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Forecasting Surface Area Fluctuations of Urmia Lake by Image Processing Technique

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ABSTRACT

Urmia Lake's water surface area is among the most important parameters needed for water balance analysis. Periodical measurement of this parameter directly by conventional topography almost seems impossible since it is costly and time – consuming. Such limitations highlight the needs for new approaches to be taken, namely remote sensing technique which could provide a good approximation of lake's surface area in terms of some other parameters available or at least easily measured. This paper considers development of a new model for lake's surface area measurement according to available water levels and its comparison with other methods in this field as well as the calculations regarding salt-land formation and coastline changes. High resolution images provided by NASA satellites, Aqua and Terra were collected and passed an image processing stage through MATLAB software for surface area calculations. Finally, the water level and surface area values resulted from the home made code, were put together to reach relationship. The comparison between the results of proposed method and provided data by Eastern Azerbaijan Water Organization and also a similar study indicated that the proposed image processing technique has good performance to estimate the surface area of Urmia Lake. The maximum error between the results of proposed model and a similar study which was used combination method of Cellular Automata and Markov Chain was 5.96 % which indicates the good performance of image processing technique in estimation of surface area of Urmia Lake.

1. Introduction

Earth, on the whole, and all terrains on it, as an inseparable part of our world, is continuously experiencing an eternal process of transformation. Exploring and monitoring these changes, as much as possible, could lead to perception of the natural and artificial phenomenon causing them, as well as reasonable predictions about the future changes. Among these various changes, those which can be harmful to human residence are of most importance.

Lake Urmia is one of the largest saltwater lakes on earth and a highly endangered ecosystem, Monitoring Urmia Lake coastline and territory, as the second hyper saline lake in the world, and the first one in Iran has been considered in this investigation (Aghakouchak et al. 2014). Progressive decrease in size and amount of water in this lake due to the recent regional droughts and some artificial changes made in the neighborhood by human activities has made it a major concern requiring more research on this area which might lead to a proper solution for the current issue.

1.1. 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 (Ahmadzadeh et. al. 2009). With a semi-rectangular shape, a maximum length of 135 km, it covers an average area of 5,100 square kilometers. The maximum and average depths of this lake are 16 and 5 meters, respectively. Due to its unique biological and ecological features, it is internationally registered as a protected area as both a UNESCO Biosphere Reserve and a Ramsar site. Also, on the national level, it is designated as a "National Park" by the Iranian Department of Environment (Eimanifar and Mohebbi. 2007).

The Lake encompasses a total of 102 islands among which is the Shahi, the biggest island, covering 250 square kilometers. About 30 main rivers, including 13 permanent and more than 17 seasonal ones, namely Zarinneh Rood, Simineh Rood, Mahabad Chai, Godarchai, Barandoozchai, etc. supply most of the inflow to the lake (4900 mm^3 out of 6900 mm^3) (Ghaheri. 1999).

1.2. Purpose

Among the effective factors considered in evaluating the annual water balance of the lake, surface area is of the most importance, since it directly influences parameters like evaporation. On the other hand, continuous falling trend in water level and progressive changes in coastlines during recent decade. Retreat of Urmia Lake from its original shoreline is not only a hydrological concern, but it also presents serious challenges for water quality, conservation, human health and economics (Sima and Tajrishy. 2013). Dried coastal salt lands, which leads to salt marshes creation, has brought to attention the importance of our knowledge about the water surface area. Since direct measurement of the lake's surface area is costly and time-consuming, therefore development or employment of new methods and tools for this purpose will be valuable. Considering some rational assumptions, surface area is a function of few parameters, among which water level is the most important one (see Fig. 1). Taking into account abovementioned, this paper aims to provide a reliable correlation between lake's surface area and level. In other words, a novel formula is proposed for area prediction in terms of lake's surface level, which is a vital relationship in practice for various hydrological and

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environmental analyses. To this end, remote sensing techniques have been utilized to estimate the lake area in terms of water level.

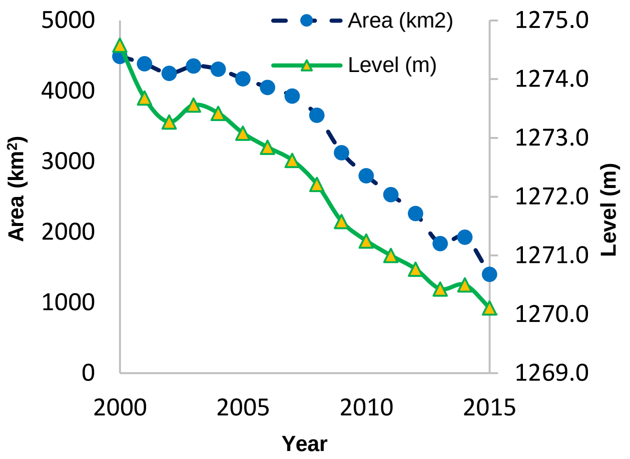

Fig. 1. Relationship between water level of Urmia Lake and its surface area, (Ahmadi. 2012).

1.3. Literature review

According to the stated purpose of this research mentioned in previous part, there is not a direct relationship between Urmia Lake level and surface area in the reported literature, except an empirical correlation presented and employed by Eastern Azerbaijan Regional Water Organization as following;

$$S_{(km^2)} = 479923 - \frac{6.05501*10^8}{L_{(meter)}} \quad (1)$$

S and L are the predicted water surface area in km^2 and water level in meters, respectively. Moreover, since this research takes advantage of remote sensing, some of researches which have employed remote sensing for similar purposes have been reviewed. Singh et al. (1991) of Indian Bopal Research and technology association employed the remote sensing technology as a hybrid approach for evaluating surface waters and Bhopal Lake management. This research demonstrated that data collected via satellites can successfully be used for monitoring and surveying large water reservoirs.

Digital image processing is a discipline which can be applied in many areas such as astronomy, genetics, remote sensing, video communication, biomedical, transportation system (Kosesoy et al. 2015). Qudah & Harahsheh (1994) combined remote sensing and GIS as an efficient tool to determine the coastlines of Bahr ol Mayet, located in Jordan. Results from this research indicated a vast range of changes in lake coastlines and water surface area during the study period, which seemed impossible without taking advantages of image processing and precise images provided by satellites.

Seang et al. (1998) studied the coastline bound of Tonel Sap Lake of Thailand in which image processing was utilized for coastline determination during droughts. Their research was another case of successful employment of image processing and remote sensing. Furthermore, similar investigations have been done by Zavoianu et al. (2001), Kish (2002), Bayram et al. (2004), Najafi (2003), Alsheikh et al. (2007).

Rasuli et al. (2008) monitored the level fluctuations in Urmia Lake processing multi-sensor and multi-time satellite images. Their research revealed a noticeable fact that during recent decade lake area is decreased by 23 %, equal to 1200 km^2. This is an alert, calling the authority in charge for an immediate action against salt marshes development which will be crucial to the surrounding vegetation as well as human beings dwelling in neighborhood.

All above-mentioned researches have proved that remote sensing and image processing are among the best techniques for geographical and environmental investigations especially in expanded area studies.

2. Material and methods

Clearly, it could be concluded that water surface area is an indication of the lake's bed topography in various levels. Therefore, the water surface area is generally a function of two factors: lake's water level and ground topography inside the lake limits. Although, the first factor is influenced by different parameters such as evaporation, precipitation, surface and underground water entrance to the lake, tidal range, but it could be measured easily because level fluctuation due to the waves and tide is negligible. The second factor, lake topography, could also change due to natural and artificial phenomena. Natural events such as erosion, sedimentation, etc. and artificial ones like massive man-made embankments inside the lake limits, as was created in causeway construction, can impressively alter the surface area. This factor is also influenced by many parameters which could not be measured to account for in surface area estimation. The only way for this purpose, other than the costly method of surveying and mapping, is remote sensing technique which employs up-to-date images provided by satellites. Most of the time, these images are not available to public, so they could not be utilized. Furthermore, processing these images besides the water level to reach the water surface area is also a matter of question.

According to the abovementioned statement, surface area could be estimated in terms of water level and topography change detection. Since topography changes are not considerable compared to the water surface changes due to the level fluctuations, lake water surface area could be assumed only dependent on water level, of course considering the accuracy level we aim in this paper. For this purpose, holding water surface area in various lake water levels which has been recorded in the past, can lead to a correlation between these parameters. To this end, a database should be collected, including water level and surface area during the past time. These data have been gathered and been computed, as following.

2.1. Data collection and selection

Images provided by NASA website from Terra and Aqua satellites, taken from 2005 to 2012 years, were collected and selected for this study. These images were taken with resolution accuracy equal to 250 m which have been the only source for lake area calculations during the abovementioned period. On the other hand, lake level data are retrieved by daily measurements carried out and provided by Eastern Azerbaijan provincial water organization's archive. These two data sources have been put together to predict the lakes area directly and its topography indirectly to some extent.

Totally, 44 images, obtained from abovementioned satellites, beside the corresponding water level in the same date, from Mar. 2005 to Dec. 2015, measured by Eastern Azerbaijan Water Organization were used in this study. Data records include water level fluctuation from 1271 m to 1274 m above mean sea level with a mean value of 1272.75 meters. This variation during the study time period is illustrated in Fig. 1. According to this figure, Lake's water level has experienced a descending trend during the last seven years, despite some seasonal increases. This is an alert for the lake and surrounding neighborhood form the environmental point of view.

2.2. Data preprocessing and analysis

Satellite images used for this study, were processed in Photoshop graphical software and MATLAB Programming software to extract the surface area values. Thus, Lake surface and surrounding ground were precisely separated using Photoshop tools considering the different colors belonging to each part, as the distinction criteria. Extracted Lake was then exported to MATLAB and set on a white background for further calculations. MATLAB was employed for computing surface area by enumerating total pixels and white colored pixels, which represent surrounding ground as well as islands and causeway embankments. Consequently, white colored pixels number subtraction from total pixels will result in the number of pixels presenting lake surface area. As a result, pixel size and quantity multiplication will result in the gross surface area value. The whole process was carried out through a code prepared in MATLAB Programming software. Date of photos and calculated areas are as Table 1.

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Table 1. Calculated areas using MATLAB and Photoshop software.

Date	Area	Level	Date	Area	Level
20050317	4437.8	1273.72	20090901	3091.5	1271.6
20050411	4508.2	1273.9	20091001	3040.8	1271.5
20050801	4216.5	1273.54	20091201	3119.1	1271.6
20050901	4198.6	1273.37	20100401	3409.6	1271.85
20051001	4165.6	1273.22	20100601	3556.9	1272.01
20051101	4145.6	1273.12	20100701	3356.4	1271.82
20051201	4185	1273.11	20100801	3090.1	1271.62
20060602	4321.1	1273.43	20100901	3024.2	1271.48
20060702	4222.1	1273.32	20101101	2819.4	1271.28
20060802	4160.9	1273.08	20101201	2852.6	1271.25
20060902	4117.4	1272.93	20110228	2813.9	1271.31
20070202	4179.1	1272.95	20110510	3468.2	1271.51
20070303	4175.2	1273	20110604	3273.8	1271.64
20070611	4275.9	1273.28	20110704	3101.5	1271.42
20070811	4160.7	1272.93	20110804	2873.3	1271.23
20080601	3860	1272.48	20110810	2977.2	1271.24
20080701	3761.9	1272.33	20110904	2738.9	1271.09
20080901	3670.4	1272.1	20110920	2779.7	1271.01
20090401	3542.4	1272.21	20121004	2664.2	1270.99
20090501	3576.1	1272.17	20131215	1270.77	2262.55
20090701	3435.8	1272	20141208	1270.43	1836.82
20090801	3299.9	1271.7	20151203	1270.50	1927.51

Throughout the above process, surface area values were obtained for all available images, then water levels (L) and corresponding water surface areas (A) were coupled to investigate the probable correlation and its reliability for future applications. This data is presented in Table 2.

Simple polynomial regression analysis resulted in a reliable relationship between these parameters as following;

$$S_{km^2} = 115665570 - 0.018623 \times - \frac{35092679000}{L^{1.5}} \tag{2}$$

In which S is the water surface area in square kilometers predicted by the proposed correlation, and L is the water level in meters. The performance of this correlation has been evaluated in next section via appropriate criteria.

3. Results and discussion

Performance of proposed model have passed two different comparison tests; first, a comparison with Eastern Azerbaijan Water Organization's Model and second, a comparison with Ahadnejad's (2007) calculations who had used a different method to evaluate surface areas of the Urmia Lake during 2001-2007.

3.1. Comparison of proposed model and Eastern Azerbaijan Water Organization's

The proposed model performance is assessed considering three criteria namely Pearson correlation coefficient (R), Mean Absolute Error (MAE) and Root Mean Sum of Error (RMSE). The formulas and results are as following equations and Table 3.

$$R = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - x)^2 \sum (y_i - y)^2}} \tag{3}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |y_i - x_i| \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n} \sum (y_i - x_i)^2} \tag{5}$$

Graphical comparison between proposed model and Eastern Azerbaijan Water Organization's has been illustrated in Fig. 2, which indicates that proposed model has a reliable performance and could substitute with the previous one.

This also has been illustrated in Fig. 3. According to the Fig., the proposed correlation performance is considerably reasonable, since data points scattered very close to the diagonal line.

3.2. Proposed Model and Ahadnejad's (2007) calculations comparison

Remote sensing technique has been used by others to predict the surface area of Urmia Lake like Ahadnejad (2007) who has used a Combination method of Cellular Automata and Markov Chain to measure the area of the lake. In spite of different methods, a simple comparison shows that maximum error of proposed model to Ahadnejad (2007) estimations is only about 6 percent which is negligible and reliable. Table 4 provides such comparison.

Table 2. Summary of statistical measures.

Parameters	Data set No.	Min	Max	Mean	Standard Deviation
Level (m)	44	1271.5	1273.9	1272.7	0.72
Area (km^2)	44	3040.8	4508.2	3914.7	444.7

Table 3. Statistical Comparison between proposed model and Eastern Azerbaijan Water Organization's.

Predictor	Train Datasets	Test Datasets	R_{Test}	MAE[b]	RMSE[c]	Mean Prediction/Target	Standard Deviation of Prediction/Target
E.A.W.O.[a]	NA	5	0.978	263.5	322.4	1.08	0.063
Proposed Relationship	25	5	0.991	49.5	59.4	1.001	0.015

a. Eastern Azerbaijan Water Organization; b. Mean Absolute Error; c. Root Mean Sum of Error

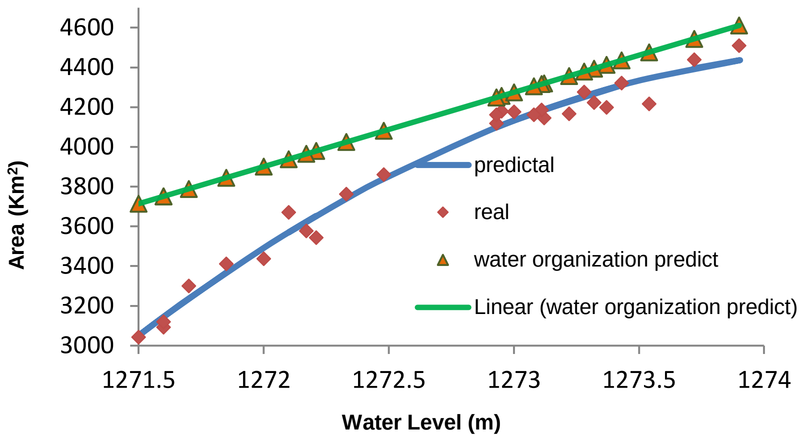

Fig. 2. Graphical comparison between proposed model and Eastern Azerbaijan Water Organization's.

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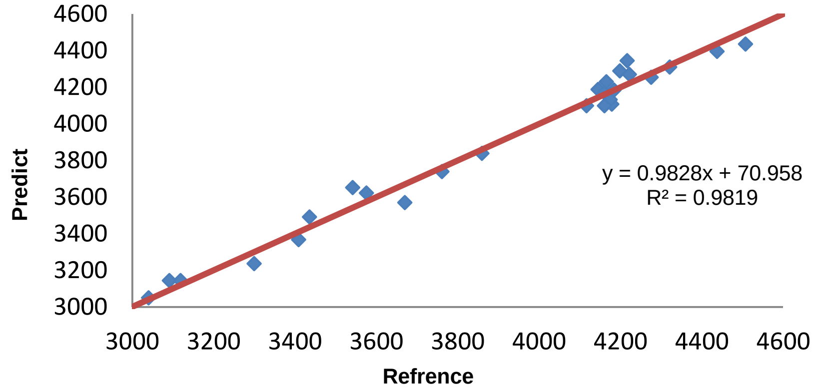

Fig. 3. Performance of proposed relationship (Predict Vs Reference Area Values).

Table 4. Comparison between Ahadnejad's calculations and proposed model.

Water year	Water Level	Model prediction	Ahadnejad (2007)	Error
2001-2002	1273.76	4406	4158	5.96%
2002-2003	1273.62	4370	4329	0.94%
2003-2004	1273.73	4399	4242	3.70%
2004-2005	1273.57	4355	4146	5.04%
2005-2006	1273.19	4219	4099	2.93%
2006-2007	1273.16	4206	4064	3.49%
2007-2008	1272.21	3653	3497	4.46%

4. Conclusion

The lake has faced extreme water loss in recent years due to overuse and mismanagement. Over the last thirty years, the population in the lake basin has been doubled and the agricultural area fed by water resources of the lake basin has tripled. To investigate the reasons of water loss of the lake, following items brought up by several specialists and authorities: 1) Shahid Kalantary causeway, which divides the lake, prevents the water circulation and this has caused the salinization of the lake, 2) vastness of lake area surface in comparison to its depth which leads to large evaporation surface, 3) construction of several dams and diversion of surface water for agriculture, in Urmia Lake basin without proper environmental risk assessments 4) reduction of precipitation and 5) warming of the region.

Urmia Lake's water surface area is one of the most important parameters needed for water balance analysis for the purpose of evaluation or modeling. Surface area measurement based on conventional methods consumes lots of energy and time for topographical works. Remote sensing technique has solved this problem and availability of water level data of the Urmia Lake has eased the way through surface area evaluation. Using Photoshop tools for extracting satellite images and processing theses photos through MATLAB software, combining these areas with available water levels; current paper has introduced a new equation for evaluating surface area of Urmia Lake using remote sensing technique, which doesn't have the former one's defects. According to abovementioned comparisons; proposed model has a reliable precision and could be used for surface area evaluations using water level data. After 40 years of Ramsar convention stating emphasized protection of Urmia Lake, Artemia Urmiana is on the edge of distinction, migrant birds have left the Lake forever, more than 52 percent of the lake surface area has become salt marsh, and the lake is transforming to a salt desert. According to proposed model 1800 square kilometers of lake surface area have been transformed to salt marshes since 2005. In case of complete desiccation of Urmia Lake, we will have 5100 square kilometers salt land. Spreading such amount of salt by wind power will destroy the economy and agriculture of the region (Nadjafi et al. 2012). We need to do something about this.

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