Environ Monit Assess (2016) 188: 462
DOI 10.1007/s10661-016-5456-3

Investigating the causality of changes in the landscape pattern of Lake Urmia basin, Iran using remote sensing and time series analysis

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Received: 19 November 2015 / Accepted: 27 June 2016 / Published online: 12 July 2016

Abstract Lake Urmia is the second largest hypersaline lake in the world in terms of surface area. In recent decades, the drop in water level of the lake has been one of the most important environmental issues in Iran. At present, the entire basin is threatened due to abrupt decline of the lake's water level and the consequent increase in salinity. Despite the numerous studies, there is still an ambiguity about the main cause of this environmental crisis. This paper is an attempt to detect the changes in the landscape structure of the main elements of the whole basin using remote sensing techniques and analyze the results against climate data with time series analysis for the purpose of achieving a more clarified illustration of processes and trends. Trend analysis of the different affecting factors indicates that the main cause of the drastic dry out of the lake is the huge expansion of irrigated agriculture in the basin between 1999 and 2014. The climatological parameters including precipitation and temperature cannot be the main reasons for reduced water level in the lake. The results show how the increase in irrigated agricultural area without considering the water resources limits can lead to a regional disaster. The approach used in this study can be a useful tool to monitor and assess the causality of environmental disaster.

Keywords Lake Urmia basin · Time series analysis · Remote sensing

Introduction

Lake Urmia is located in the center of an endorheic basin. Due to its ecological values, the lake is internationally registered as a UNESCO biosphere reserve and a Ramsar site (UNESCO 2009) and is assigned as a national park. In recent decades, the drop in water level of the lake has been one of the most important environmental issues in Iran. At present, the entire basin is threatened due to abrupt decline of the lake's water level and the consequent increase of salinity (Khatami and Berndtsson 2013). In these circumstances, saving the lake is considered necessary for sustainable development of the entire region. Furthermore, determining the causal factors for the declining lake level is a prerequisite for dealing with the issue.

Many studies have been conducted to detect and forecast the changes of the lake surface area and to

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determine the main factors contributing to the decline of the lake water level (Abbaspour et al. 2012; Alesheikh et al. 2007; Farzin et al. 2012; Fathian et al. 2015; Hassanzadeh et al. 2012; Kakahaji et al. 2013; Karimi and Mobasheri 2011; Kavehkar et al. 2011; Rokni et al. 2014; Sima et al. 2012; Sima and Tajrishy 2013; Tisseuil et al. 2012). Using remote sensing techniques, Alesheikh and his colleagues found that the area of the lake has decreased by 1040 km^2 from August 1998 to August 2001 (Alesheikh et al. 2007). Based on another study, there was an intense decreasing trend in the lake's surface area between 2000 and 2013; and between 2010 and 2013 the lake lost about one third of its surface area (Rokni et al. 2014). To determine the main causal factor of the lake level depletion, a simulation model based on a system dynamics method has been developed by E. Hassanzadeh and her colleagues. They claim that based on the study's results, changes in inflows due to climate change and overuse of water resources are the main forces causing the decrease in the lake's water level (Hassanzadeh et al. 2012).

Despite the numerous studies, there is still an ambiguity about the main cause of this disaster. Environmental bodies consider the dam building on upstream rivers as the main factor while the water companies claim that the climate change and less precipitation is the primary reason (Hassanzadeh et al. 2012).

Landscape pattern changes, as a result of human activities, are reflected in spatial and temporal distribution of water resources during large-scale development of land resources (Wang and Wang 2013). Therefore, it seems meaningful to detect and analyze the pattern dynamics of the main related landscape elements in order to study the water resource dynamics. Quantifying the dynamics of land use pattern in water consumer elements can be a useful tool to support decisions and policies in water resources management.

With emerging of new technologies such as remote sensing, geographic information system (GIS), and statistical models, the spatial pattern of landscape and its dynamics can be mapped and quantified in a reliable way (Yang and Lo 2003; Zha et al. 2008).

Land use change and its consequences have received worldwide attention since the 1990s (Turner et al. 1993) and since then, this issue has been largely researched (Luo et al. 2008). This paper is an attempt to detect the changes in the main landscape structure elements of the whole basin using remote sensing techniques and analyze the results against climate data with time series analysis for the purpose of achieving a more clarified illustration of processes and trends.

Material and methods

Study area

The Urmia lake basin, northwest part of Iran, covered an area of 51,974 km^2 and lies between latitude 35° 40′ to 38° 29′ N and longitude 44° 14′ to 47° 53′ E (Fig. 1). Based on political boundary, the basin lies amid the three provinces (East Azarbaijan, West Azarbaijan, and Kurdistan) and the lake is divided almost equally between East Azarbaijan and West Azarbaijan (Banihabib et al. 2015).

Climate in the lake's basin is affected by the mountains surrounding the lake and there is considerable seasonal variation in the air temperatures: usually between 0 and −20 °C in winter and up to 40 °C in summer (Ghaheri et al. 1999). The climate is specified by cold winters and temperate summers (Rokni et al. 2015). The mean annual precipitation and evaporation (over a 30-year interval) over the lake area are about 350 mm, and 900–1170 mm, respectively (Sima et al. 2013).

In terms of surface area, Lake Urmia is the 20th in the world and it is also the second hypersaline lake in the world (Alesheikh et al. 2007). There are about 60 rivers (permanent and episodic) in the basin area of the lake which almost all of them flow through agricultural, industrial and urban areas befor reaching the lake (Ghaheri et al. 1999; Rokni et al. 2015).

As a consequence of rapid population growth in the region, increased nearly 73 % from 1976 to 2000 (ISCE 2011), agricultural area in Lake Urmia basin has been rapidly increased. Since then, many environmental interfering projects such as dams and irrigation and drainage systems have been implemented to supply increasing water demands (Abbaspour and Nazaridoust 2007). Local offices in each province take care of the water projects in their own borders (Hassanzadeh et al. 2012). Water demand for agricultural use had been about 3482 MCM in 2003 and it is expected to reach about 4300 MCM in 2020 (WRI 2006). Total water consumption in industrial and domestic uses had been about 400 MCM which will be around 619 MCM in 2020 (WRI 2006).

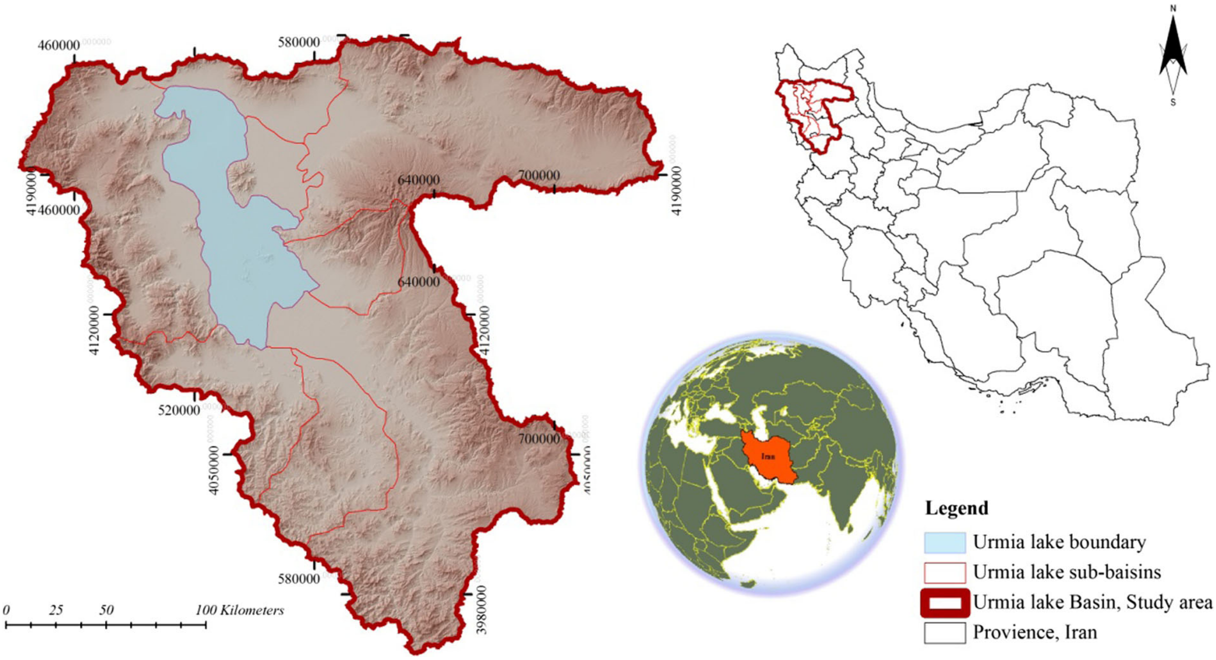


Fig. 1 The study area, Lake Urmia basin, geographical location

Data used

To determine the lake area changes (from 1974 to 2014, for each 4 years), images of MSS, TM, ETM and ORI and TIRS sensors on Landsat satellites were used. The property of these satellite images are presented in Table 1. Due to the seasonal variation of lake level (Karimi and Mobasheri 2011), images from the same season are utilized. It must be noticed that more than one scene of Landsat Images are needed to cover the area of the lake. In order to analyze the changes in landscape structure of the whole basin area 21 satellite images for 1984, 1999 and 2014 have been processed. To cover the basin, seven scenes of Landsat Images are needed (Table 2).

The satellite images were pre-geo-referenced; however, to make sure of the accuracy, all images were examined and edited geometrically and projected in the Universal Transfer Mercator (UTM) coordinate system before starting the process. To minimize the depiction of changes due to atmospheric conditions and sensor differences, radiometric corrections were applied. Climatological data, including monthly precipitation and mean temperature, was gathered from all synoptic station existed in the Lake Urmia basin to examine climatological trends. Other data used in this study are ancillary data such as Digital Elevation Model (DEM), shape file data sets of boundaries, cities, synoptic stations, existed land cover maps of the study area and etc.

Data processing

Based on the expert judgment about the main causes of the lake dry out and considering the approach of the study, changes in the extend of urban, irrigated agricultural area and the lake surface area and also changes in climatological factors including precipitation and temperature were selected to be analyzed specially and temporally though the whole basin area. To determine the accurate boundary of Lake Urmia basin as the study area, a hydrological analyst was conducted using DEM of the three provinces surrounding the lake. ArcMap software (ESRI 2004) was used to execute this process.

All image processing was undertaken in the eCognition Developer software (Definiens 2005) which is a powerful environment for Object-Based Image Analysis (OBIA). It is increasingly acknowledged that an Object-Based Classification (OBC) yields higher accuracy than the traditional Pixel-Based Classification (PBC) approach (Cleve et al. 2008). This is mainly due to the more spatial information which can be

Table 1 Characteristics of satellite images used to detect the changes of Lake Urmia surface

Year	Number of scenes to cover the lake surface	Julian day	Satellite/sensor	Cloud cover	Resolution		
					Spatial (m)	Radiometric (bit)	Spectral (band)
1974	2	157, 156	Landsat 2/MSS	2 , 1	60	6	4
1978	2	199, 182	Landsat 2/MSS	1, 33	60	6	4
1982	2	255, 218	Landsat 3/MSS	2, 0	60	6	4
1986	3	252, 252, 165	Landsat 5/TM	0, 10, 0	30	8	7
1990	3	231, 231, 232	Landsat 5/TM	0, 10, 10	30	8	7
1994	3	197, 197, 216	Landsat 5/TM	0, 0, 39	30	8	7
1998	3	237, 237, 230	Landsat 5/TM	0, 0, 0	30	8	7
2002	3	256, 272, 249	Landsat 7/ETM+	0, 1, 0	30	8	8
2006	3	243, 243,204	Landsat 5/TM	0, 0, 0	30	8	7
2010	3	222, 22, 231	Landsat 5/TM	0, 1, 0	30	8	7
2014	3	217, 217, 226	Landsat 8/OLI and TIRS	3, 1, 3	30	16	11

made in the OBC approach, such as image texture, geometric attributes of features and contextual information (Burnett and Blaschke 2003; Blaschke 2010). Time series analysis of all data was conducted in R software (RDevelopmentCoreTeam 2005).

Precipitation and temperature

Based on data availability and location of weather stations in the basin, monthly precipitation and temperature data of seven synoptic stations is analyzed to examine the trend of climatological factor in the basin area. Precipitation and temperature data for each station from 1984 to 2014 were imported in R software as time series data separately. To assign the portions of the basin to each station, Thiessen polygons method have been conducted. The location of these synoptic stations in the basin, the boundary of Thiessen polygons and the plots of precipitation time series for each station are illustrated in Fig. 2. Thiessen-area weighted mean (TAWM) of all stations was calculated to obtain a single precipitation time series (Fig. 3) and a single temperature time series which stand for the whole basin area. Figure 4 shows the plots of temperature time series for each station and a TAWM of all stations as temperature time series of the whole basin.

In order to examine the trend of precipitation and temperature, Mann-Kendall test (Mann 1945; Kendall 1975) was used. Mann-Kendall is a rank-based nonparametric statistical test which has been commonly applied to assess the significant of trends in precipitation and temperature data (Hamed and Rao 1998; Yue et al. 2002). This test as a non-parametric method has the advantage of being insensitive to the form of the data

Table 2 Characteristics of satellite images used to detect the changes in the landscape structure of the basin

Year	Number of scenes	Julian day	Satellite/sensor	Cloud cover	Resolution		
					Spatial (m)	Radiometric (bit)	Spectral (band)
1984	7	231, 231, 240, 240, 240, 233, 192	Landsat 5/TM	0, 10, 0, 10, 10, 20, 10	30	8	7
1999	5	184, 184, 193, 193, 186	Landsat 7/ETM+	0, 4, 0, 1, 0	30	8	8
	2	217, 226	Landsat 5/TM	0, 20	30	8	7
2014	7	217, 217, 226, 226, 226, 219, 219	Landsat 8/OLI and TIRS	3, 1, 0, 3, 25, 0, 0	30	16	11

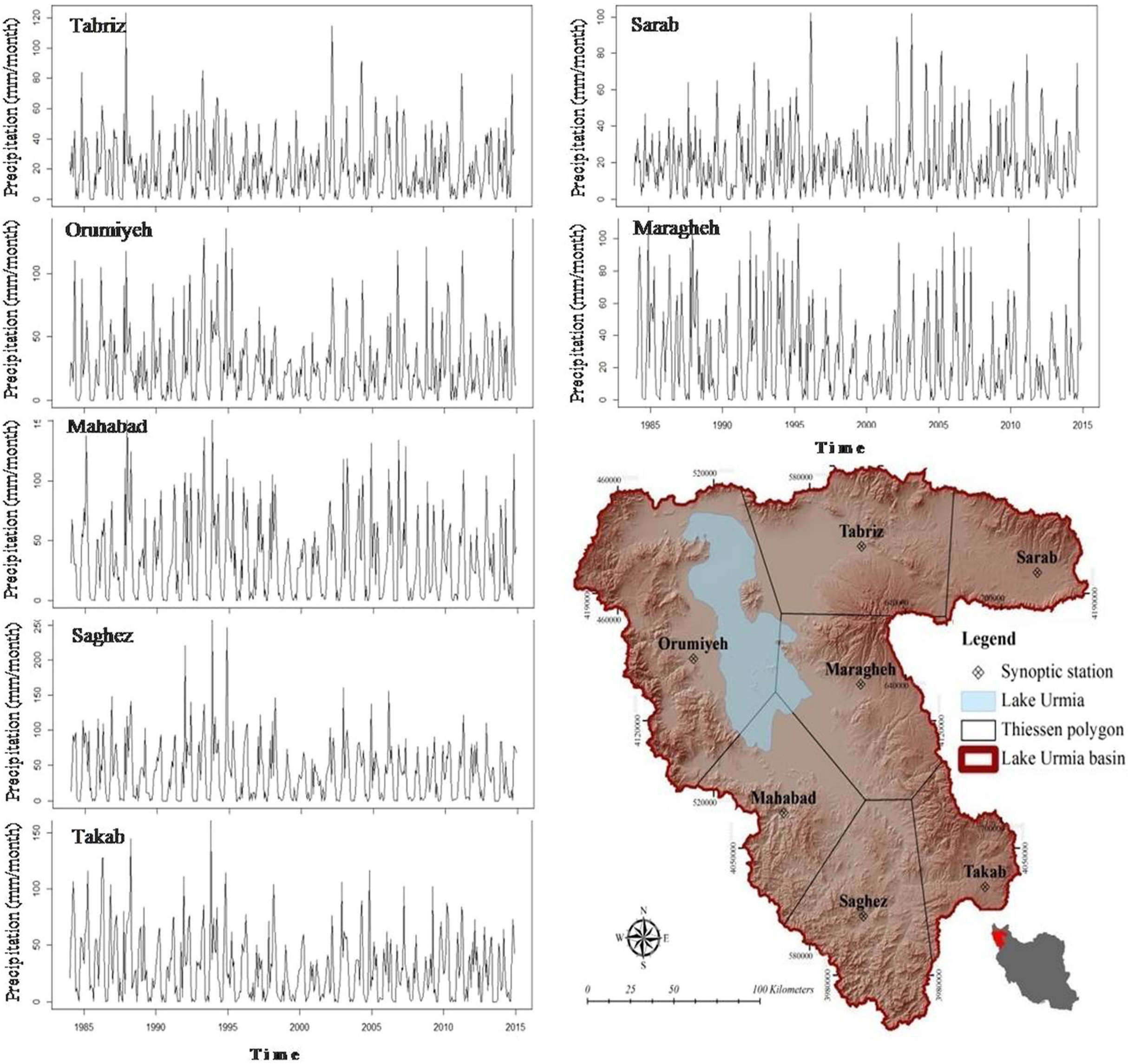
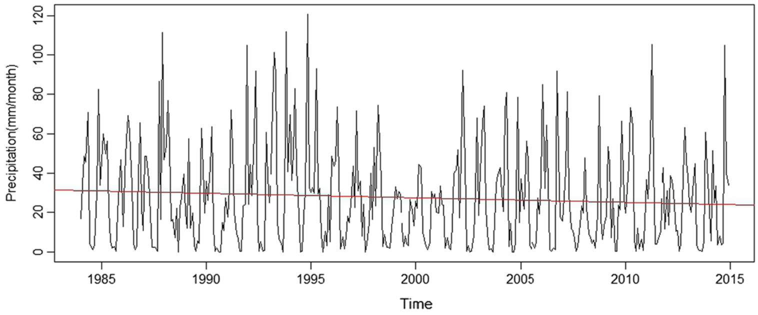


Fig. 2 Monthly precipitation data (1984–2014) for each synoptic station in Urmia basin, location of the stations and Thiessen polygons

Fig. 3 Thiessen-Area Weighted Mean (TAWM) of all stations as precipitation time series of the whole basin, and corresponding linear trend line



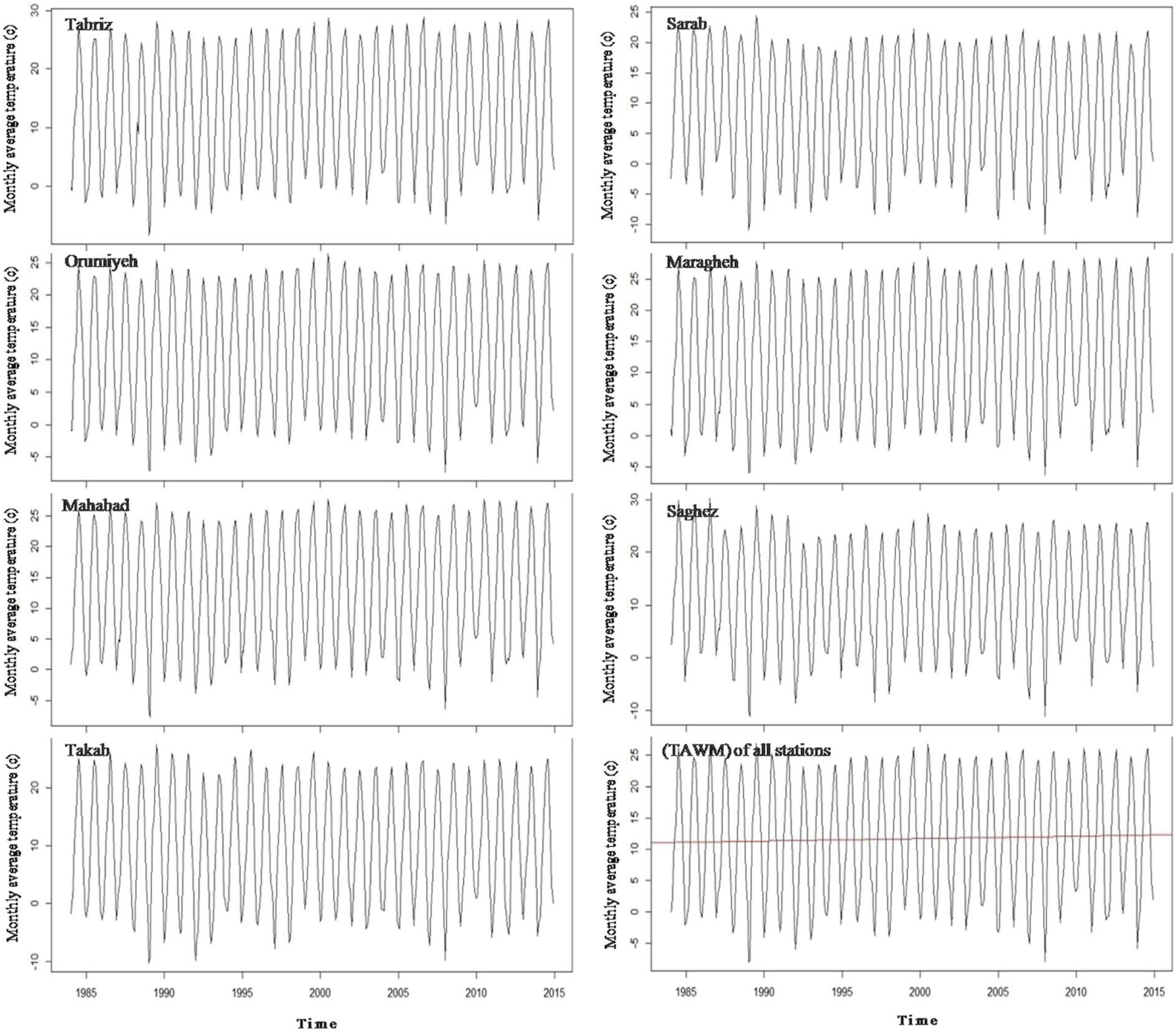


Fig. 4 Monthly average temperature data (1984–2014) for each synoptic station in Urmia basin, and the Thiessen-Area Weighted Mean (TAWM) of all stations as temperature time series of the whole basin with a corresponding linear trend line

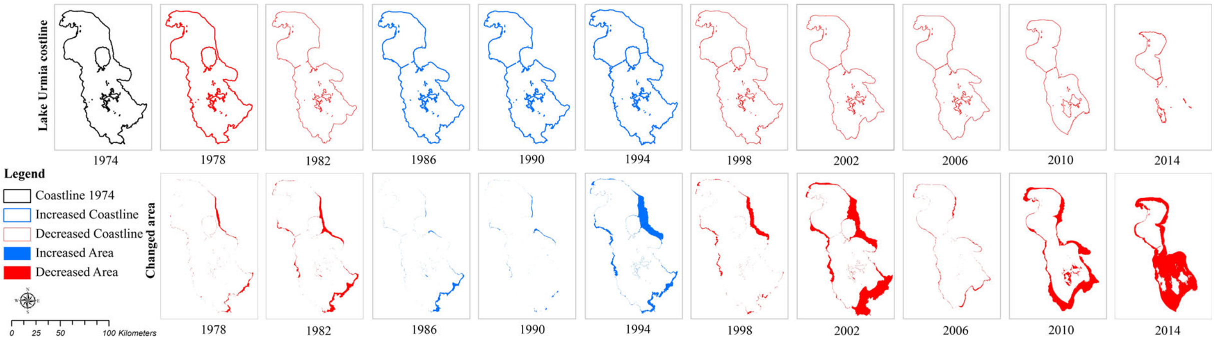


Fig. 5 Lake Urmia surface change detection during the past 40 years (from 1974 to 2014)

distribution (Serrano et al. 1999). The null hypothesis (H_0) is that there is no trend among the observations. In order to ignore the seasonal trend in trend analysis, the annual aggregation of precipitation and the annual mean of temperature were used as input data.

Landscape structure dynamics

In order to obtain the thematic maps of Lake Urmia surface, and irrigated agricultural and urban area from satellite images using an OBC approach, eight steps were applied: (1) determining the optimal parameters for segmentation in each satellite image; (2) applying segmentation; (3) classification; (4) editing the classification results manually using manual tool embedded in eCognition software; (5) merging the objects assigned to each class; (6) importing the results as vector layers to ArcMap software; (7) mosaicing the thematic maps of same years into a single thematic map covering the whole basin; and (8) accuracy assessing.

Segmentation groups the pixels of an image into objects based on spectral behavior, shape and context (Benz et al. 2004). In this study, *Multiresolution Segmentation* (*MS*) which is a bottom-up region-merging technique (Darwish et al. 2003), was used for image segmentation. The merging process in MS is based on Homogeneity Criterion (HC) and Scale Parameter (SP). HC is a combination of spectral values and shape properties (smoothness and compactness), and SP is a threshold to terminate the process of merging (Darwish et al. 2003). To obtain meaningful objects, the HC and SP for segmentation in different satellite images (different sensor) were determined by using a trial and error approach and visual interpretation.

In all image segmentation processes, the weight of spectral values and shape properties were 0.9 and 0.1, respectively; the shape factor was divided between compactness and smoothness equally. SP for images of MSS, TM, ETM+ and OLI and TIRS sensors were chosen to be 12, 20, 53 and 122, respectively. This difference in SP is because of the differences in image resolution.

To classify irrigated agricultural area and water body (the lake area), Normalized Difference Vegetation Index (NDVI) (Equation1) and a Land and Water Mask (LWM) (Eq. 2) were applied. NDVI is the ratio of the difference between Near-Infra-Red reflectance (NIR)

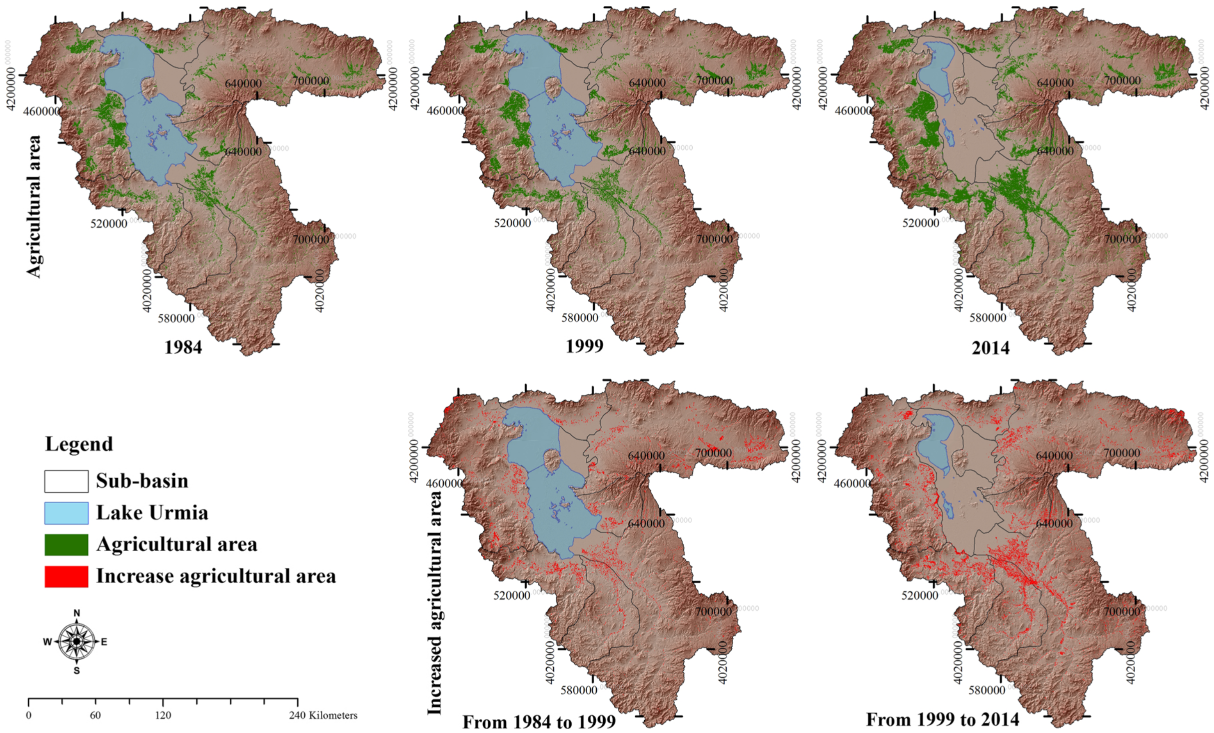


Fig. 6 Irrigated agricultural area (in 1984, 1999 and 2014), and the changes

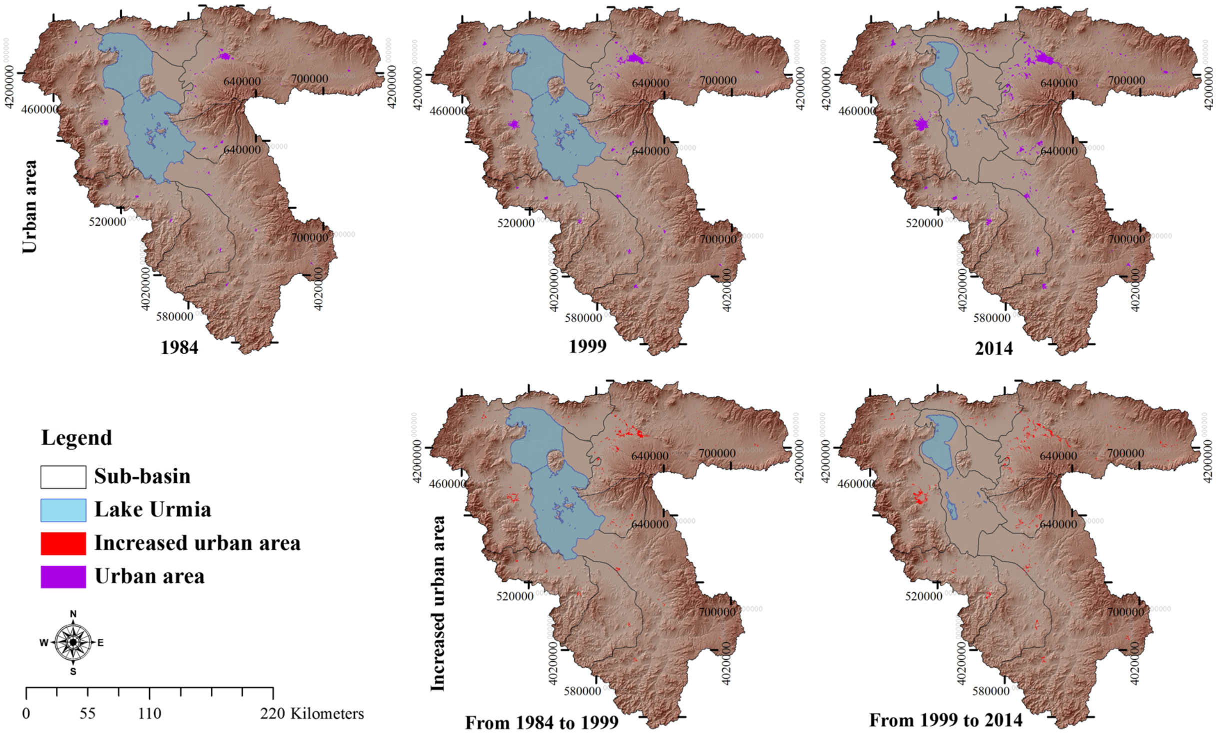


Fig. 7 Urban area in Lake Urmia basin in 1984, 1999 and 2014, the changes in urban area

and red visible reflectance to their sum (Tucker 1979; Deering 1978). In recent decades, NDVI has been widely used as an indicator of plant photosynthetic capacity and efficiency with the applications such as detecting green biomass and vegetation productivity (Tucker et al. 2005; Benedetti and Rossini 1993; Tucker et al. 1986). LWM is a ratio of mid-infrared reflectance (MIR) to green visible band. To calculate these indexes for each object mean of pixel values was applied.

$$\mathrm{NDVI} = \frac{NIR_{\mathrm{mean}} - red_{\mathrm{mean}}}{NIR_{\mathrm{mean}} - red_{\mathrm{mean}}} \tag{1}$$

$$LWM = \frac{MIR_{\mathrm{mean}}}{\mathrm{green}_{\mathrm{mean}} + 0.0001} * 100 \tag{2}$$

In this study, irrigated agriculture including orchard or crop fields is considered as areas located in agricultural zone with high level of NDVI. Every object with an NDVI more than 0.22 was assigned to irrigated agriculture except the objects that were not located in agricultural zone. To extract the lake surface area, a threshold of 49 in LWM was used. For MSS images without MIR band, the object of the lake surface was selected manually based on a visual interpretation in different color composites. The thresholds were deter-

Table 3 Changes in irrigated agricultural area in the Lake Urmia basin

Year	Irrigated agricultural area (ha)—in the basin	Changes in 15 years Area (ha)	Area (%)
1984	303,588	_	_
1999	332,494	28,906	9.5
2014	508,660	176,166	53

Table 4 Changes in urban area in the Lake Urmia basin

Year	Urban area (ha)—in the basin	Changes in 15 years Area (ha)	Area (%)
1984	17,394	_	_
1999	31,462	14,068	81
2014	55,935	24,472	77

Table 5 Changes in the area of the Lake Urmia, and mean annual temperature and precipitation in the basin

Year	Lake Urmia surface (ha)	Changes in 4 years		4 years-mean of climatological parameters in the basin	
		Area (ha)	Area (%)	Precipitation (mm)	Temperature (°c)
1974	543,555	_	_	_	_
1978	529,233	−14,321	−2.63	_	_
1982	494,818	−34,414	−6.58	_	_
1986	508,298	13,479	2.72	377	11.7
1990	510,816	2518	0.49	315	11.4
1994	584,266	73,449	14.3	444	10.4
1998	554,294	−29,972	−5.12	310	11.5
2002	424,120	−130,173	−23.4	263	12.3
2006	412,073	−12,047	−2.84	337	11.8
2010	301,242	−110,830	−26.8	270	12.1
2014	102,247	−198,995	−66	327	11.7

mined based on a trial-and-error approach. After trying different methods to classify the urban area, it was realized that manually assigning objects of urban area based on visual interpretation gives the best results. To finding the location of each city on the images, a point-shape file of cities of the basin was used.

In order to assess the accuracy of the results, 200 points were randomly selected as. The reference data for this points was collected from field survey, existed land use maps, aerial photos, Google earth images and the information provided by the local residents. Overall accuracy of the land types in this study ranged from 88 % to 95 % for different years.

Figure 5 presents the maps of changes in the Lake Urmia coastline from 1974 to 2014 (in each 4 years). In this map, the increased and decreased coastline and area in each 4 years are highlighted by blue and red colors. The changes in irrigated agriculture and urban area are illustrated in Figs. 6 and 7, respectively; the increased area in these land uses in each 15 years is emphasized in red.

Results and discussion

The results of the landscape structure analysis indicated that population rapid increase in the Lake Urmia basin has led to a significant increase in urban and irrigated agricultural areas. The area of irrigated agricultural land increased by 9.5 % from 3035 km^2 in 1984 to 3324 km^2

Table 6 Result of Mann-Kendall test for precipitation data for Lake Urmia basin

Station name	Mean annual precipitation (mm) (1984–2014)	Mann-Kendall test				Test interpretation
		S	Var(S)	tau	2-sided *P* value	
Tabriz	241	−21	3461	−0.0452	0.7339	*H0*Not rejected
Sarab	242	84	3460	0.181	0.1582	*H0*Not rejected
Orumiyeh	313	−23	3461	−0.495	0.7084	*H0*Not rejected
Maragheh	302	−191	3461	−0.411	0.0012**	*H0*Rejected
Mahabad	402	−43	3461	−0.0925	0.4753	*H0*Not rejected
Saghez	460	−115	3461	−0.247	0.0526	*H0*Not rejected
Takab	350	−118	3460	−0.254	0.0511	*H0*Not rejected
(TAWM) of all	238	−97	3461	−0.209	0.1027	*H0*Not rejected

** indicates values significant at $p<0.01$ level

Table 7 Result of Mann-Kendall test for temperature data for Lake Urmia basin

Station name	Mean annual temperature (c) (1984–2014)	Mann-Kendall test S	Var(S)	tau	2-sided *P*-value	Test Interpretation
Tabriz	12.75	219	3461	0.471	0.0002**	H_0Rejected
Sarab	8.8	−55	3459	−0.119	0.3585	H_0Not rejected
Orumiyeh	11.31	192	3460	0.413	0.0011**	H_0Rejected
Maragheh	12.83	251	3461	0.54	0.000021463**	H_0Rejected
Mahabad	13.05	200	3460	0.431	0.00071**	H_0Rejected
Saghez	11.43	−50	3460	−0.108	0.4048	H_0Not rejected
Takab	10.16	−84	3460	−181	0.1582	H_0Not rejected
(TAWM) of all		131	3461	0.282	.0271*	H_0Rejected

*indicates values significant at $p<0.05$ level; ** indicates values significant at $p<0.01$ level

in 1999 and 53 % from 3324 km^2 in 1999 to 5086 km^2 in 2014 (Table 3). The area of urban land increased by 81 % from 173 km^2 in 1984 to 314 km^2 in 1999 and 77 % from 314 km^2 in 1999 to 559 km^2 in 2014 (Table 4).

Table 5 shows the changes in the Lake surface area from 1974 to 2014 (in each 4 years). The lake decreased by almost 9 % from 1974 to 1982; increased by 17.5 % from 1982 to 1994; and decreased by 82.5 % from 1994 to 2014.

The results of Mann-Kendall test for precipitation data in each station and TAWM of them and the same results for temperature data are presented in Tables 6 and 7, respectively. If the *P* value is less

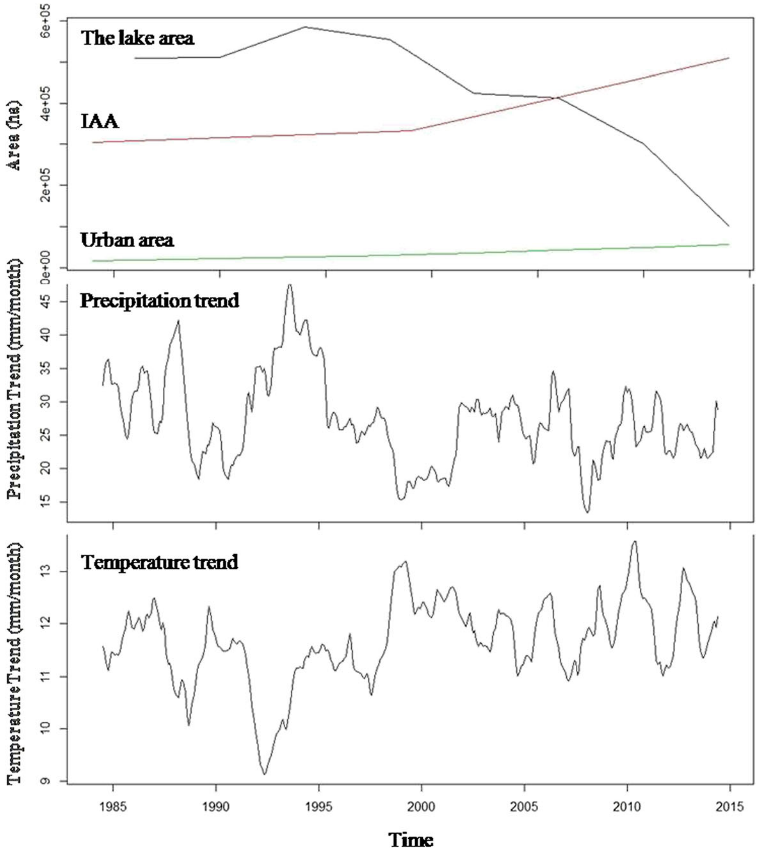


Fig. 8 The multiple time series of structural and climatological parameters from 1984 to 2014

than the significant level (0.05), H_0 is rejected; it means that the trend is significant. Based on the results for precipitation data, only for one station (Maragheh) H_0 has been rejected (i.e., there is a significant trend in precipitation). Considering the Mann-Kendall score which is a negative number for this station, it is proved that a descending trend of precipitation have been occurred in this station from 1984 to 2014. The TAWM of all stations in precipitation data shows the P value 0.1027 which means H_0 is not rejected. Therefore, it can be suggested that the precipitation has not been significantly decreased or increased in the basin from 1984 through 2014.

According to the results of Mann-Kendall test for temperature data, there have been a significant ascending trend in Tabriz, Orumiyeh, Maragheh and Mahabad stations. In the three other stations (Sarab, Takab and Saghez), there is an insignificant descending trend. Temperature trend for whole basin, based on the TAWM of all stations is significant at *5 %* probability level and not significant at *1 %* probability level. It should be noticed that the four stations with a significant ascending trend in temperature are the closest ones and the three others with an insignificant descending trend are the remotest ones to the lake. According to these results and considering the significant descending trend of the lake surface area, it can be claimed that the lake dry-out is likely one of the causes of increased temperature around the lake which consequently, increases evapotranspiration levels in the region.

In order to present a better view of changes in the Lake Urmia basin, Fig. 8 shows the multiple time series of structural and climatological parameters in a single picture.

Before 1999, the irrigated agricultural area has being extended with a low rate. In this period, the Lake surface changes have been mainly due to the changes in the precipitation amount. From 1974 to 1998, the lake surface increased by 2 %. It can be mentioned that the high level of precipitation in 1990 to 1994 with an annual mean of 444 mm is the reason of increase in the lake area by 14 % in this period. After 1999, the irrigated agricultural area has been grown with a high rate. In this period, even with increasing the precipitation amount in some periods (in the basin), the lake surface is still shrinking. For instant, the lake surface decreased by 2.84 % from 2002 to 2006 while the mean annual precipitation in this period increased by 74 mm comparing to the last period (1998 to 2002); and it decreased by 66.06 % from 2010 to 2014 while the mean annual precipitation in this period increased by 57 mm comparing to the last period (2006 to 2010).

Considering the results of man Kendal test (Table 6) in which there is not a significant descending trend in precipitation; and also the annual mean (for each 4 years) of precipitation data (Table 5), it is proved that precipitation changes are not significantly contributing in the drastically descending trend of the lake dry out. Based on the results, large expansion of irrigated agricultural area in the Lake Urmia basin especially after 1999 is the main reason of severe descending trend of the lake surface.

Comparing to the other studies conducted to determine the main factor contributing to the decline of the Lake Urmia water level (Abbaspour et al. 2012; Alesheikh et al. 2007; Farzin et al. 2012; Fathian et al. 2015; Hassanzadeh et al. 2012; Kakahaji et al. 2013; Karimi and Mobasheri 2011; Kavehkar et al. 2011; Rokni et al. 2014; Sima et al. 2012; Sima and Tajrishy 2013; Tisseuil et al. 2012), this study has been used a new approach. In this study, all affecting factors including land use dynamics and climatological parameters were investigated simultaneously using proper tools and techniques. One major difference of this study is that the changes in the whole area of the Lake Urmia basin have been detected. Since the lake is located in the center of an endorheic basin, changes in all areas of the basin can affect the lake.

Conclusion

To investigate the causality of changes in Lake Urmia surface, an integrated approach including remote sensing, time series analysis, geographical processing and landscape ecology concepts were used in this paper. Several scenes of Landsat images were processed to reveal the temporal and spatial changes in the Lake surface, irrigated agriculture and urban area in the basin. Trend analysis of the different affecting factors indicates that the main cause of the drastic dry out of the lake is the large expansion of irrigated agriculture in the basin between 1999 and 2014 and climatological parameters including precipitation and temperature could not be the main reasons. The results show how the increase in irrigated agricultural area without considering the water resources limits can lead to a regional environmental crisis. The approach used in this study can be a useful tool to monitor and assess the causality of environmental crisis.

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