

Where R is the reflectance value of red band (band 3) and NIR is the reflectance value of near-infrared band (band 4) in both of the Landsat images. The NDVI values are in the range of +1 to 1, with positive values indicating vegetated areas and negative values signifying non-vegetated surface features.

To evaluate the quality of vegetation, the vegetation percentage is calculated according to Eq. (2).

$$CP = (NDVI+1) \times 50 \quad (2)$$

Land surface temperature retrieval (LST)

To assess the impact of LULC on LST, LST data were retrieved from the radiometrically and geometrically corrected images using Landsat TM. In radiometric calibration, a conversion of the digital number (DN) for Landsat images to satellite radiance units (L) is possible using the following equation (Tan et al, 2012):

$$L_\lambda = \left(\frac{L_{max} - L_{min}}{QCal_{max} - QCal_{min}}\right) \times (QCal - QCal_{min}) + L_{min} \quad (3)$$

Where L_λ is spectral radiance at the sensor in W m^{-2} sr^{-1} μm^{-1}. L_{max} Spectral radiance is scaled to $QCal_{max}$, W m^{-2} sr^{-1} μm^{-1}. L_{min} Spectral radiance is scaled to $QCal_{min}$, W m^{-2} sr^{-1} μm^{-1}. $QCal_{max}$ Maximum quantized calibrated pixel value (DN=255) corresponds to $L_{max\lambda}$. The minimum quantized calibrated pixel value (DN=0) corresponds to $L_{min\lambda}$. QCal is the Quantized calibrated pixel value [DN].

The next step involves transforming the spectral radiance to at-satellite brightness temperature under the assumption of a uniform emissivity using the following formula:

$$BT = \frac{K_2}{\left\{LN\left[\frac{K_1}{L}+1\right]\right\}} \quad (4)$$

Where T_b is the effective at-satellite temperature in Kelvin and K_1 and K_2 are calibration constants. For Landsat 7 ETM+, K_2 = 1282.71*K* and K_1 = 666.09m W m^{-2} sr^{-1} μm^{-1}; for Landsat 5 TM, K_2 = 1260.71*K* and K_1 = 667.76m W m^{-2} sr^{-1} μm^{-1}, and L_λ is the spectral radiance in W / (m^2 sr μm) (Jiang and Tian, 2010). Finally, the land surface temperatures are calculated as follows:

$$T_s = \frac{T_b}{\left[1+\left(\frac{\lambda T_b}{a}\right)Ln\varepsilon\right]} \quad (5)$$

Where λ = wavelength of radiance (λ = 11.5 μm), α = *hc / k*; k is Boltzmann constant (1.38 × 10^{-23} J/K), h is Plank's constant (6.626 × 10^{-34} J.sec), c is velocity of light at a vacuum (2.998 × 108 m/sec), and ε is emissivity. It is essential to calculate surface emissivity in order to retrieve the LST. The surface emissivity could be obtained using a theoretical approach by considering the surface as a mixture of bare soil and vegetation. The proposed method is able to compute the emissivity values from the NDVI considering different cases:

(a) NDVI < 0.2

In this case, the pixel is considered as bare soil and the emissivity is obtained from reflectivity values in the red region.

(b) NDVI>0.5

Pixels with NDVI > 0.5 are considered as fully vegetated, and a constant value (typically 0.99) is assumed for the emissivity. It should be noted that the samples considered in the paper do not belong to cases (a) or (b).

(c) 0.2≤NDVI≤0.5

In this case, the pixel is composed of a mixture of bare soil and vegetation, and the emissivity is calculated according to the following equation:

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s(1 - P_v) + d\varepsilon \quad (6)$$

Where ε_v is the vegetation emissivity is, ε_s is the soil emissivity and P_v is the vegetation proportion obtained as follows:

$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2 \quad (7)$$

Where NDVImax = 0.5 and NDVImin = 0.2.

The term dε in Eq. (7) covers the effect of geometrical distribution of natural surfaces as well as internal reflections. For plain surfaces, this term is negligible, but for heterogeneous and rough surfaces, like forests, this term can reach as high as 2%. A good approximation for this term can be given by:

$$d\varepsilon = (1 - \varepsilon_s)(1 - P_v)F\varepsilon_v \quad (8)$$

Where *F* is a shape factor whose mean value, under the assumption of different geometrical distributions, is 0.55. According to Eqs (7) and (9), the LSE can be obtained as:

$$\varepsilon = m P_v + n \quad (9)$$

With

$$m = \varepsilon_v - \varepsilon_s - (1 - \varepsilon_s)F\varepsilon_v \quad (10a)$$

$$n = \varepsilon_s + (1 - \varepsilon_s)F\varepsilon_v \quad (10b)$$

The values of soil and vegetation emissivity are required for this method. To this end, a typical emissivity value of 0.99 for vegetation was chosen (Sobrino et al, 2004).

Results

The present study was undertaken to investigate variation in NDVI and LST in the 10 km buffer of Maharlu Lake. To study the effects of water area variations of Maharlu Lake on its surrounding areas, two periods - the end of winter and the end of rainy season in early June - were chosen as the study period. Table (2) shows total precipitation until the time of capturing images. The results suggested that precipitation in the water year of 1987 was higher than the average rainfall over the last 50 years (465 mm). In contrast, the water year of 2000 with a mean precipitation of 192.8 mm was less than the average rainfall over the last 50 years. Meanwhile, in the second half of 1999 and 2009, 303.9 mm and 104 mm precipitation were recorded, respectively.

Table 2. Total precipitation in mm until the time of capturing images

Water year/month	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1987	0	54.2	272	8.5	11.8	66.5	52	0	465
1999	0	0.4	11.8	142.3	35.1	0.7	2.2	0.3	192.8
2000	0.1	0	0	94.7	82	127.1	-	-	303.9
2009	0	32	5.3	25.9	18.2	22.5	-	-	104

After setting wet and dry periods at the end of winter and the end of summer, the effect of the water variations of the lake on their surrounding area was assessed by plotting a 10 km buffer and values of LST and vegetation index were calculated by adjusting soil reflectance and humidity.

Normalized Difference Vegetation Index NDVI

Qualitative changes of vegetation were studied as variation in the degree of luminosity. To analyze these changes, the percentage of vegetation index was divided into five categories, and then a comparison was made between these changes. Accordingly, the average value of this index was greater than 52% in 1987 and less than 38% in 2000, with the minimum value of this index falling from 22% to 5%. The maximum value of this index does not indicate any significant change. Figures (3) and (4) show that vegetation index in the category of 46 to 53 percent covered a vast area in 1987, while in 2000; the category of 5.9 to 37 percent covered the largest area. In 1999, the average percentage of vegetation index was 54%, from 51% in 2009. In general, the lowest percentage of categories in 2009 covered a larger area compared to 1999 (Figures 5 and 6).

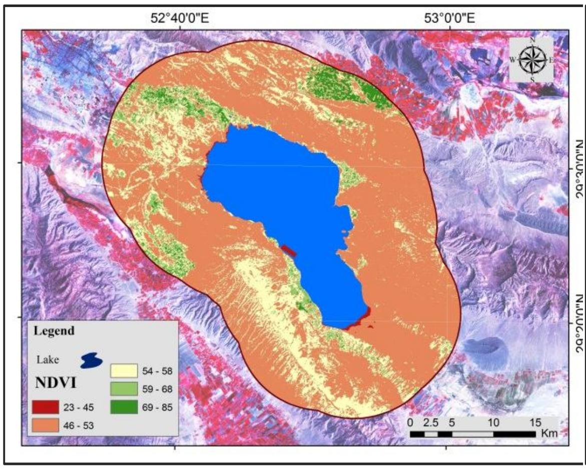

Figure 3. The percentage of vegetation index in Maharlu Lake in 1987

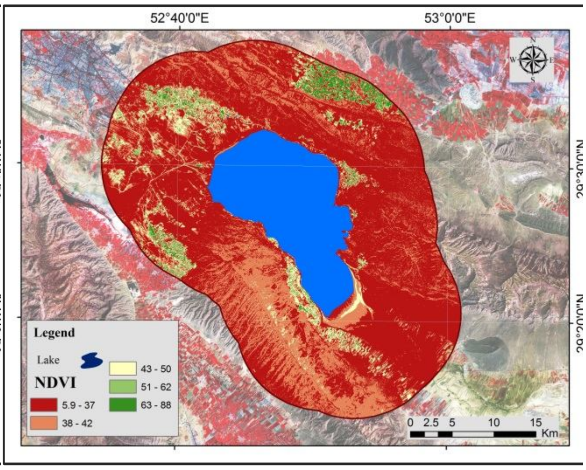

Figure 4. The percentage of vegetation index in the Maharlu Lake in 2000

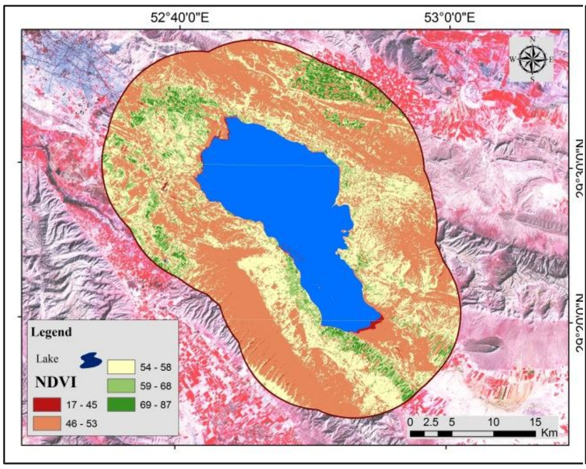

Figure 5. The percentage of vegetation index in the Maharlu Lake in 1999

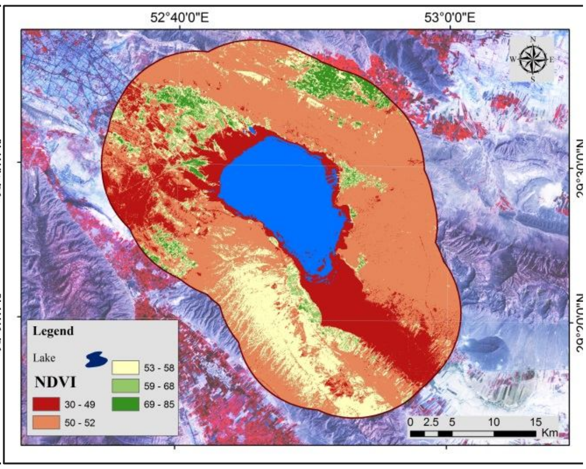

Figure 6. The percentage of vegetation index in the Maharlou Lake in 2009

Land surface temperature

To evaluate the effect of extent and area of Maharlu Lake water on climatic elements (minimum, average and maximum temperature, dry and wet temperature, dew point and evaporation rate, minimum LST and minimum, average and maximum moisture), the values of these elements registered on the dates of capturing image were used (Table 3). Accordingly, most elements in 2000 and 2009 (dry years) exhibited an increase compared to 1987 and 1999 (wet years). Also, comparing the statistical features of the climatic elements in Shiraz synoptic station at the dates of capturing images and over long term average (1956- 2012) suggested that the temperature elements demonstrated a modest increase in wet years as compared to dry years in long-term average.

Table 3. Statistical data on the climatic elements of Shiraz synoptic station at the dates of capturing image and long-term average (1956-2012)

				Temperature (°C)						Humidity (%)	
Date	Min	Mean	Max	Dry	Wet	Dew	Evap.	Min LST	Min	Mean	Max
22/5/1987	17.2	25.4	33.6	26.2	13.8	3		15	13	24.1	43
Average 1956-2012	15	23.7	32.4	24.4	13.1	1.1		11.1	11.53	24.6	39.53
17/5/2000	20.8	26.7	32.6	26.6	13.5	1.1	16.4	16	13	19.6	26
Average 1953-2023	14.5	23.4	32	24	13.1	1.8	11.1	10.2	12	26.3	43.21
20/3/1999	4.4	12.9	21.4	13.4	6.8	-2	6.1	1	14	39	66
Average 1956-2012	5.7	12.6	19.4	12.4	7.2	0.2	4.9	2.6	25	49	67.3
18/3/2009	3.8	13.7	23.6	-	-	-	4.2	2.6	28		92
Average 1956-2012	5.5	12.5	19.7	-	-	-	5.3	2.5	25.2	-	67

By analyzing the extracted temperature maps, the pattern of temperature distribution in 1987 can be observed (Figure 7). The minimum, average and maximum temperatures of 1987 were 14, 23, and 32 °C, respectively with SD=4.1. In 2000, these figures reached as high as 20, 36 and 48 °C, respectively with SD= 7.4. According to these images, the temperature pattern is consistent in both dates. In 1999, the minimum, average and maximum temperatures were 6, 15 and 26 °C, respectively with SD= 2.4 and in 2009, these figures were 16, 25 and 34 °C, respectively, with SD= 3.3. However, the temperature pattern in these two images is different, as shown in Figures (9) and (10). The hot spots expanded in northwestern areas in 2009, and in areas where the lake had regressed, the LST was higher.

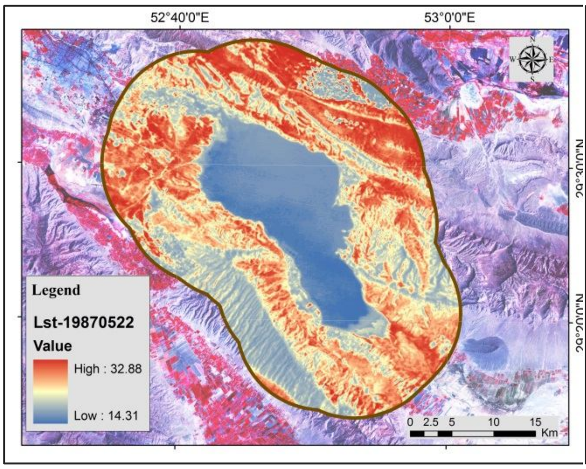

Figure 7. Temperature patterns extracted from the TM images of Landsat Satellite in 1987 - Maharlu Lake buffer

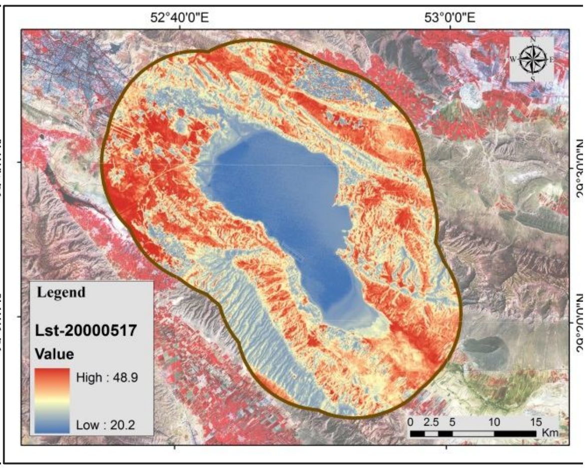

Figure 8. Temperature patterns extracted from the ETM+ images of Landsat Satellite in 2000 - Lake Maharlu buffer

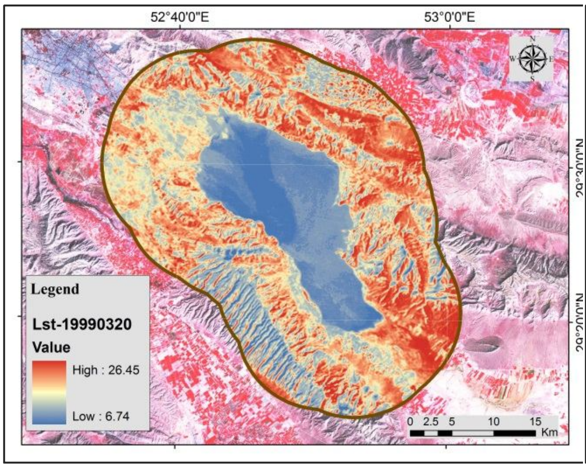

Figure 9. Temperature patterns extracted from TM images of Landsat Satellite in 1999 - Maharlu Lake buffer

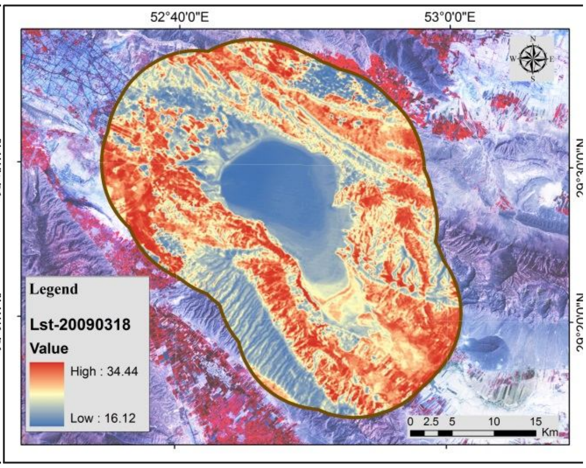

Figure 10. Temperature patterns extracted from TM images of Landsat Satellite in 2009 - Maharlu Lake buffer

Discussion and conclusions

The monitoring of changes in the area of Maharlu Lake showed that during wet years (water year of 1987) with a precipitation of 465 mm, the lake was full of water until October. In the water year of 1999 with a 450 mm precipitation, this supplied the required water of the lake until October. In the water year of 1999, however, where raining dropped below 200 mm, the lake faced severe drought in October, and in 2009, after two consecutive dry years (water years of 2007 and 2008), the lake was dry in August. In the next water year (2009), precipitation soared to 245 mm, but the situation did not change, and the lake remained dry in August. These conditions demonstrate the dire situation of the lake and its heavy dependence on rainfall. In years when rainfall is below average (300 mm), the lake goes dry in May. Conversely, in the years when precipitation is more than 400 mm, the lake experiences wet conditions in all months. The heavy dependence of the lake on rainfall, the small size of the catchment and the seasonality of the rivers flowing into the lake has severely affected the lake's conditions. Based on the above, it is essential to avoid construction of any dam, especially reservoirs, in this basin. Therefore, the construction of Tang Sorkhi dam in the northwest of the basin may impose irreparable damages on the lake. In general, the severe effects of fluctuations in lake water on the percentage of vegetation index compared to other variables should be taken into account. However, the drying of the lake due to the northwest direction of the prevailing wind can have devastating effects, including salinization and environmental problems for the areas on the east of the lake .

Moreover, given the considerable tourism and ecological potentials of the lake (Manafi and Hayati, 2010; Nairi, 2013), it is necessary to preserve and protect the lake, both quantitatively (the area of the lake), and qualitatively (water quality of the lake) in light of the non-biological constraining conditions, such as high salinity which is up to 300 g/L, and relatively high water temperatures, which contain *Artemia parthenogenetica* (Hafezia, 2002: 11). A comparison of the results of other studies indicates that the diminishing trend of lakes and wetlands in Iran, especially those in critical conditions (Mahsafar *et al.*, 2010) has turned into a regular and probable phenomenon. The threats of diminishing level of water in the past few decades (Ale Sheikh *et al.*, 2005; Rasouli *et al.*, 2008) and complete drying of the permanent aquifers of Iran are serious. The greatest impact of fluctuations in the lake water is on the minimum temperature of Shiraz, so that the minimum temperature in the wet year (1987) was 17.2 °C, revealing a 2.2 °C increase compared to the long-term average (23.06. 2012). In the dry year (2000), the temperature was 20.8 °C, which is 6.3°C higher than the average long-term and 3.6 °C greater than its corresponding day in 1987. In general, an increase in major temperature elements of 2000 and 2009 compared to that of 1987 and 1999 can be observed in the synoptic station of Shiraz.

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