Developing System Dynamics Model for Assessing Restoration Plans in Water Management; Case study Urmia Lake, Iran

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Abstract
Finding management practices to achieve sustainable ecological status of the Urmia Lake is necessary. In this study, impact of different plans under climate change were assessed using system dynamics. Therefore firstly GCM models were downscaled by using LARS-WG model. The results indicated that the basin would get warmer from 2011-2030 and there will be an increasing trend in rainfall in autumn and winter, and a decreasing trend in spring and summer. Four restoration plans were considered separately and then simultaneously in VENSIM environment. The simulation results revealed that none of the single plans are suitable. Among the hybrid plans, increasing the efficiency of irrigation, changing crop patterns and reducing cultivated areas, was the most sustainable one. The results indicated that after 47 months from applying this plan, lake level will achieve the ecological level. This SD model can help watershed managers to take necessary measures to restore this ecosystem.

Keywords: System Dynamics, Climate Change, Modelling, Environmental Management, Urmia Lake

1. INTRODUCTION
Urmia Lake with 5,000–6,000 km2 is the largest lake in Iran. From 2011 Lake water level dropped progressively and in recent 15 years, the lake’s water level has been decreased up to 4 meters [1]. Furthermore, decreasing trend of the Urmia Lake level during the last fifteen years had been converted to a challenge and made it one of the most problematic issues in the region. This ongoing reduction of water level had critical impacts on agriculture population, environment and economy [2].

Despite global water resources are limited, increasing population growth and human activities led to greater water demand. Among all of natural resources water is one of the most challenging issues to manage [1]. Alipour (2006) studied hydrochemistry of the Urmia Lake and mentioned that a shortage of precipitation and progressively dry climate led to reduction of water level so as water level in the lake has been decreased 3.5 m in the last decade [3]. While the current status of the Urmia Lake is catastrophic, the continuation of the lake’s retreat could lead to yet another major environmental tragedy similar to the fate of the nearby Aral Sea in Eurasia. Once one of the largest lakes on earth, the Aral Sea gradually declined to less than 10% of its original size after diversion of the lake's in flow from Amu Darya and Syr Darya rivers for ill-conceived irrigation development in the Soviet era, causing severe economic, environmental, and health consequences [4].

System dynamics models are tools to facilitate understanding of the interactions among diverse but interconnected sub-systems that drive the dynamic behavior of the system [5]. A system dynamics based water resource model allows users to understand the most sensitive parameters to improve the water use efficiency at system scale [6]. Different SD water resources studies had been also developed in Iran. An SD model was used to manage Zayandehrud River basin [7]. SD model was used to study the effects of various factors on drop of the Urmia Lake's water level in the recent years. Results showed that the effect of changes in inflows due to the climate change and overuse of surface water resources by 65%, is the main factor, while constructing four dams has effect of 25% on reduction of the lake’s level, less precipitation on lake is responsible for 10% of the problem [8]. Hence, an assessment of the impacts of climate change on water resources is crucial for determining the future possible challenges. Amirrahmani and Zarghami (2014) studied climate change and impacts on water resources of Zolachay in the Urmia Lake basin in northwestern Iran for horizon 2020 [9]. In
their study, expected precipitation and temperature changes are obtained from the results of general circulation models (GCMs) approved by IPCC AR4 in three emission scenarios of A1B, A2, and B1. They simulated operation of the multipurpose Zola Reservoir using the system dynamics approach. Results show that a warmer and drier climate in the future will result in temporal and quantitative changes in hydrograph. New set of emission scenarios are consistent with new Representative Concentration Pathways (RCPs) and they are different from the emission scenarios described in the IPCC Special Report on Emissions Scenarios (SRES), and included no policy intervention and were used in the earlier IPCC Fourth Assessment Report (AR4) [10]. The RCPs include mitigation measures to achieve specific emission targets. But attention needs to be paid to the scenarios that latest version of Lars-WG model uses, Lars-WG does not use RCPs. Schewe et al, used RCPs in assessing global water scarcity under climate change [11]. The results show that dwindling per-capita water availability is likely to pose major challenges for societies to adapt their water use and management. Also, the finding suggests that, although climate model uncertainty remains an important concern, further impact model development promises major improvements in water scarcity projections.

Due to results of mentioned researches, various factors of climate change and sustainability can contribute to water resource management policies. Water resources management is complex and climate change brings more complexity to the problem. Hence, assessing water resources sustainability should be done by consideration of effect of climate change. In this way water resources can be managed better and more comprehensive. With this background, finding management practices to achieve sustainable ecological status of the Urmia Lake is necessary. It is hoped that the study will further demonstrate the value of system dynamics modelling in design of restoration plans or similar managements for environmental stewardship.

2. CASE STUDY

The Urmia Lake basin in the North West of Iran is a closed drainage basin (i.e. no outlet) with an area of about 52000 km². The Urmia Lake has important socio-economic and ecological role in the Northwestern part of the country. The Urmia Lake is a hyper saline Lake with a unique ecosystem. Due to its unique ecological features, the lake has been designated as a UNESCO Biosphere Reserve [12]. Inflow to the Lake includes rainfall, surface water, and groundwater and the only outflow from the lake is evaporation.

Because the required ecological water level for the Urmia Lake is 1274.1 m above sea level [1], As seen in the Fig. 1, the Lake’s annual water level dropped below the ecological level from 2001. Urmia Lake's current status had many socio-economic impacts, too. The use of Artemia in fish and shrimp aquaculture is commercially important and recently has been restricted and it is going to extinct. Due to fish kill in the Urmia Lake no fishing benefits can be expected which has led to reduce economic benefits. Windblown salty dusts from dry areas of the lakebed can threaten the health of the people residing in the basin Saving the Urmia Lake is currently one of the top priorities of national and several international organizations. When the toxins and minerals from the salt flats are blown into the air by these storms and inhaled, the toxins and minerals may cause throat and lung cancer, infant mortality, decreasing the life expectancy and increase in birth defects [13]. However, the absence of comprehensive research to evaluate the effect of adaptation/mitigation strategies on the lake is evident [14]. Finding management practices to have sustainable ecological status of the Urmia Lake is necessary. This will help watershed managers to take necessary measures to restore this ecosystem and making it sustainable.

![Fig. 1 Water level and ecological level of the Urmia Lake between 2000-2014](image_url)
3. METHODOLOGY
LARS-WG model was used to study the climate of the Urmia lake basin. The results of this modeling was used to prepare a dynamic model of the Urmia Lake using VENSIM software. In this study, the SD model of the Urmia Lake was prepared by consideration of the hydrological factors and climate change, population and water consumption. In this way, the impact of various water policies would be seen on the lake and on the basis of practical decisions to restore the lake.

3.1. CLIMATE CHANGE
In this study, data from eight synoptic stations in Urmia, Tabriz, Takab, Sarab, Salmas, Sardasht, Maragheh, Mahabad were used as LARS-WG model inputs in order to study the climate of the lake basin. A 25-year base weather data (1991–2014) was used to generate the long-term weather series from 2011 to 2031.

In order to assess the performance of LARS-WG model, proper statistical tests were done to compare the observed and synthetic time series. This consisted of two steps: 1) Analyzing the observed data series by the model and calculating required statistics. 2) Using calculated statistics. Each test produces a p-value which measures the probability that both sets of data come from the same distribution. Hence, a very low p-value means that the synthetic climate is unlikely to be the same as the ‘true’ climate and so the generator is probably behaving poorly [16]. The results of the t and F tests at 1% probability showed that the model-predicted monthly rainfall means and standard deviations are in agreement with the observed series. Similar is evident for maximum and minimum temperatures in the region.

According to the results of LARS-WG model, in Fig. 2 and Fig. 3 show the average temperature and precipitation changes of the watershed under A1B, A2 and B1 scenarios, respectively.

![Fig. 2 Temperature changes of the watershed under A1B, A2 and B1 scenarios (2011-2030)](image)

![Fig. 3 Precipitation changes of the watershed under A1B, A2 and B1 scenarios (2011-2030)](image)

3.2. SYSTEM DYNAMICS
System dynamics models can reproduce the system’s response over time, which assists addressing the problems at appropriate scale and scope [17]; [18]. However, the ability of these models to provide proper insights into potential consequences of system perturbation are dependent on efficiently recognizing the main constituents and feedback loops among them [19].

In the context of SD, variables are either stocks or flows. Stocks are accumulations and are used to characterize the state of the system and create the information upon which decision making. Flow variables are used to define rates which can change the stock variables [8]. The stock value at any time (t) when it has one inlet and one outlet is calculated using Eq. 1:

\[
Stock(t) = \int_{t_0}^{t} [\text{Inflow}(t) - \text{Outflow}(t)]dt + Stock(t_0)
\]

where
- Stock(t) Stock in time t
- Inflow(t) Inflow in time t
- Outflow(t) Outflow in time t
- Stock(t0) Stock in time t0

The following steps were done to build the SD model: (i) describing the problem and inputs; (ii) defining key variables to develop the model; (iii) preparing casual loop diagrams; (iv) building a stock and flow model in Vensim environment; and (v) calibration and validation of the model.
Most of the input data are obtained from various governmental agencies such as Iran Ministry of Power, Ministry of Agriculture, Meteorological Organization, Statistical Center of Iran, and Urmia Lake restoration programs (ULRP).

- **Surface water flow**
  Seventeen hydrometric stations which are located in coastal big rivers leading up to the Lake were used to determine the surface water flow (Fig. 4).

![Fig. 4 Monthly runoff using Seventeen hydrometric stations in the Urmia Lake basin from 2015 to 2031](image)

- **Rainfall**
  Data and statistics on monthly rainfall were collected from five stations close to the lake. The average of this stations were considered as rain inflow to the lake (Fig. 5).

![Fig. 5 Monthly rainfall using five stations in the Urmia Lake basin from 2015 to 2031](image)

- **Evaporation**
  Evaporation intensity is calculated as follows: Data and statistics on monthly pan evaporation were collected from five stations close to the lake (Fig. 6).

![Fig. 6 Monthly evaporation using five stations in the Urmia Lake basin from 2015 to 2031](image)

- **Agriculture**
  As a considerable percentage of the water in the lake's basin is consumed in agricultural sector, agricultural sector is known as the main culprit of the basin's water shortage. In this study some effective variable such as Water demand (millimeters per month), cultivated area (hectare per month) and irrigation efficiency were used in crop and horticultural cultivated lands modelling. According to reports of the Iran's ministry of energy [20], approximately 70% of the Urmia Lake basin's cultivated lands are the crop lands (Fig. 7) and 30% of the cultivated area is dedicated to horticultural lands. The average irrigation efficiency of crop lands is 37 percent and it is equal to 45% for horticultural lands.
4. RESULTS AND DISCUSSION

In this section, the SD model is simulated, considering different plans and then the outcomes are discussed. First, the model should be verified.

4.1. VERIFICATION AND VALIDATION

Model testing consists of model verification and model validation. Model verification refers to testing whether the model is incorrectly coded or simulated incorrectly, that is, whether it has been coded incorrectly, whether the units are inconsistent (dimensional analysis), or whether there are numerical. Model validation refers to the entire range of tests to check whether a model meets the objectives of the modeling study. As such, validation is really about building confidence in its fitness for purpose. Validation in many research areas corresponds largely to testing whether a model reproduces past real data. But there is a large set of tests that could help in establishing confidence in the usefulness of a model or modeling process for its intended purpose [21].

4.1.1. EXTREME CONDITION TEST

Structure in a system dynamics model should permit extreme combination of levels (state variables) in the system being represented. By examining model structure for extreme conditions, one develops confidence in a
model's ability to behave plausibly for a wide range of conditions and thereby enhances the model's usefulness to explore policies that move the system outside of historical ranges of behavior [22]. To do this test, the evaporation intensity (the only outflow of the lake) considered to be equal to zero. As shown in Fig 9, Lake's volume would rise progressively in absence of evaporation.

![Fig. 9 Change of the Urmia Lake volume with and without evaporation](image)

**4.1.2. BEHAVIOR-REPRODUCTION TEST**

Here the generated model behavior is judged with the historical behavior. So, to test the model the behavior of it vs. the observed one should be compared firstly. Fig. 10 shows the observed and estimated values for the water level in the lake. To assess the model performance, statistical measures such as coefficient of determination ($R^2$) and Root Mean Square Error (RMSE) were used to compare the estimated and observed lake's water level.

![Fig. 10 Observed and estimated water level by the Urmia Lake SD model](image)

Coefficient of determination is defined by Eq. 6 and Root Mean Squared Error (RMSE) is also defined by Eq. 7:

$$R^2 = \left( \frac{\sum_{i=1}^{n}(Q_i - \bar{Q})(\bar{Q}_i - \bar{Q})}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2 \sum_{i=1}^{n}(\bar{Q}_i - \bar{Q})^2} \right)^2$$  \hspace{1cm} (6)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Q_i - \bar{Q}_i)^2}{n}}$$  \hspace{1cm} (7)

$Q_i$  Estimated water level  
$\bar{Q}$  Average of Estimated water levels  
$\bar{Q}_i$  Observed water level  
$\bar{Q}$  Average of Observed water levels  
$N$  Number of the months between 2001 until 2014.  

These parameters were obtained 0.90 and 0.37, respectively, which means that the simulation results are acceptable. After this successful model verification, some plans are defined to prevent declines of the lake level and to improve the lake's status. Some of the policies of ULRP were considered in the suggesting plans.

**4.2. SIMULATION PLANS**
In this research, among the various plans changing the lake’s level, five restoration plans are considered. These policies, strategies and projects are among suggestions of ULRP, which is responsible for saving the lake in Iran [23]. The impacts of these plans are considered separately and then simultaneously to investigate if the lake could be saved by combination of these plans (Fig. 11).

Plan 1: Impact of increasing irrigation efficiency on lake level
As the agriculture sector is a high water demand sector, managing water in this sector is crucial. According to the local authorities and experts, farmers are not aware of the impacts of their practices and most of the time they follow their preferences and benefits. For instance, if one of the crops like sugar beets is profitable in West Azerbaijan, most farmers in the next harvesting year are willing to cultivate sugar beets. So a good irrigation plan is essential to achieve sustainable agriculture to some extent, since irrigation is seen as beneficial by farmers [24]. Irrigation efficiency for crop cultivated lands is about 0.37 and for horticultural cultivated land, it is about 0.45 in the Urmia lake basin. While it will increase up to about 0.90 by using mechanized or drop irrigation. Hence changing the irrigation method in some of cultivated lands will highly reduce agricultural water consumption. In this study, it is assumed that irrigation method in 50 percent of cultivated lands of the basin will be changed to mechanized irrigation.

Plan 2: Impact of reducing cultivated area on lake level
Rapid growth in farmed land area in the basin is known as one of main factors of this disaster. Therefore, stopping its growth and decreasing area are followed in plan 2. It is assumed to have maximum reduction about 15% considering social resistances. Changing the 15% of irrigated cultivated land to dry farming lands is suggested. Government has paid attention to this plan. Some subsides are considered to pay for recompense of the damage of applying these kind of plans in agricultural sector. This way, farmers tend to accept the changes of water allocation in the Urmia Lake basin [23].

Plan 3: Impact of changing crop pattern on the Urmia Lake level
Due to different water demand of crops, changing crop pattern to crops with less water demand and more economic crops, can be considered as a solution for saving water. In this study it is assumed that planting alfalfa, watermelon, clover, sugar beet and sainfoin in crop cultivated land section and apple, pear, walnut and almond in horticultural cultivated land section would be stopped or reduced. Applying this plan may influence the farmer’s income, but subsidies the compensation were considered to be paid for damage that crop pattern change caused. In fact, farm subsidies are intended to raise farmer incomes by remedying low crop prices.

Plan 4: Impact of inter-basin water transfer on the Urmia Lake level
The other way of adding water to a basin is water transfer projects. Two main suggested water transfer projects are named Zaab and Aras. Zaab basin is supposed to transfer 700 MCM annually to the Urmia Lake basin to have contribution in lowering water load in the basin by supplying increasing demands. Also, 300 MCM is planned to be transferred annually from Aras basin in north of lake to it.

Plan 5: Impact of inter-basin water transfer and changing crop pattern on the Urmia Lake level
This plan is the accumulation of inter-basin water transfer and changing crop pattern in the Urmia Lake basin.

Plan 6: Impact increasing irrigation efficiency and changing crop pattern on the Urmia Lake level
This plan is the accumulation of increasing irrigation efficiency and changing crop pattern in the Urmia Lake basin.

Plan 7: Impact of increasing irrigation efficiency and changing crop pattern and inter-basin water transfer on the Urmia Lake level
This plan is the accumulation of increasing irrigation efficiency and changing crop pattern and inter-basin water transfer in the Urmia Lake basin.

Plan 8: Impact of increasing irrigation efficiency and reducing cultivated area and changing crop pattern on the Urmia Lake level
This plan is the accumulation of increasing irrigation efficiency and reducing cultivated area and changing crop pattern in the Urmia Lake basin.

In this study by developing the Urmia Lake SD model, some important points can be achieved. The effect of climate change in the basin added to the hydrological and agricultural sub-models and this model is the completed version of other simple models of the Urmia Lake that were made before in this region. This model represents the complex reaction among the variables. Besides it can be understood how much water is required for the Urmia Lake to have its level above the ecological level.
Based on the results of this paper implementing none of individual plans cause the Urmia Lake to be restored. The results of this study showed that due to different management practices, in average at least 35 to 40 percent of water in consumptions should be reduced to restore the lake and make it sustainable. This result matches the ULRP output. It is obtainable with implementing hybrid plans (Plan 7, plan 8 and plan 9) which includes increasing the efficiency of irrigation, changing cropping pattern, reducing cultivated area and water transfer is changed.

The results of this research correspond with the study of Zarghami and Amirrhmani (2015) [14]; in their study, policies such as increasing irrigation efficiency, reducing agricultural area, seeding clouds and water transfer were considered for restoring the Urmia Lake. The results of this study showed that among these policies, increasing irrigation efficiency and reducing agricultural area are the most effective policies and none of them causes the Lake to be restored. As mentioned before, agricultural sector is the most important part to be managed. Paying more attention to education and public awareness is crucial in solving this problem. NGOs and local authorities should get involved and educate the farmers on the impact of their essential role on saving the Urmia Lake ecosystem. In addition, government considered some subsidies to pay for the farmers who have lost some of their income due to the management plans. This kind of considerations may encourage farmers to go along with restorations plans.

To improve the efficiency of this SD model, some general recommendations for effective management of the Urmia Lake are listed here: constructing hydrometric stations in near the lake to understand more exact water inflow to the lake, considering the cooperation of stakeholders and assessing the effect of climate change on groundwater level variations. Accurate assessment of evaporation as the only outflow from the lake can be suggested. Furthermore, operation cost of plans should be considered and a comprehensive comparison including economical, technical and operational parts should be made in future studies.

5. CONCLUSION

Downscaling the results of GCMs using LARS-WG model has revealed that the Urmia Lake basin would have a warmer climate in horizon of 2030 (the temperature would rise 0.68 °C from 2011 to 2030), especially during the summers. The results showed that despite rainfall decreases during the historical period, there will be an increasing trend in autumn and winter, and in spring and summer there will be a decreasing trend. Among A1B, A2 and B1 emission scenarios, A2 is the most pessimistic one which the same scenario was used in assessing restoration plans. It is expected that the average runoff to the lake from 2015 to 2031 will be reduced 15 percent compared with the period of 1996 to 2014 Average change range of the effect of different emission scenarios was from 2 to 5 percent.

Urmia Lake SD model describes variables that affect the lake level. After verifying the model, the impact of implementing various restoration plans on the lake were discussed. The results showed that none of the single plans are suitable. Among the hybrid plans, eighth plan that is the increasing the efficiency of irrigation, changing crop patterns and reducing cultivated areas, is the most effective one. The results indicated that after 47 months from applying this plan, lake level will achieve the ecological level and this situation will remain sustainable in the future. In addition, giving special attention to the agricultural sector as the most important factor influencing water balance of the lake basin, is necessary in developing restoration plans. Due to considering comprehensive factors, the proposed model can help watershed managers to take necessary measures to restore this ecosystem and making it sustainable. This SD modeling provided an integrated...
simulation of this complex case and it is suggested for other water resources systems especially those in semi-arid regions.

REFERENCES