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Drying of Urmia Lake: modeling of level fluctuations

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Abstract

Background: Urmia Lake, the second largest hyper-saline lake of the world, has experienced lack of water and other environmental issues in recent years. Now, there is a danger of the lake drying out, which will affect the region and its inhabitants. This study aimed to present a model which can relate the water level of the lake to effective factors.

Methods: Parameters that influence water level, such as precipitation, evaporation, water behind dams, and the previous year's water level, were considered in the modeling procedure. The proposed model, based on evolutionary polynomial regression, can be used to evaluate salt marshes produced in the region in recent years.

Results: Results show that the high surface-area-to-depth ratio of Urmia Lake is most influential on its drying; however, omitting this characteristic as an inherent one, the main cause is the construction of dams on rivers in the Urmia Lake basin.

Conclusion: The proposed model predicts that by 2015, the water level of Urmia Lake will fall below 1269 m, and by 2030, the lake will dry out completely.

Keywords: Urmia Lake, Water level, Air pollution, Health impacts

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Introduction

Urmia Lake, Iran's biggest internal lake, is located in northwestern Iran (37°42′N 45°19′E), between the provinces of Western Azerbaijan and Eastern Azerbaijan in an alpine climate like that of Van Lake in Turkey. It is the 20th largest lake and second largest hyper saline lake in the world (1).

In the past 10 years, human activities and global warming has caused the lake water to diminish dramatically, leading to a fall in water level and surface area. Figure 1 (from NASA databases) illustrates the catastrophic changes in Urmia Lake's coastline that occurred between 2001 and 2011.

Urmia Lake has a maximum length of 140 km, its width ranges between 15 km and 50 km, and its surface area measures between 4750 and 6100 km^2. Its maximum depth is 16 m and its average depth is 6 m (2,3). Located at an altitude of 1275 m above sea level, the lake's volume is between 25 billion m^3 and 27 billion m^3 (4). Artemia brine shrimp of Urmia Lake (sometimes called *Artemia urmiana*) is one of the unique Artemia species which can live in the high salinity of Urmia Lake's water (5,6).

Urmia Lake basin, one of the six main basins in Iran, has an area of 51331 km^2 which is bordered by the Aras river basin from the north, the Ghezel Ozen river basin (the main branch of the Sefid Rood river) from the east and south, and the Zab river basin from the west (1). Today, the conditions of the lake have become a critical and challenging environmental issue for the region, particularly for Western Azerbaijan where there are hundreds of farms and orchards. Huge amounts of work have been done to revive the lake and mitigate its disappearance, but drying continues. The drying of Urmia Lake could impose dire consequences on the inhabitants, environment, and economics of the region. A dry lake will leave thousands of tons of salt to be dispersed by the wind and to penetrate the soil through precipitation; this would make the region uncultivable and uninhabitable. In the Ebinur region of China's Western Dzungaria, about 4.8 million tons of salt-rich dust are carried away (as far as 100-200 km) from the dry lakebed of Ebinor lake annually (6-8). The salt and transformed chemicals have caused respiratory diseases,

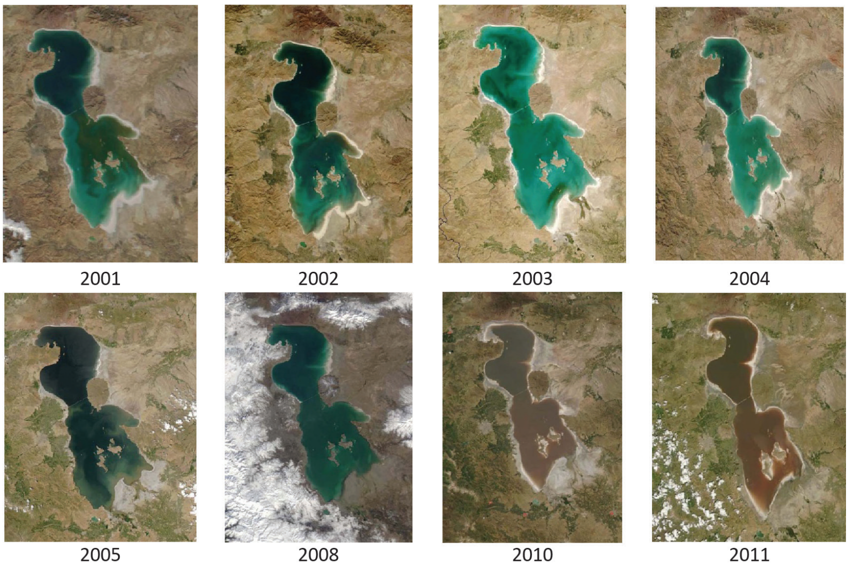

Figure 1. Urmia Lake coastline changes from 2001 till 2011 (from: Terra & Aqua Satellite Images).

malnutrition, anaemia, and leber in nearby urban and rural areas; this was also experienced in one of the largest environmental disasters of this kind, around the Aral Sea (6,9).

Monitoring the parameters influencing the drying of Urmia Lake and modeling the lake's changes are crucial actions for identifying the reasons for this phenomena and ways to control it (10). In this study, the water level of Urmia Lake based on influential parameters is modeled using the evolutionary polynomial regression (EPR) method. The model is then applied to investigate the impact of each parameter on fluctuations in lake water levels.

Methods

In this study, the Evolutionary Polynomial Regression (EPR-Version: 2.0 Stand-Alone) toolbox was applied to model water level variations. EPR is a data-driven method based on evolutionary computing and used to create polynomial structures representing a system (11). This model has been used in recent environmental studies to forecast air pollution in urban areas, predict the shear strength of a municipal solid waste landfill, and for other environmental issues (12).

Davidson et al (13,14) proposed a new regression model (rule-based symbolic regression, R-BSR) for creating polynomial models based on both numerical and symbolic regression. Their approach combines genetic programming and symbolic regression which use only the multiplication and non-negative integer powers operators (14). Giustolisi and Savic (11) presented an improved method based on the combination of numerical and symbolic regression with the elimination of cumbersome and often slow components (11).

The original EPR uses single objective genetic algorithm (SOGA). The multi-objective genetic algorithm (MOGA), based on the Pareto dominance criterion, is used in the developed version of EPR due to its advantages over SOGA (15).

The objectives of the developed EPR search are:

- Maximization of model accuracy
- Minimization of the number of polynomial coefficients
- Minimization of the number of inputs.

The final version of EPR is called multi-case strategy for EPR (MCS-EPR). This approach is based on the existing EPR technique, which uses the observed data available for multi-utility data to simultaneously identify the best model structure. The details of the EPR approach are delineated in Giustolisi and Savic (11).

To predict level fluctuation, a set of documents obtained from Eastern Azerbaijan Water Organization were evaluated. Precipitation, evaporation, water behind dams, and surface area of the lake were selected as influential parameters and used in assessing water level fluctuations of Urmia Lake. Due to the lack of surface area data, the water level information available for the same water year was used; there is a direct correlation between lake surface area and lake water level (Figure 2), 43 years (1969-2010) of data was obtained from Eastern Azerbaijan Water Organization and used in this study.

Evaporation data from Ghurigol, Sahlan, Mirkuh Haji, Bonab, Alavian, Sharafkhaneh dam, and Lighvan stations was employed in modeling. Because the precipitation range varied from place to place in the basin, the average precipitation from the water year starting in October and ending in September was used. The resulting model can predict lake water levels based on the influential parameters. The summary statistics of the data used in the model are available in Table 1.

The data for each model was divided into two parts: training and testing. Seventy percent of all data in each model was chosen randomly for training, and the remainder was used for testing. Therefore, 13 data sets (30% of data) were used for validation. Related information is available in Table 2.

In the Urmia Lake basin, the average precipitation for the

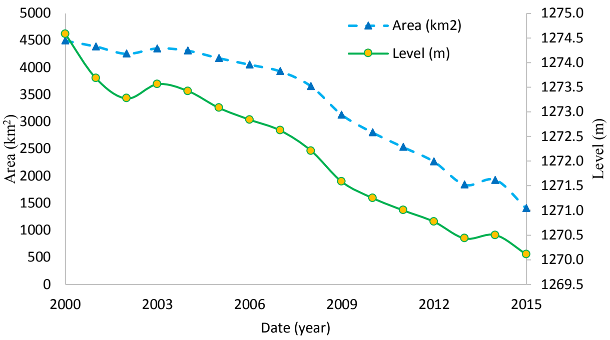

Figure 2. Urmia Lake surface area evaluation using remote sensing technique

last 43 years was 243 mm. The maximum precipitation was 461.8 mm in 1969, and the minimum was 136.95 mm in 1989. The available data did not show great variations in precipitation rates; in some stations like Tabriz and Sarab, precipitation increased, but in other stations, it has declined. Average evaporation from Urmia Lake in the last 43 years was 1386.9 mm, with a maximum evaporation of 1703 mm in 1975 and a minimum of 1067 in 1995. The average water level for the last 43 years was 1275.8 m; the maximum was 1278.3 m in 1995, and the minimum was 1271.8 m in 2010 (16).

By 2010, 36 dams had been commissioned in the Urmia Lake basin. The specifications for these dams are available in Table 3 (17).

Up to 2010, the sum of the adjustable annual water basin of the lake was 1601 million cubic meters. Considering the amount of dam construction taking place in the Urmia Lake basin, it is predictable that this number will rise to 3060 million cubic meters. Figure 3 shows the dams of the Urmia Lake basin that are in operation, under construction, and under study.

Sensitivity analysis

Sensitivity was analyzed to determine the most influential parameter on the drying of Urmia Lake. The influence of parameters such as evaporation, precipitation, water behind dams, and previous year's water level on the current water level of the lake were assessed using the proposed model for water level prediction, data obtained from the Eastern Azerbaijan Water Organization, and Minitab software.

In order to perform sensitivity analyses using the proposed model, average annual changes, volume fluctuations of water behind dams (400 million m^3), precipitation rate (40 mm), evaporation rate (100 mm), and previous year's water level (1 m) were all taken into account.

Results

EPR was used to extract a bank of test and training data; Urmia Lake water levels were evaluated as the output of the algorithm. From the equations optimized by the EPR software, the equation with the highest COD was reported (Equation 1). Figure 4 shows a comparison of measured results and modeled ones for Equation 1. Furthermore, the details of Equation 1 are reported in Table 4. Minitab software was used to see the influence of the studied parameters on the fluctuations in water level of Urmia Lake, and the analyses results are summarized in Table 5.

$$\begin{aligned} L &= 1270.15 - 149.1429 + 4.1963\sqrt{PW} - 0.0012905P\sqrt{D} \\ &-5.6111\times[10]\hat{}(-5)D\surd w + 1.4544\times 10\hat{}(-11)DPW\hat{}2 \end{aligned} \tag{1}$$

Discussion

Modeling was performed using 5 different functions and variable expressions from 1 to 20; the most efficient model was selected. This model uses EPR to calculate the water level of Urmia Lake based on precipitation, evaporation, water volume behind dams, and previous year water level. Maximum error/maximum variation in the data was less than 20%. Outputs of the model, in comparison with the original data, were completely acceptable for the purpose

Table 1. Model input and output data specifications

Symbol	V	P	D	W	L
Parameter	Evaporation	Precipitation	Water behind dams	Previous year water level	Predicted water level
Unit	Millimeter	Millimeter	Million cubic meter	Meter	Meter
Number of Data	43	43	43	43	-
Minimum	1067	136.95	0.13	1271.8	-
Maximum	1703	461.8	650	1278.3	-
Mean	1368.9	243	45/34	1275.8	-
Standard Deviation	145.94	68.97	117.53	1.57	-

Table 2. Validation parameters of the model

Symbol	V	P	D	W	L
Parameter	Evaporation	Precipitation	Water behind dams	Previous year water level	Predicted water level
Unit	Millimeter	Millimeter	Million cubic meter	Meter	Meter
Number of Data	13	13	13	13	-
Minimum	1067	136.95	635.8	1271.5	-
Maximum	1571	579.5	2169.19	1278.2	-
Mean	1356	271.66	1097.11	1275.1	-
Standard Deviation	156.23	108.76	473.35	2.30	-

Table 3. Dams specifications in Urmia Lake basin

Dam Name	Mahabad	Kazemi	Khormalu	Baruq	Amand1	QaziKandi	MolaYaqub	Yegaja	Amand2
Annually adjustable water (million m^3)	197.8	425	0.35	0.15	0.25	1.5	4	1	0.25
Useful volume (million m^3)	170.3	650	0.35	0.15	0.25	1.2	3	1	0.25
Start of operation	1971	1972	1980	1983	1984	1985	1985	1985	1986
Dam name	Til	Hacha Su	Deh Gorji	Pireyusefian	Khuniq	Hasanlu	Nahand	Amand	Yegaja
Annually adjustable water (million m^3)	0.7	3.1	0.45	0.25	1	94	32	4	3
Useful volume (million m^3)	0.67	0.35	0.13	0.4	0.7	94	21.1	2.2	2.3
Start of operation	1986	1987	1989	1989	1989	1994	1994	1994	1994
Dam Name	Alavian	Sefidan	Param	Ardalan	GavDush	Kordkandi	MalekKian	QalaChay	Tajyar
Annually adjustable water(million m^3)	123.4	0.6	4	4.5	2.5	6.03	10	55	4.5
Useful volume (million m^3)	57	0.36	3.3	4.5	2.5	5.18	8.8	38.8	3.5
Start of operation	1996	1998	1998	1999	2000	2000	2001	2001	2004
Dam name	Qushkhana	Shahr Chay	Quri Chay	Increasing the height of the Kazemi dam	Qeysarq	Dash Espiran	Kanespi	Saruq	Zola
Annually adjustable water(million m^3)	0.14	199	0.8	232	2.8	1.2	1.79	51.8	132.5
Useful volume (million m^3)	0.14	213	3.93	232	2.6	1	0.5	35	72
Start of operation	2004	2005	2005	2006	2007	2007	2010	2010	2010

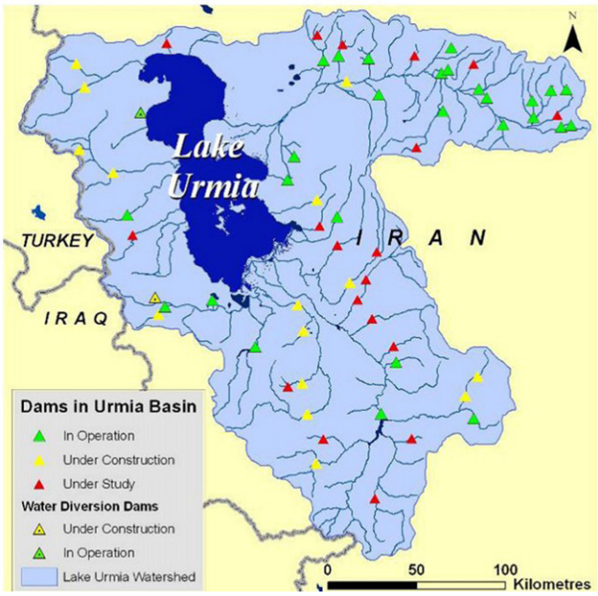

Figure 3. Dams in operation, under construction, and under study in Urmia Lake basin (17).

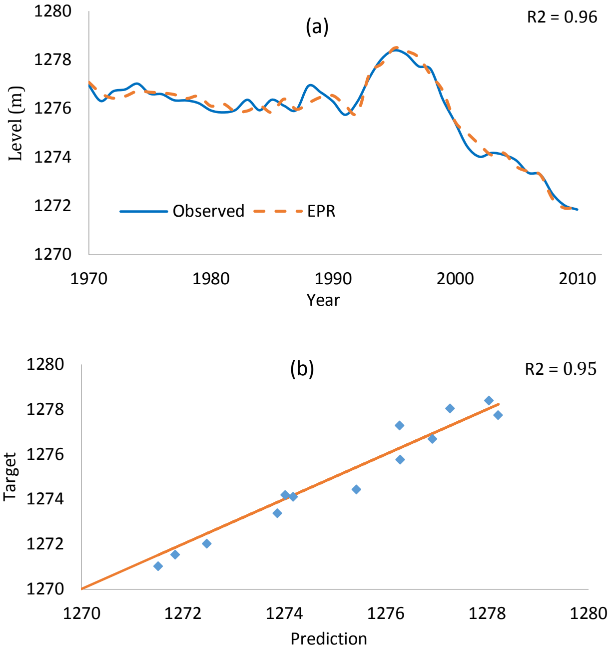

Figure 4. Predicted water levels of Urmia Lake using EPR vs. target values (a) level vs. year (b) predicted values vs. observed values.

of evaluating Urmia Lake water levels. The EPR technique was applied quite successfully with a high level of precision. It must be noted that it is possible to get even more precise equations for the purpose of predicting Urmia Lake water levels using more data points and the same technique. Sensitivity analyses results show that lake surface area with *P* value = 0 and F test = 2803438 is the most effective parameter in the decline of the Urmia Lake water level. Respectively, lake surface area, dam construction with F = 245107, precipitation with F = 31638, and evaporation with F = 21088 are the other important factors in

Table 4. Proposed model details for predicting Urmia Lake water level

Maximum error	**1.251**
Minimum error	0.001
Average error	0.292
Maximum variation in data	6.537
Maximum error/ Maximum variation in data	0.190
SSE	0.091
BIC	0.080
MSE	0.063
COD	0.992
CODV	0.962

Abbreviations: SSE, sum of squared errors; BIC, best information criterion; MSE, mean square error; COD, coefficient of determination; CODV, coefficient of determination-validation.

Table 5. Sensitivity analysis parameters effective in Urmia Lake level fluctuations

Source	F test	*P*	DF
Dam	245107	0.000	5
Precipitation	31638	0.000	6
Water level of previous year	2803438	0.000	5
Evaporation	21088	0.000	4
Dam-precipitation	2038	0.000	30
Dam-previous year water level	1	0.033	25
Dam-evaporation	1089	0.000	20
Evaporation- previous year water level	0	1.000	20

Abbreviation: DF, degree of freedom.

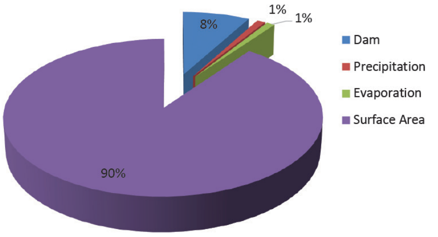

Figure 5. Degree of importance of influential parameters on Urmia Lake water level fluctuations.

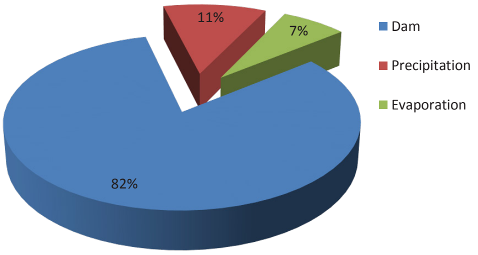

Figure 6. Dams, precipitation, and evaporation influence on Urmia Lake drying.

the drying of Urmia Lake (Figure 5).

Based on the current results, the vastness of lake surface area compared with its depth is the characteristic most accountable for the catastrophic lake drying. Omitting this characteristic as an inherent property of the lake, the construction of dams in the Urmia Lake basin at 82%, precipitation at 11%, and evaporation at 7% were identified as other influential parameters in the Urmia Lake drying process (Figure 6).

Conclusion

In this study, Urmia Lake water level fluctuations were accurately modeled based on parameters such as precipitation, evaporation, water behind dams, and lake surface area. A comparison of the model outputs and practical data revealed the maximum error to be about 19%, which is acceptable compared to other methods. Therefore, this method could be an important tool for predicting water level fluctuations through different time intervals in either the past or the future. Using the model, the parameters influencing fluctuations in Urmia Lake water levels were evaluated. Results show that, omitting the huge amount of evaporation as a result of vast surface area, dam construction in the Urmia Lake basin, precipitation, evaporation due to climate changes, and the gradual rise in temperature during recent years, respectively, are the most important factors leading to the desiccation of Urmia Lake. In general, it seems that the principal reason for the decrease in water level is human activity rather than climate change. Considering the average precipitation and evaporation rates in the last 43 years and the completion of dams under construction, it is predicted that by 2015, the water level of Urmia Lake will fall to 1269 meters. Based on the model, it can also be predicted that, by 2030, there will no longer be a lake in Urmia. If the Iranian Ministry of Energy does not allocate enough of the Urmia Lake water share, large salt marshes measuring 6100 km^2 in area will occur, and a catastrophic environmental disaster will be fall this beautiful ecosystem.

Acknowledgments

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Ethical issues

The authors certify that all data collected during the current study are presented in this manuscript and no data from the study has been or will be published separately.

Competing interests

The authors have no competing interests.

Author's contributions

All authors were involved in study design, data collection, and article approval.

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