

INVESTIGATION OF 2019 RAINFALL EFFECTS ON URMIA LAKE SURFACE AND EXTRACTION OF LAKE SHORELINE CHANGES AND COMPARISON WITH THE PREVIOUS DECADE USING REMOTE SENSING IMAGES AND GIS

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ABSTRACT:

Urmia Lake has experienced many fluctuations during recent decades, which played a key role in the socio-economic changes in the north-western part of Iran. Consequently, socio-economic planning and land management around the lake require anticipation of changes' trend. In this paper, regarding continual rainfall in the beginning of 2019, shoreline and water level changes of this lake have been studied and compared to the previous decade. To this aim, Landsat satellite imagery (OLI, ETM and TM sensors' images) was used to extract NDWI index by using Green and NIR bands. The results of this study showed that Urmia Lake has declined over the past ten years and reached its lowest level in the year 2015. However, due to rainfall of 2019, these changes have had ascending trend which made water area equal to the situation in 2010. It, also was observed that similar to the trend of water level, the shoreline has progressed toward the Lake from the east and the south and become salt marsh. But, the West and the North parts have not changed significantly. Then, in 2019 salt marsh lands have been submerged once again, and the vast eastern island, which was completely blended in with the surrounding lands, returned to its previous state, the peninsula. In addition, considering the trend of rainfall and Lake's restoring activities, the minimum and maximum time required to reach the area in 2010 were estimated 23 and 38 years respectively, assuming the volume of precipitation remains constant and the reduction of these activities at a constant rate.

1. INTRODUCTION

Urmia Lake is the largest saline lake in Iran and plays imperatively significant role in ecological, subsistence, economic and social, flood flows' control and sustainability of region's ashore (Çimen, Kisi, 2009). Also, it helps to moderate temperature and humidity in surrounding and supplies an appropriate place for agricultural activities (Hoseinpour et al 2010). However, water level of Urmia Lake has levelled off remarkably. Changes of Water level cause negative alternations in basin such as increasing of saline areas, widespread of dust, considerable temperature fluctuations, reduction of crops and lessening of annual rainfall in its zone. During previous decade, 10 percentage of lands been converted to saline under this lake's water (Karbassi et al, 2010) and from 1955 to 2014 its level has decreased about 80 percent (Kamran et al, 2018).

Urmia Lake, known the second largest hypersaline lakes on earth (Karbassi et al, 2010) and accounted as a preserved water land since 1967 (Fathian et al, 2014b) with more than one hundred islands (Schulz et al, 2020), during consecutive years, it has faced with decreasing and increasing changes. Human behaviour, climate changes and rainfall's amounts have caused such changes in this basin, and in recent decade it has reached to quarter comparing to prior decades (Hassanzadeh et al, 2010).

Progressive drying causes disastrous damages, and desertification results climate changes, reduction of water resources and financial income of agricultural industry, declining of ship diversity, population migration from connected area or Lake District, threaten of physical and mental health (Taravat et al, 2016). The minimum level of water happened in the year 2015 up to this time (Haghi et al, 2016).

Lake's changes, in recent years, have been a regional and national challenge, and its restoration is essentially vital plans of government (Abdoli et al, 2018). Recent rainfall during March and April in 2019, has given a promise about lake's restoration which has captivated environmentalists' attention and agitation. This study has investigated changes occurred in water level

surface, its shoreline fluctuations and comparison with previous decade.

Remote sensing technology for monitoring changes is widely used in different applications such as land use/cover (Ross et al, 2015), change disaster, monitoring, forest and vegetation changes, urban sprawl, and hydrology (Taravat et al, 2016). The knowledge about water resources can be efficiently improved by the use of remote sensing which includes radar, microwave, infrared, and visible sensors. There are various methods for Land Cover change detection had particular function to extract different phenomenon's changes and distinctive consequences (Mishra et al, 2017). The exploitation of satellite data about water bodies provide reliable information for the assessment of present and future water resources, climate models, agriculture suitability, river dynamics, wetland inventory, watershed analysis, surface water survey and management, flood mapping, and environment monitoring, which are critical for sustainable management of water resources on the Earth (Yangab et al 2017; Taravat et al, 2016). In miscellaneous related literatures to analyse water volume variation, remote sensing has been used very often.

Extraction surface level of waters, lakes, rivers and seas are mostly based on hydrological modeling (Hassanzadeh et al, 2010), water index difference NDWI (Ouma et al, 2006; Zareei et al, 2017; Tan et al, 2018), bands ratio and L-V-NSCT (Xin et al, 2019) methods, which give more accurate results. Al Sheikh et al., 2005 used two the compounding algorithms, thresholding on the histogram of image and bands ration, to monitor Urmia Lake shoreline from 1989 to 2000 by using Landsat ETM 7 and Landsat TM 5, and area of Lake has decreased about 1040 KM² in mentioned period (Al Sheikh et al, 2007).

Zeynali and Asghari (2012) by using Landsat 7 images and statistical analysis of continental data, monthly discharge of the whole district from 1970 to 2005 as well as principal components analysis, estimated changing of Urmia Lake coastline in east shoreline, especially in eastern south (the permanent and lush river, Zarrine Rood) (Zeinali et al., 2015). Sehhat et al. (2015)

calculated lake area by using Landsat 7 satellite imagery at the beginning of each year from 2003 to 2013. They showed that over a period of 10 years, the area of lake has been decreased approximately 1800 KM² and has become salt-marsh. Besides, shoreline has converted to salt-marsh about 13.8 KM from eastern area and 6.2 KM from southern part (Dastranj et al., 2018). Zamani and Maleki (2005) investigated process of changes occurred from 1989 to 2005 by using remote sensing data (ETM Landsat 7, TM Landsat 5, and TM Landsat 4 and Aster) as well applying GIS. Results showed that during foresaid period reduction in amount of rainfall, deteriorating effects of manmade constructions such as building dams and extremely excessive exploitation of surface and underground water resources has predisposed to an eco-environmental crisis in Urmia Lake basin which initiated with a deduction in Lake water level, and resumption of its trend has caused desertification in the high quality agricultural lands (Zamani et al., 2010). Taravat et al. (2016) demonstrated the impacts of climate change and human pressure on the variations in surface extent and water level, Lake Sevan and Van Lake with different characteristics studied along with the Urmia Lake in the period 1975–2015 by using the multi-temporal satellite altimetry and Landsat (5-TM, 7-ETM+ and 8-OLI) images and investigated various indices NDWI, WRI, NDWI-PCs, NDMI, MNDWI for the extraction of surface water from Landsat data. The results showed that the area of Lake Sevan and Van Lake have increased, while the area of Lake Urmia has decreased by 65.23% in the past decades. Lake Shoreline has been receding severely between 2010 and 2015 with no sign of recovery (Taravat et al., 2016). Rokni et al. have extracted occurred changes in the year 2000 to 2013 for Urmia Lake. They used Landsat images and MNDWI, NDWI and NDWI-PCs indices to calculate Urmia Lake area, and accuracy of those indices has been estimated by Kapa. The results

indicated that NDWI index was more accurate than others (Rokni et al., 2014).

Abdollahi et al. (2017) has done another research to detect shoreline of Urmia Lake fluctuation and surrounding salt lands during 1976 to 2015 in which used Landsat satellite images and NDWI index. They found that Urmia Lake was receding about 1360 KM² from 2006 to 2011, and shoreline has considerably changed, specifically in the south and eastern south (Abdollahi et al., 2015). Therefore, based on previous studies, NDWI index has been selected to extract water level, and the goal of this research was to estimate the shoreline changes of Urmia Lake from 2010 to 2019, compare to each other and predict proper time required to reach aimed area amount, before the beginning of drought in 1990.

2. MATERIALS AND METHODS

2.1 Study Area

Located in north-west of Iran (37° 4'–38° 17' N and 45°–46° E), Urmia Lake is ranked 20th largest and second hyper saline lake in the world (Schulz et al., 2020). With a semi-rectangular shape, a maximum length of 135 KM, it covers an average area of 5,100 KM². The maximum and average depths of this lake are 16 and 5 meters, respectively (Ahmadi et al., 2015). The Lake encompasses a total of 102 islands among which is the Shahi, the biggest island, and covering 250 KM². About 30 main rivers, including 13 permanent and more than 17 seasonal ones, namely Zarinne Rood, Simine Rood, Mahabad Chai, Godarchai, Barandoozchai, etc. supply most of the inflow to the lake (4900 mm³ out of 6900 mm³) (Schulz et al., 2020). (Figure 1.)

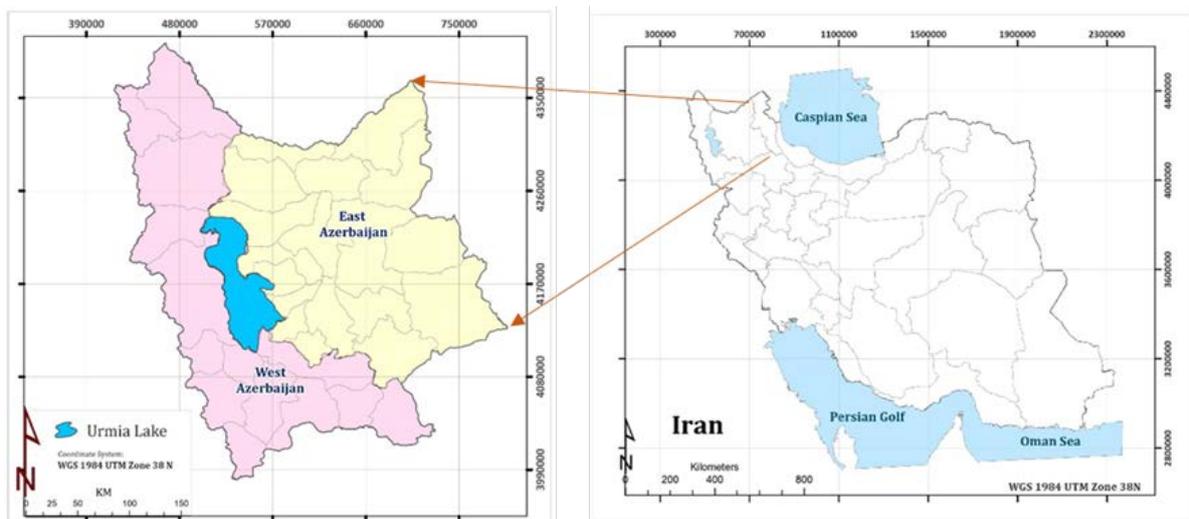


Figure 1. Geographic overview of Lake Urmia

2.2 Data

Remote Sensing technology enables the extraction of Land use/Land Cover and a variety of geomorphologic phenomenon possibility by producing periodic images, and by preparing such high-resolution images feasibility of natural phenomenon and dynamic trend of the environment change detections have been the subject of much research. Remote sensing satellites at different spatial, spectral, and temporal resolutions provide an enormous amount of data that have become primary sources,

being extensively used for detecting and extracting surface water and its changes in recent decades (Rokni et al., 2014). Landsat satellite images with acceptable resolution are an adequately sufficient source to data acquisition and include additional features that make it a more versatile and efficient instrument for global change studies, land cover monitoring and assessment, and large area mapping than its design forebears (Williams et al., 2006; Franklin et al., 2002). These images from 1999 to 2012 with 16 days period and from 2013 to present with 14 days period make it possible to monitor changes in Urmia Lake surface and other ones. In this study, Landsat 8 images for 2013 to 2019 and

Landsat 7 and 5 for 2010 to 2012 have been used, which are listed in table 1.

Satellite	Sensor	Date
Landsat 8	OLI	2019-04-13
		2018-04-26
		2017-04-09
		2016-04-20
		2015-04-18
		2014-04-24
Landsat 7	ETM	2012-04-10
Landsat 5	TM	2011-04-15
		2010-04-20

Table 1. List of Landsat Images to extract changes

2.3 Investigation of Changes by NDWI

It is obvious that before calculating and extracting physical parameters such as surface temperature, emissivity, surface reflective radiance or thermal and albedo radiometric correction of images are required. In this study, since the purpose was to investigate the water level of the Urmia Lake, just the atmospheric correction was done on the images. To this aim, we inserted image in MATLAB and subtracted the minimum DN values in the histogram from an entire scene from all pixels by considering essential data in each image from metadata (Fig 2). By this correction and processing required calculation, all features on the ground are detected simply.

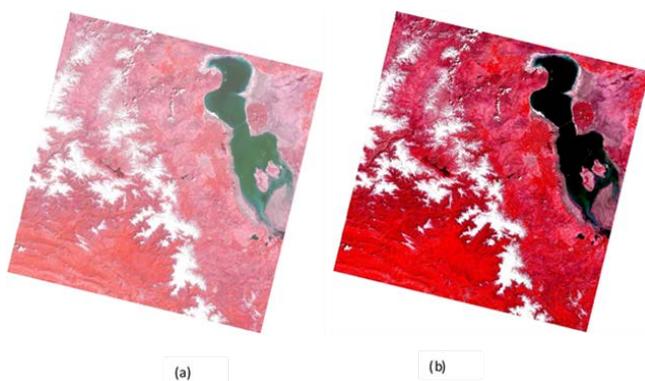


Figure 2. Atmospheric correction, a) image before correction, b) image after correction

The purpose of this paper is to identify changes in Urmia lake water between 2010 and 2019, water level was individually extracted at each slice of temporal scale. Therefore, by using images (TM, ETM, and OLI) NDWI index was calculated. A water to land threshold was estimated using non-automatic methods considering only two main classes, land and water. For this purpose, the appropriate threshold of water index was specified by tests and trials as well as a comparison with map outputs using visual interpretation. For the visual interpretation of water area the NIR band is the most suitable as it is absorbed by water and reflected by plants and the land. The result was a precisely digitized Urmia Lake surface from the Landsat NIR band. Reference maps were then extracted by visual interpretation. The following equation defines how this index was derived and shows the relation between bands.

$$NDWI = (Green - NIR) / (Green + NIR), \quad NDWI > 0 \quad (1)$$

Water spectral indices can enhance the difference between water bodies and background features. Thus, they have been widely used to extract and map surface water bodies based on multispectral satellite imagery. Urban surface water mapping faces an extreme overestimation phenomenon because certain types of objects such as shadow, dark roads and some artificial features may return similar values to water bodies after an index computation (Yangab et al., 2018). By default, in this index the values larger than zero are considered as water class. It is important in using this index to extract water pixels that the features placed out of maximum border of lake should be removed in order to do classification more accurate and quick (www.ulrp.ir). Water indices represent multi-band information into a band image with dual exponential histogram features, spatio-temporal changes of Urmia Lake area from 2010 to 2019. Considering 2010 reference map extracted by visual interpretation and calculating RMSE, NDWI index gave almost same accuracy of previous studies and was accomplished as a reliable method monitoring the coastline of Lake Urmia. Having obtained raster of results by NDWI index, it was converted to vector in order to conduct statistical and vector analysis. Then, finalized polygons were compared together during 10 years period.

In shoreline calculation, we overlooked island and bridge path to get a rough result. Also, to get a complete frame of Lake, two or more images have been combined in the same date in some years. (Fig 3)



Figure 3. Combining two frames of images

3. CHANGES ANALYSIS

In all images used in this study, pre-processing corrections were made to extract the required information. The values of the areas obtained using the NDWI index are listed in Table 3 and April has been considered as the comparison month for all the years studied.

Year	Area
	KM ²
2010	3510
2011	2998
2012	2516
2013	2451
2014	2115
2015	1921
2016	2474
2017	2310
2018	2521
2019	3433

Table 2. Water level of Urmia Lake extracted by NDWI

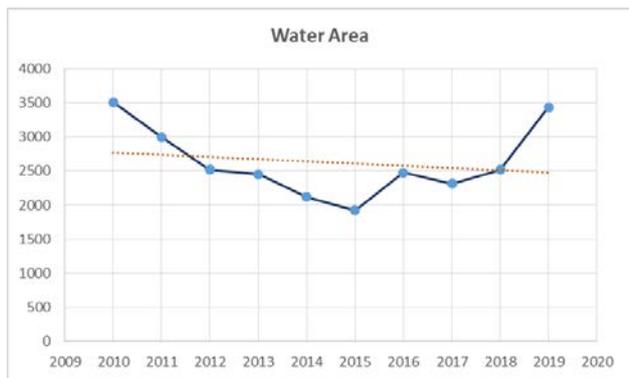


Figure 4. Trend of water level during 10 years

According the reference map, the amount of ERROR has been conducted in results which obtaining by following equation:

$$e = (E_0 - E_i) / E_0 \quad (2)$$

Where:

E_0 = Area of final map

E_i = area of year by using NDWI index.

The amount of obtained area by applying error coefficient and comparing with previous studied region, the results are depicted in following table and graph in which the least amount in 10 years period happened in the year 2015.

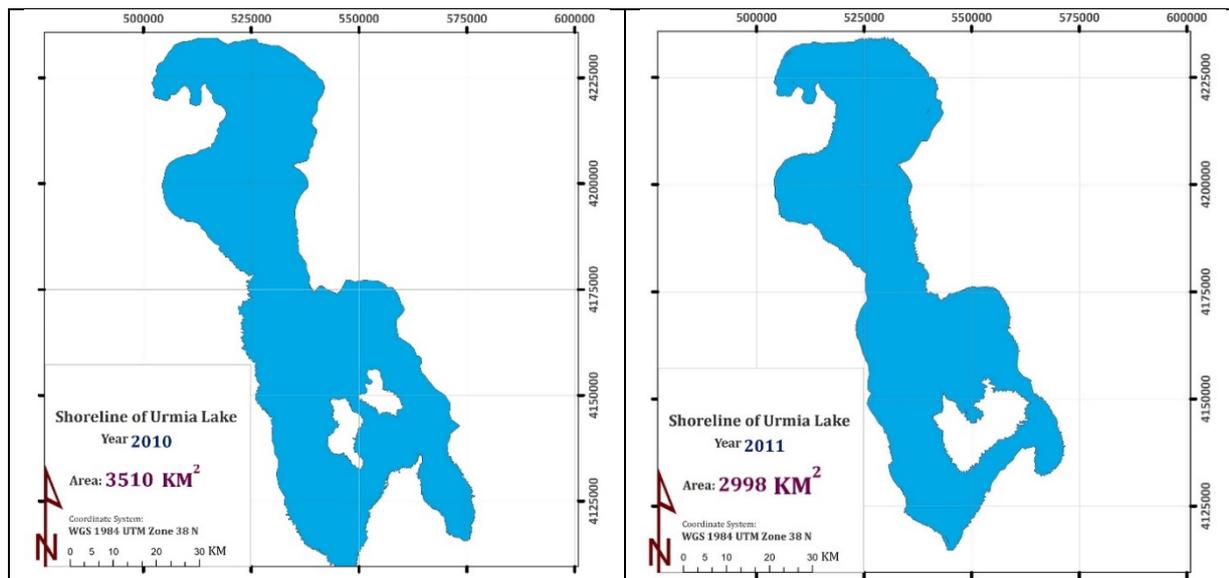
Year	Area	Difference
	KM ²	KM ²
2010	3510	
2011	2998	-512
2012	2516	-482
2013	2451	-65
2014	2115	-336
2015	1921	-194
2016	2474	553
2017	2310	-206
2018	2521	211
2019	3433	912

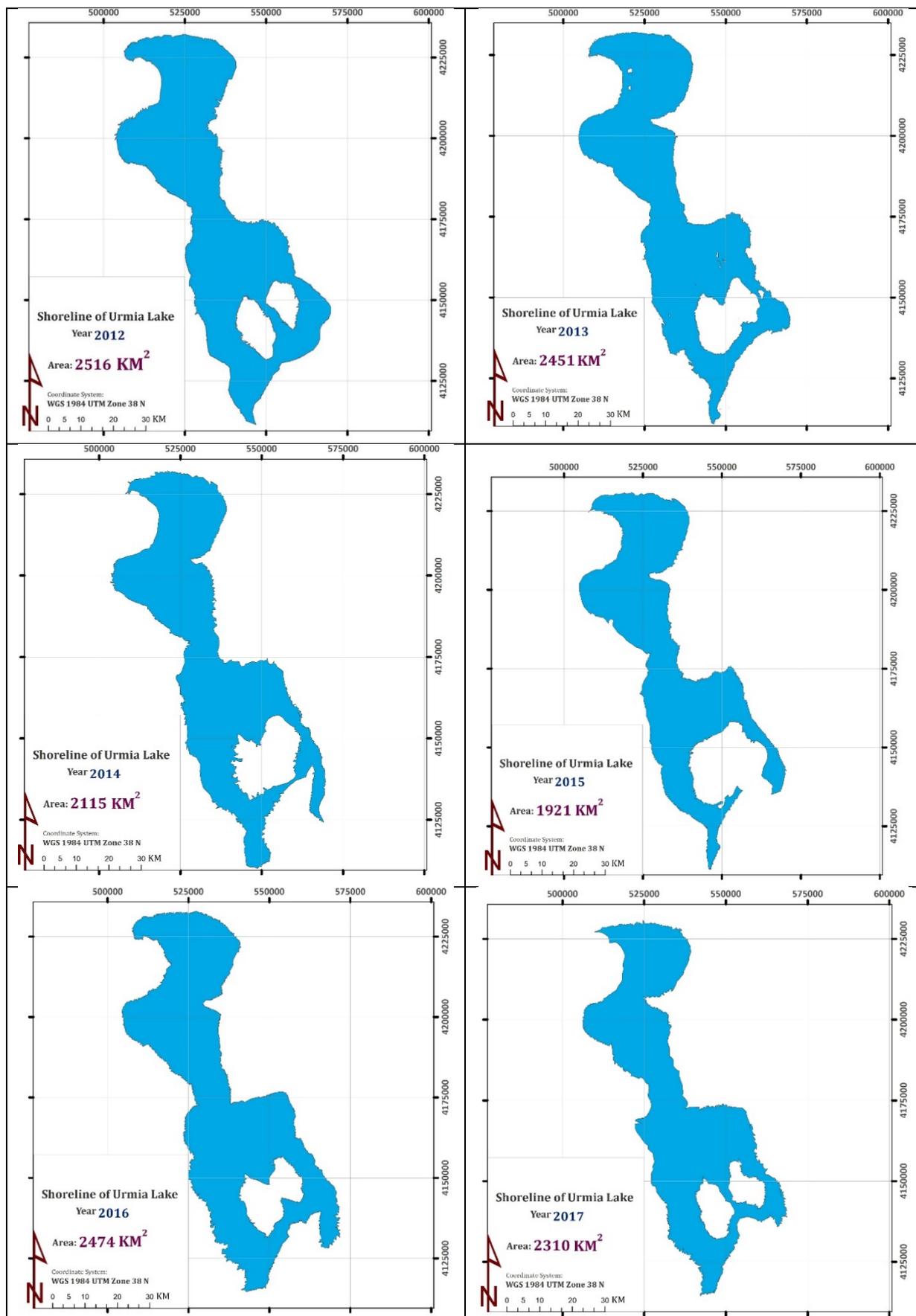
Table 3. Diversity of water level compared previous year after applying error

Regarding table 3 and graph 1, it was observed that Urmia Lake water level has contained almost 4 period during 10 years: first from 2010 to 2015 it was decreasing which reached the minimum amount of level in 2015, second from 2015 to 16 its trend was increasing. Then, it faced with decreasing trend until 2018. Finally, from 2018 started increasing and at the beginning of 2019, the amount of Lake Water has been approximately as same as was the water level in 2010.

Finally, multipurpose maps of lake level were overlaid to monitor shoreline changes during 2010 to 2019. Following maps show the extracted area in mentioned period.

In this research, Urmia Lake water level changes were extracted by NDWI index for a decade, shown in figure 5 showing the shoreline derived from these maps in the same figures. As shown in fig. 5, shorelines have been enjoyed significant fluctuations from 2010 to 2018. In the spring of 2019 shoreline changes are vividly obvious comparing with previous year. In water-absorbing bands, using band ratios and their relations could be applied as accurate methods to extract Lake Shoreline. However, it was not an appropriate method to use these ratios in shallow areas of the Lake due to reflection of light from the sea floor. In 2014 and 2015, the lake's shoreline, especially on its east coast, has declined sharply, and in the year 2019 it has drifted to the land.





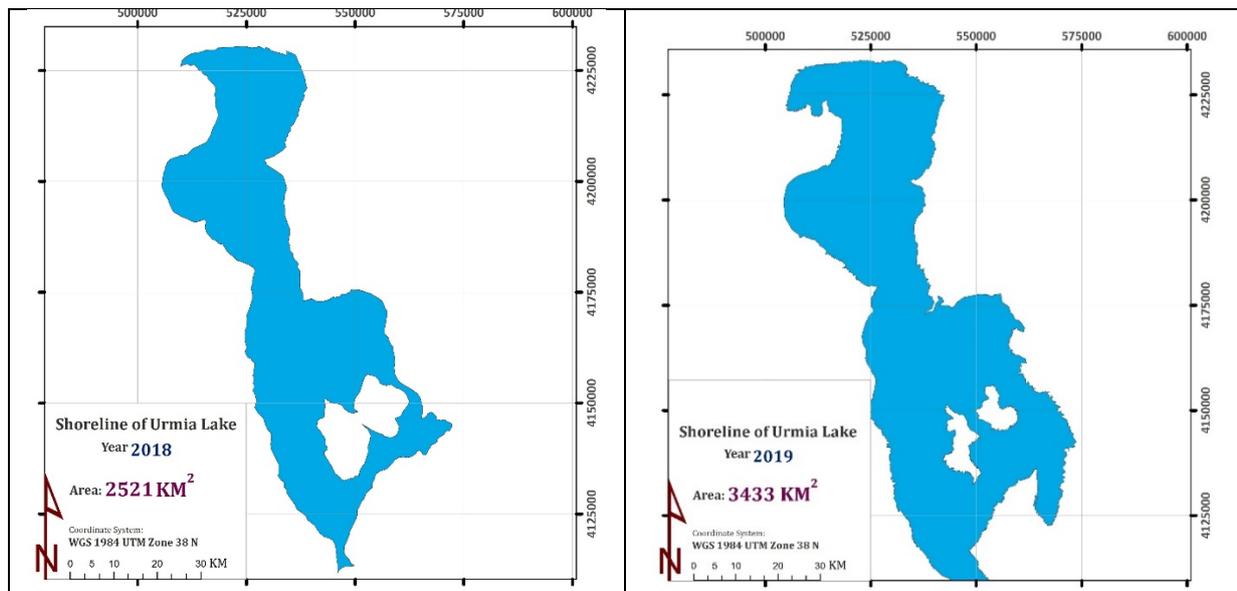


Figure 5- Shorelines and areas of Urmia Lake 2010 to 2019

4. PREDICTION

Due to the irregular trend of Urmia Lake during the last ten years and also the significant effect of spring 2019 rainfalls, in this study we attempted to estimate the time required for the lake to return its water level had before 1990, which declining of Urmia Lake's drought has been started. For this purpose, the proposed Zareei and Emami method (2016) (Zareei, et al, 2017) has been used. As they mentioned, activities carried out to resolve the crisis of Lake Urmia in recent years and average rainfall in the region can be mentioned as two factors affecting the water level of the lake in the recent decade. The equation (Zareei, et al, 2017) for this prediction is as follows:

$$S_n = S_0 \left[\alpha \left(1 + \frac{r'}{mn} \right)^{\frac{n}{m}} + \beta \left(1 + \frac{r''}{m} \right)^{\frac{n}{m}} + \dots + \gamma \left(1 + \frac{r'''}{m} \right)^{\frac{n}{m}} \right] \quad (3)$$

In which S_n is the goal area to reach after n years, S_0 is the current area of Lake covered with water, α , β , γ , r' and r'' are the weight of the average annual rainfall, the weight of the whole activities carried out to restore the lake's water level, Weight related to the factors affecting water level changes that the total weight is equal to one, the growth rate annual rainfall and the growth rate of restoring activities, respectively, and n number of years and m is the number of effective criterion in water level changes. Since two factors were considered in this study, the equation is simply as follows:

$$S_n = \left[\alpha \left(1 + \frac{r'}{2} \right)^{\frac{n}{2}} + \beta \left(1 + \frac{r''}{2} \right)^{\frac{n}{2}} \right] \quad (4)$$

The weight was assumed to be 50% for both factors. Most of the activities carried out to rehabilitate Lake Urmia depend on the amount of rainfall and other downfalls, collecting surface water, releasing some dam water into the lake, and so on (Zareei, et al, 2017). Some of the activities done in the basin of the lake is not as irregularly dependent on rainfalls such as agricultural activity, and changing the type of cultivation and crops, significant changes in the rivers leading to the lake, excessive utilization of minor dams and so on. In Equation 4, all variables are known, and the area of lake in 2019 was considered as the initial area and

for 1990's area, 5263 KM^2 , as the area that is the target area. The only number n is the number of years needed to reach the target amount. For the first factor, the average annual rainfall over the past 10 years was considered. The average annual rainfall in the Urmia Lake basin using the information of synoptic meteorological stations in the table (4) is shown.

Year	Annually average rainfall
	Mm
2010-2011	409.12
2011-2012	347.43
2012-2013	343.47
2013-2014	290
2014-2015	391
2015-2016	404
2016-2017	277
2017-2018	407.6
2018-2019	494

Table 4. Annually Average of rainfall (2010-2019)

Due to the average rainfall (373 mm), in the final year of the study period, the amount of rainfall is more than the annual average of the ten-year period, and it can be optimistically concluded that the possibility of Lake Urmia restoring is increasing. In this study, considering the amount of rainfall in future periods and the steady decreasing trend of restoring activities of Lake Urmia, the minimum and maximum numbers of years required to reach the area before the beginning of drought will be 23 and 38 years respectively, which considered a promising forecast.

However, noteworthy to mention is that this forecast is almost accurate and close to that fact if the amount of rainfall is constant and follows the rate of rainfall in the final year of current study. Otherwise a new scenario should be considered according to different factors and different rainfall rates.

5. DISCUSSION

In this study, for Urmia Lake water level investigation, observing shoreline changing trend in light of spring rainfall in the beginning of 2019 and comparing with previous decade condition, it has been enjoyed Landsat time-series imagery.

Having studied accomplished researches in this subject, it has observed that applying NDWI index could be the best process to reach this aim in which Green and NIR Bands are used for calculating. To estimate error and apply to obtained results by NDWI index, Landsat TM 2010 has been considered as a basic indicator and RMSE has been calculated by equation 1. According results gained from the year 2010, the amount of water level in Urmia Lake until 2015, when the lowest amount of lake water was estimated this year, had a downward trend. Then, it turned out increasing trend until April 2017, when it had almost the same amount of water in 2015. The period of increasing water level has started again from 2018, so in the target month of 2019, it has almost equalized the lake's water level in the year 2010. Also, the shoreline has moved toward the water from the east since 2010, so that in 2015, a small peninsula on the east coast has become completely an Island. In addition, from the south of lake there has been a remarkable receding. However, by increasing of rainfalls in 2019 as well as water level progress from the east coast, stated island has turned into a peninsula once again and situated adjacent on Urmia Lake. Furthermore, the lake has not changed much from the west or north coast, and it can be said that on the west side there is almost a steady trend. To predict the time required to reach the water area of Lake Urmia before the beginning of its drought, the year 1990, the equation (4) was used in which two factors of annual rainfall and activities carried out for restoring Lake Urmia have been critical and only factors. The target area is 5263 KM² and the average rainfall considered to reach that aim is 373 mm³. The average annual rainfall during the ten-year period was used for annual rainfall. It was also considered that the effective activity in restoring Lake Urmia has been a steady decline, so that activities related to agriculture or dam have been decreasing and rainfall in coming years to estimate the water required for the lake, equal to or more than the amount of rainfall in 2019. With such assumptions and information, the minimum and maximum time required for this process have been estimate 23 and 38 years, respectively, which considered as optimistic time. Zareei and Emami (Zareei, et al, 2017) supposed that minimum and maximum years required for restoring were 11 and 18 years, depending on the precipitation rate and the activities carried out for restoring Lake Urmia which they considered 2002 as the aim area and the existence of situation in 2016. Considering the area of Urmia Lake in 2002 (4300 KM²), the same approximation (assuming the similarity of factor rates) has been gained by predicting this research.

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