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RESEARCH ARTICLE

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System dynamics applied to water management in lakes*

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Abstract

Water withdrawal and changes in hydrologic fluxes have lowered the level of Urmia Lake in Iran, adversely impacting its ecosystem. The continued lowering of the Urmia Lake water level would put Iran's most important aquatic ecosystem in danger of extinction. Therefore, there is an urgent need for management of water withdrawals and for reduction of water use in upstream dams and rivers to halt its continuing decline and allow storage recovery. The Urmia Lake basin was herein modelled with system dynamics (SD) to assess the effects of modifying reservoir operation and water use management on the sustainability of Urmia Lake storage. The model performance was evaluated with the root mean square error (RMSE) and the correlation coefficient (R^2). The results show that SD with RMSE = 18.0 (10^6 m^3) and R^2 = 0.952 is accurate in simulating Urmia Lake storage. Evaluation of the impacts of several scenarios of agricultural water use on lake storage indicates that reductions in the agricultural sector appear inevitable to restore the water balance of Urmia Lake.

KEYWORDS

modelling, system dynamics, Urmia Lake, water demand, water rationing

Résumé

Les prélèvements d'eau et les changements de flux hydrologiques ont abaissé le niveau du lac Urmia en Iran, affectant négativement son écosystème. La baisse continue du niveau d'eau du lac Urmia mettrait en danger d'extinction le plus important écosystème aquatique d'Iran. Par conséquent, il est urgent de gérer les prélèvements d'eau et de réduire l'utilisation de l'eau dans les barrages et les rivières en amont pour arrêter son déclin continu et permettre la récupération du stockage. Le bassin du lac Urmia a été modélisé ici avec system dynamics (SD) pour évaluer les effets de la modification du fonctionnement du réservoir et de la gestion de l'utilisation de l'eau sur la durabilité du stockage du lac Urmia. La performance du modèle a été évaluée avec l'erreur quadratique moyenne (RMSE) et le coefficient de corrélation (R2). Les résultats montrent que SD avec RMSE = 18.0 (10^6 m^3) et R2 = 0.952 est précis dans la simulation du stockage du lac Urmia. L'évaluation des impacts de plusieurs scénarios d'utilisation agricole de l'eau sur le stockage du lac indique

*Dynamique des systèmes appliquée à la gestion de l'eau dans les lacs

que les réductions dans le secteur agricole semblent inévitables pour rétablir le bilan hydrique du lac Urmia.

MOTS CLÉS

Lac Urmia, demande en eau, modélisation, dynamique des systèmes, rationnement de l'eau

1 | INTRODUCTION

Today's complex problems involving multifaceted water issues pervade many domains (Bozorg-Haddad *et al.,* 2009; Soltanjalili *et al.,* 2011; Sabbaghpour *et al.,* 2012; Fallah-Mehdipour *et al.,* 2014). SD is an object-oriented method for modelling a wide variety of systems, does not require complex mathematics and is efficient and general for modelling water resources systems. The SD method, introduced by Forrester (1961), has a long history of applications for improving the understanding of strategic issues in dynamic systems. Fletcher (1998) applied the SD method as a tool to support decision making in the management of scarce water resources. Royston (1999) applied the SD method for managing water demand and operation of a multipurpose reservoir.

Teegavarapu and Simonovic (2000) implemented the SD method for modelling the operation of a multireservoir system to produce hydroelectric power efficiently. Ho (2005) studied the impact of the SD method for water management decisions in southern Taiwan. Ewers (2005) introduced a model for optimal water allocation in the Sun Juan River basin of the United States and Mexico. Winz *et al.* (2009) discussed the use of SD in water resources management and traced the theoretical and practical evolution of SD over 50 years. Kotir *et al.* (2016) implemented SD modelling to assess interaction between population, water resources and agricultural production in the Volta River basin, West Africa. The results showed that SD accurately calculated uncertainties in the major parameters. Nassery *et al.* (2017) identified safe groundwater level fluctuations, the water supply and deficits of municipal–industrial and agricultural uses using SD in the Tabriz plain, Iran.

The main purpose of the SD method is simulating and learning a system's behaviour under current and future conditions. The SD method is an object-oriented simulation method that captures a system's feedbacks to explain their functioning, and allows users to intervene in model development and gain familiarity with its application. Rapid model development, ease of shared model construction, effective communication of model results, and the raising of confidence in model application through user participation are the key features of SD. These features make SD particularly well suited for simulating the water and environmental processes of Urmia Lake, and to shed light on proper strategies to abate the decline of its storage. Urmia Lake, 5750 km^2 in area and threatened by human activities, is Iran's largest lake and one of its most valuable aquatic ecosystems (Stone, 2015).

Notwithstanding various studies on Urmia Lake, further research is needed to understand its storage dynamics and restore a sound water balance. Several studies have been reported in recent years concerning the water balance of Urmia Lake, its water resources, and environmental impacts of factors affecting the lake's storage. Hasanzadeh *et al.* (2011) applied SD and reported that water storage in Urmia Lake had been reduced by a combination of drought, withdrawal and damming of rivers draining to its basin. They established that a quarter of the area of Urmia Lake has been converted to salt marsh. Hasanzadeh *et al.* (2012) reported the main factors behind the decline of the level of Urmia Lake using SD. Their results demonstrated that climate change and overuse of surface water resources were the main cause (65%) of storage decline, followed by construction of four dams (causing 25% of storage reduction), and less precipitation on the lake reduced its storage by 10%. Ghasemi *et al.* (2012) used statistical methods to evaluate the effects of climatic and hydrological factors on the western part of Urmia Lake basin. The latter authors showed that unusual climatic and hydrological factors have contributed to the reduction of the lake's water level in recent years. Eamen and Dariane (2013) evaluated the effect of agricultural water consumption on the Urmia Lake level with the WEAP software. Ghashghaie *et al.* (2014) evaluated the results of construction dams and water demand priorities on downstream of Bukan Dam by using SD. Zarghami and AmirRahmani (2017) simulated the restoration plans in Urmia Lake, and modelled increasing irrigation efficiency and decreasing irrigated land by using the SD approach. Hosseini-Moghari *et al.* (2018) quantified the effect of human water use in reducing the inflow into Urmia Lake. They discovered that even if human water use were eliminated completely, Urmia Lake would have a significant loss of water caused by drought. Ebrahimi Sarindizaj and Zarghami (2019) studied restoration plans in Urmia Lake by the SD method and in climate change conditions and showed that hybrid plans are more efficient rather than single ones. Mohebzadeh and Fallah (2019) analysed the water balance of Urmia Lake quantitatively, and water balance components were calculated by remote sensing. Their results established a negative water balance of about 3440 MCM yr^{-1}.

Our literature review indicates there have been no studies yet that consider SD in Urmia Lake storage simulation and agricultural water use effects. This study introduces simulation scenarios for agricultural water use seeking to increase the lake's storage, because the agricultural sector is one of the most important water users and economic sectors in Iran (Ardakanian, 2005). We know that total water resources in the Urmia Lake basin are about 3160 MCM (million cubic metres), while total water consumption within the Urmia Lake catchment is currently about 4830 MCM, of which 4290 MCM are consumed by agriculture. This means that about 90% of the total water consumed in this basin is devoted to agricultural activities (Jabbari, 2019).

Therefore, the aim of this research is to improve lake modelling through innovative scenarios considering droughts and hydrological events which may assist in revitalizing the lake, and to add to the previously proposed restoration methods. To achieve these, the effect of the operation of six dams (built since 1970) on the water balance of Urmia Lake over the simulation period 1970–2005 is evaluated. These dams divert water that would otherwise flow to Urmia Lake. Hence, SD is applied to assess the effects of reservoir operation and agricultural water supply in the search for sustainable management of Urmia Lake. Firstly, we modelled the Urmia Lake basin system driven by changes due to human activities (withdrawals from aquifers and surface water) and to the occurrence of droughts and hydrological events. Secondly, the restoration of the volume of Urmia Lake is evaluated under several scenarios of water rationing of agricultural water supply.

2 | MATERIALS AND METHODS

2.1 | Case study (Urmia Lake)

Urmia Lake is located in north-western Iran, in the provinces of East Azerbaijan and West Azerbaijan, with an average elevation equal to 1276 m + MSL (mean sea level). Figure 1 shows the location of Urmia Lake. It has a storage capacity of 32 BCM (billion cubic metres), is the second largest hypersaline lake in the world and the largest in the Middle East (Vaheddoost and Aksoy, 2016), and is the most valuable aquatic ecosystem in Iran. The ecosystem of Urmia Lake is an example of a closed basin, the ecosystem of which includes the lake and its tributary basin. There are 16 wetlands in the vicinity of Urmia Lake with some areas as large as 1200 ha (some have dried up) that have fresh water or brackish water, and are valuable from the ecological viewpoint.

The basin is bounded to the north, east, south and west by the Aras, Sefirood, Ozan and Sirvan, and Zab River basins, respectively. Its western boundary includes part of the border with Turkey and Iraq. This basin features an area equal to 51 900 km^2 that includes part of West Azerbaijan province (21 500 km^2), a large part of East Azerbaijan province (19 000 km^2) and a part of the Kurdistan province (5000 km^2). About 33 500 km^2 of the Urmia Lake basin are mountainous, 12 600 km^2 are plains and foothills, and the area of the lake itself is about 5320 km^2. The Urmia Lake basin contains a major portion of Iran's water resources. Thus, this basin has a comparative advantage for economic development given its richness of water resources.

Figure 2 depicts the water fluxes that govern storage in Urmia Lake, be they natural or artificial. The natural inputs are surface inflows, precipitation and groundwater inflows. In open basins the outputs are evaporation, withdrawals, natural outflows and artificial withdrawals, but

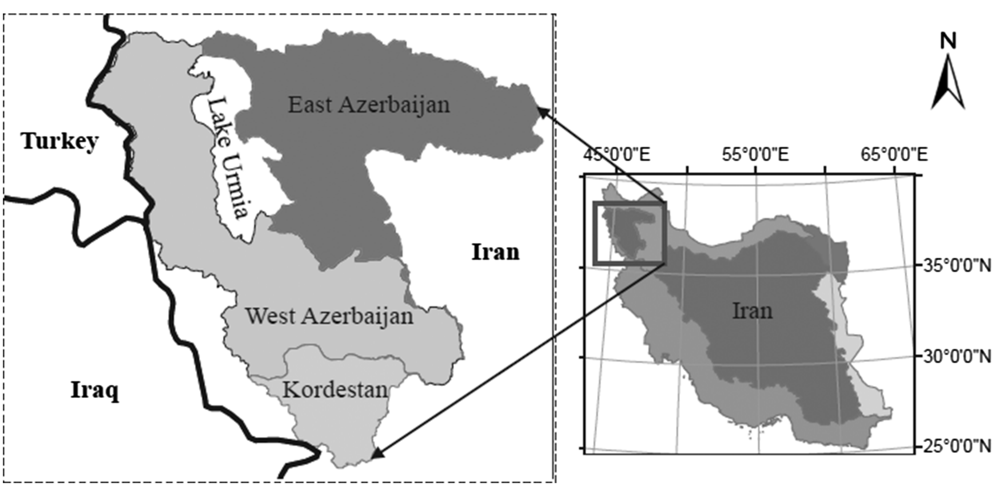

FIGURE 1 The location of Urmia Lake in Iran

in closed basins like Urmia Lake the outputs are evaporation and artificial withdrawals.

2.1.1 | Water balance factors of Urmia Lake

Another important characteristic of Urmia Lake is the significant influence of evaporation on the water balance of the lake's variable level. In this respect, Urmia Lake resembles the variable hydrology of Utah's Great Salt Lake (Powell, 1879). A water balance schematic is depicted in Figure 3, which applies to lakes in general.

The continuity equation, $I - O = \Delta S$, governs the water balance of Urmia Lake, where I, O and ΔS respectively denote the volumetric inputs, outputs and storage change in Urmia Lake, and these are explained in the following subsections. A 49-year-long period (1957–2005) is used in this paper for water balance calculations.

2.1.2 | Water inflow to the Urmia Lake basin (I)

The water resources of the Urmia Lake basin include surface inflows (permanent rivers, seasonal rivers, streams

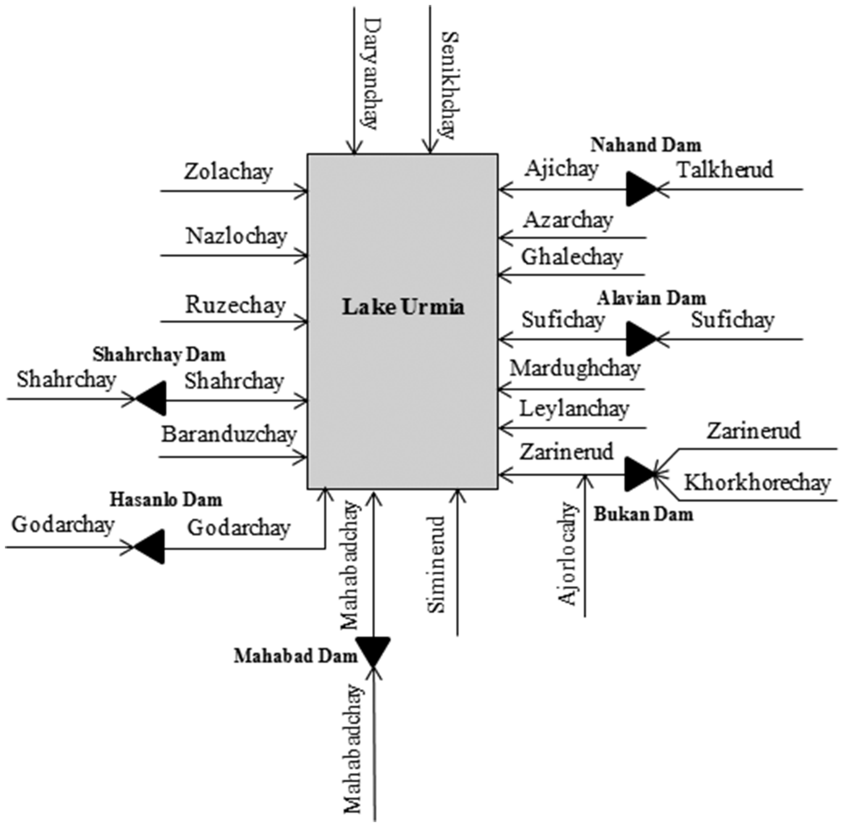

FIGURE 2 Schematic of the Urmia Lake water fluxes

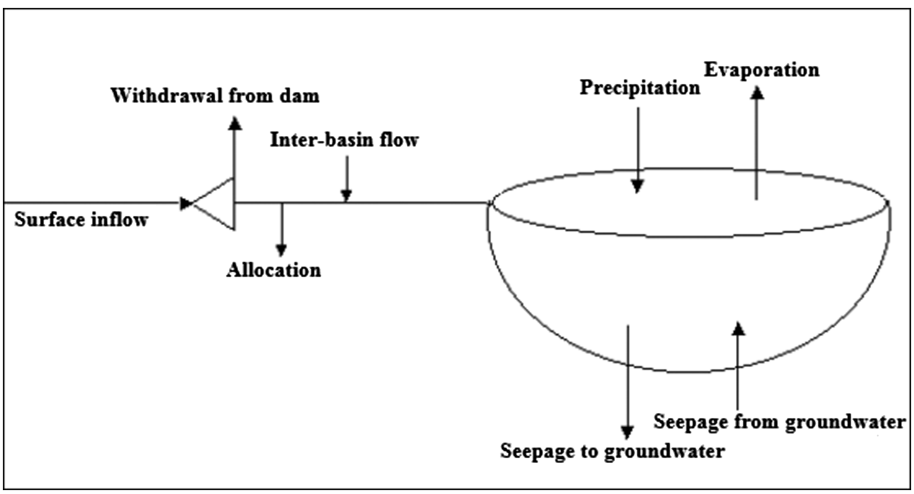

FIGURE 3 Schematic of water balance in lakes

and runoff from adjacent land), precipitation and groundwater from aquifers, which are described below.

1 *Surface inflows.* The perennial rivers of the Urmia Lake basin are called Zarrinehrud, Siminehrud, Mahabad chai, Godar chai, Barandoz chai, Shahr chai, Ruze chai, Nazlou chai, Zola chai, Aji chai, Azarshahr chai, Sufi chai, Morduq chai, Leyla chai, Senikh chai and Ghale chai; several seasonal streams flow during winter and spring, of which the major ones are the Sheyone chai, Khorkhore chai, Neyvan chai, Tesuj chai and Daryan chai. The surface water resources include in total 39 rivers and streams. Some of the major rivers are shown in Figure 4. Winter precipitation as snow is predominant, with spring snowmelt constituting a major contributor to streamflow towards the Urmia Lake basin. The Zarinerud and Siminerud rivers carry about 52% of the total surface inflows to Urmia Lake.
2 *Precipitation.* Precipitation in Urmia Lake has changed over time. Average annual precipitation over the basin of this lake is about 326 mm, that is one-third of the global mean annual precipitation (990 mm). Figure 5 depicts annual precipitation from 1967 to 2005 in Urmia Lake. The trend line shows decreasing precipitation in this period, from nearly 400 to 260 mm. This trend reflects the occurrence of droughts as shown by Sobhani *et al.* (2019).

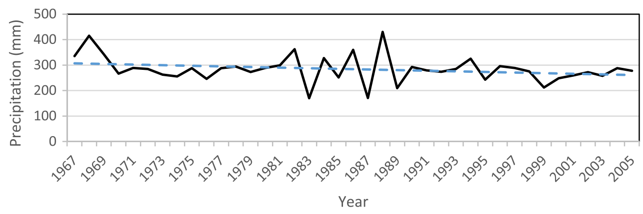

FIGURE 5 Annual precipitation in Urmia Lake [Colour figure can be viewed at wileyonlinelibrary.com]

3 *Groundwater.* Groundwater supplies about 50% of the Urmia Lake basin water input. The remainder of water use is met by surface inflows. The deepest groundwater in the alluvial fans and the perimeter of the Urmia Lake basin reaches 30 m and deeper. Urmia Lake receives groundwater accruing from neighbouring areas. Groundwater depth is reduced to less than 1 m near the lake margins. Aqueducts are located at the edge of the plains and make a small contribution to water supply. The occurrence of drought conditions in recent years and the decline in groundwater level have reduced groundwater

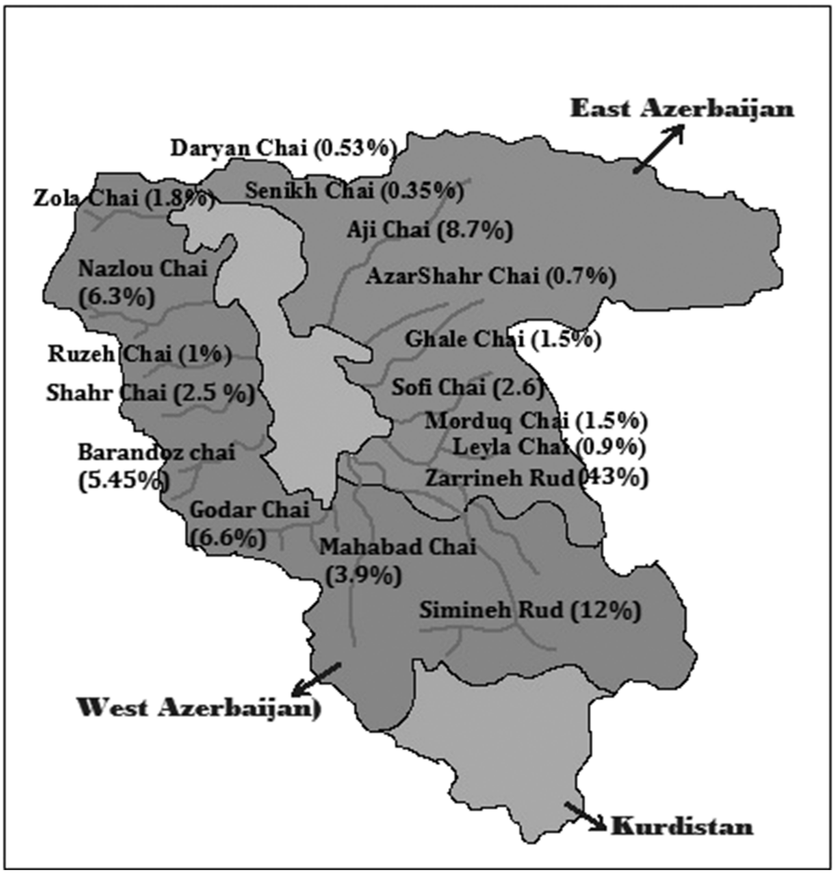

FIGURE 4 Schematic of the river system draining to Urmia Lake

extraction in several aquifers. Basin aquifers are exploited by wells and aqueducts and more than 90% of groundwater withdrawal is by wells. The operation of wells has evolved rapidly over the past two decades. Several aquifers exhibit protracted declines in groundwater levels.

2.1.3 | Water outflow from Urmia Lake (*O*)

Evaporation is the only natural output from the lake, and as it is a closed basin not featuring runoff. Evaporation depends on the lake level and surface area. Urmia Lake has an annual evaporation rate ranging from 600 to 1000 mm. In addition, there are other artificial outputs from the basin such as groundwater withdrawal that constitute SD model outputs; seepage to and from the lake is minor and not considered in the water balance equations (Bengtsson *et al.,* 2012; Ding *et al.,* 2014).

2.2 | Principles of the SD method

SD is a dynamic method for understanding complex systems based on feedback control, and analyses system changes over time. Thus, the SD method is well suited to model systems that (i) are dynamic and contain variable quantities over time, and (ii) include feedback. It has been applied in several fields of inquiry, including business, biology, sociology, economics and engineering. The SD method is efficient, user friendly and an effective modelling tool.

SD uses two types of visual display: (i) cause-and-effect diagrams that define the interactions of phenomena, and (ii) a state–flow diagram that displays phenomenological relations defined by means of specific processes. SD solves equations with the Runge–Kutta methods, which are a family of implicit and explicit iterative methods (including the well-known Euler method) used in temporal discretization for the approximate solutions of ordinary differential equations (see e.g. Hairer *et al.,* 2006).

Applicable software to code the SD method includes STELLA, Vensim, Powersim, Anylogic and Dynamo. This study implements Vensim to code the SD for Urmia Lake, because it offers flexible architecture to capture the dynamic of water problems. Vensim is simulation software developed by Ventana Systems. It primarily supports continuous simulation, with some discrete-event and agent-based modelling capabilities.

2.2.1 | Efficiency criteria

Model outputs were compared with observed data by means of two efficiency criteria, the root mean square error (RMSE) and the correlation coefficient (R^2). These criteria are considered to evaluate the efficiency of the calculated values of the simulated lake volume with the SD model. The RMSE is used to determine the error made in calculations as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - y_i)}{N}} \tag{1}$$

where x_i = a calculated (predicted) value, y_i = an observed value and N = the number of calculated values. The RMSE increases with decreasing accuracy of predictions.

The R^2 expresses linear statistical dependence between two variables, and it calculated by Equation 2:

$$R^2 = \left(\frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{N}(y_i - \bar{y})^2}} \right) \tag{2}$$

where $\bar{x}$ = average of the calculated data and $\bar{y}$ = the average of the observed data. The R^2 value falls in the interval (0, 1). As the R^2 approaches 1 (or zero) the calculated values are very close (very different) to the observed values.

2.3 | Modelling Urmia Lake with SD

The lake's storage (volume) is the state variable with a specified initial volume, and evolves according to inputs and outputs. The lake's model data include inputs (surface inflows, precipitation), and outputs (evaporation and groundwater withdrawal), and the model output is the lake's volume change. The measured parameter in Urmia Lake is the water level, which is related to the lake storage by a known functional relation.

The first step in the application of SD to the Urmia Lake basin is model calibration to time series of fluctuations in the lake's water level. The initial lake volume was determined from the known lake volume-level function from an initial lake level, and it was found to be 26 000 MCM. The initial volume was input to the model and the simulated lake levels were compared with the actual ones.

2.4 | Vensim model coupled with SD for water balance analysis

The SD method quantifies the effects of management policies on system performance. A state-flow diagram of Urmia Lake (Figure 6) was implemented to model the Urmia Lake basin with the Vensim software coupled to the SD method. The lake's volume is the model's output; the lake evaporation was obtained from available long-term evaporation water level and area-volume-level functions. Several scenarios were considered to improve the lake's water balance.

2.5 | Simulation scenarios

Overuse of water resources in the Urmia Lake basin and its nearby dams is a key driver of the reduction in the lake's level. Simulation scenarios are used to evaluate improvement of the lake's storage. Several modelling scenarios were evaluated by simulating the Urmia Lake level with SD. Thirty-four scenarios were considered for operating Bukan Dam based on the maximum storage of Urmia Lake and are listed in Table I. The storage of Urmia Lake is affected by the operation of six dams (Alavian, Bukan, Hasanlo, Mahabad, Nahand and Shahrchai), of which Bukan Dam has the greatest impact in the Urmia Lake basin (Figure 7) and is one of the main dams in it (Ghashghaie *et al.,* 2014).

Most of the water use is destined for the agricultural sector in the study area. This study considers only the operation of Bukan Dam in simulation of the effects of the curtailment of agricultural water on the storage of Urmia Lake. Therefore, these scenarios were defined in terms of the percentages of the agricultural water demand supplied by releases from Bukan Dam, the oldest in the Urmia Lake basin, based on the available storage in Urmia Lake. The available storage in Urmia Lake is expressed in terms of percentages (quartiles) of its maximum value, i.e. in terms of the non-overlapping percentages <25%, [25–50%], [50–75%], [75–100%]. For example, under scenario 2 only one-half (i.e. 50%) of the agricultural demand is supplied by Bukan Dam when the storage of Urmia Lake is in the range [25–50%] of its maximum storage, and 100% of the agricultural water demand is supplied when the lake's storage is in the range [50–75%] or [75–100%]. The lower quartile (< 25%) has no effect on restoration of the lake level because the available lake storage was equal to or larger than 25% of its maximum value in the period 1970–2005, which is the period of analysis used in this paper. Similar interpretations hold for the other simulation scenarios listed in Table I.

3 | RESULTS AND DISCUSSION

This paper's simulation results were obtained from simulations of the storage of Urmia Lake and several levels of

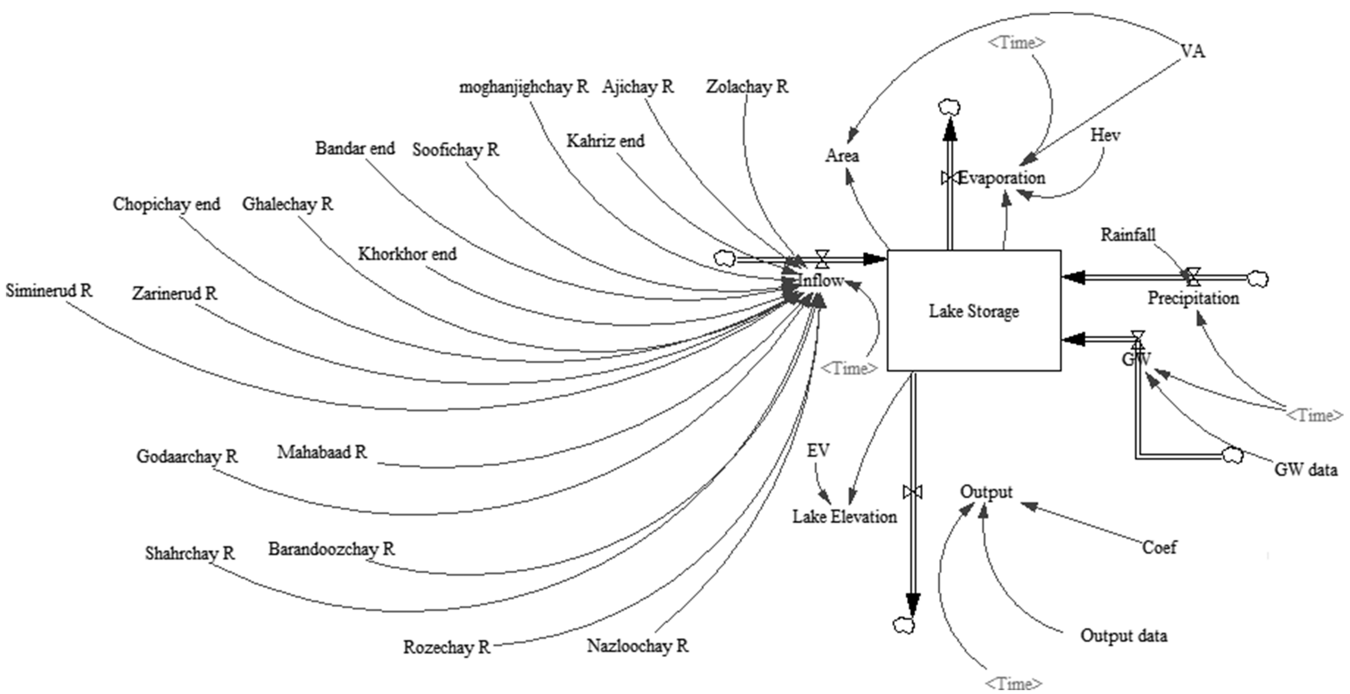

FIGURE 6 State-flow diagram of Urmia Lake

TABLE I Scenarios of agricultural water use (in %) supplied by Bukan Dam based on Lake Urmia storage expressed as the percentage its maximum storage

Scenario	Percentage of Urmia Lake's maximum storage				Scenario	Percentage of Urmia Lake's maximum storage			
	<25%	[25–50%]	]50–75%]	>75%		<25%	[25–50%]	]50–75%]	>75%
1	100	75	100	100	18	100	0	75	75
2	100	50	100	100	19	100	50	50	75
3	100	25	100	100	20	100	25	50	75
4	100	0	100	100	21	100	0	50	75
5	100	75	75	100	22	100	25	25	75
6	100	50	75	100	23	100	0	25	75
7	100	25	75	100	24	100	0	0	75
8	100	0	75	100	25	100	50	50	50
9	100	50	50	100	26	100	25	50	50
10	100	25	50	100	27	100	0	50	50
11	100	0	50	100	28	100	25	25	50
12	100	25	25	100	29	100	0	25	50
13	100	0	25	100	30	100	0	0	50
14	100	0	0	100	31	100	25	25	25
15	100	75	75	75	32	100	0	25	25
16	100	50	75	75	33	100	0	0	25
17	100	25	75	75	34	100	0	0	0

FIGURE 7 Dams in the Urmia Lake basin

agricultural water supply. This study's results are compiled in two subsections, i.e. simulation results and results concerning scenarios of agricultural water use, which are discussed separately below.

3.1 | Simulation

The water balance of Urmia Lake was simulated with the SD method. SD simulates the lake's volume and changes the level of the lake by area–volume–height diagrammatic functions. The lake's level was compared with long-term observation data for 1957–2005 to verify the model's accuracy. The efficiency of the calculated values was evaluated with the chosen efficiency criteria (i.e. RMSE and R^2). The values 18.0 (10^6 m^3) and 0.952 were respectively calculated for the RMSE and R^2 of the simulated lake volume. These values demonstrate that the SD model has a high degree of accuracy in simulating the volume of Urmia Lake. The SD accuracy was calculated by comparing calculated values with observed ones. There were 34 scenarios defined to be simulated with the SD model.

3.2 | Scenarios of agricultural water use

This study specified lake volume changes rather than lake level changes. Construction of several dams upstream of Urmia Lake has had crucial impacts on the lake's storage. We assessed the restoration in terms of lake storage (i.e. in the percentage categories >25%, 25–50%, 50–75% and >75%) through regulation of the

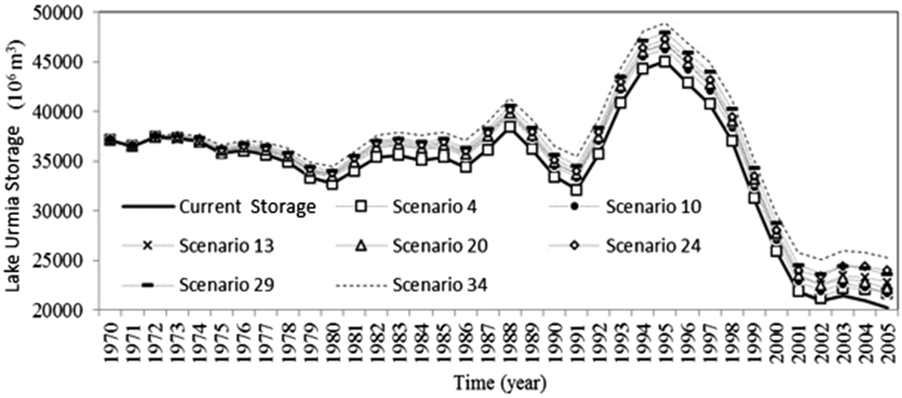

FIGURE 8 Simulated Urmia Lake storage corresponding to selected scenarios

agricultural water use supply from Bukan Dam. Figure 8 shows a graph of the simulated Urmia Lake storage (volume) for scenarios 4, 10, 13, 20, 24, 29 and 34. These 7 scenarios were randomly selected from the total 34 scenarios to represent Urmia Lake's storage projections under real-world exposure conditions. It is seen in Figure 8 that several scenarios (4 and 10, 13 and 20, and 24 and 29) are very close to each other. Scenarios 4, 10, 13 and 20 achieved maximum storage restoration in Urmia Lake, equal to 11.72% of its current storage. Scenario 24 does not supply water when current storage is in the quartiles (25–50%) and (50–75%) of the maximum; it achieves a maximum restoration of the lake storage equal to 18.4% of its current storage. Scenario 29 reduces to zero the agricultural water supply when the storage in Urmia Lake falls in the quartiles (25–50%) and (50–75%) of its maximum storage, and supplies half of the agricultural demand when the storage of Urmia Lake is in the (> 75%) quartile of its maximum storage. Scenario 29 achieves a maximum restoration of Urmia Lake's volume equal to 22.7% of its current storage. Scenario 34 reduces agricultural water supply to zero regardless of the storage of Urmia Lake. This reduction in agricultural water supply would result in adverse farming impacts. Scenario 34 achieves maximum storage restoration equal to 27.9% of its current value.

Results indicate that water consumption by the agricultural sector would have to be reduced to be effective in restoring the storage of Urmia Lake. Eamen and Dariane (2013) found that agricultural water use has a significant role in the level of the Urmia Lake and its ecosystem. Ghashghaie *et al*. (2014) indicated that one solution to prevent a critical situation in Bukan Dam and Urmia Lake as well, is to change agricultural patterns that result in decreasing water resources. Also, Moghadasi *et al*. (2015) in their research stated that agricultural water use would have to be reduced by 25–35% and 15–25% in East Azerbaijan and West Azerbaijan, respectively, to achieve the water-rights allocation of Urmia Lake.

CONCLUDING REMARKS

This study's main objective was to model the Urmia Lake basin water system driven by changes caused by human activities (withdrawals from aquifers and surface water) and by the occurrence of droughts and hydrological events. The results from the efficiency criteria and from comparing model outputs with observed data indicated that the SD model simulates the Urmia Lake basin accurately.

Fertile lands caused agricultural expansion in the Urmia Lake basin. Therefore, in addition to reduction of lake inflow due to climate change and drought there are large water withdrawals from the basin's surface and groundwater resources. This paper's second objective was to evaluate the restoration of the storage of Urmia Lake by rationing agricultural water supply according to several scenarios of curtailment of water from Bukan Dam, one of the main dams in the Urmia Lake basin; it is built on the largest river of the basin, Zarinehrood, which has significant influence in supplying water for irrigation and agricultural use. The SD model calculated storage restoration for several water-supply shortage scenarios. It can be concluded that decreasing agricultural water use is effective in regional restoration. But reducing agricultural use alone and without regard to other conditions would not be sufficient to restore Urmia Lake to a healthy condition. Because reduction of agricultural water use would have negative impacts on farming and food production in the region. Therefore, decision makers must consider the lake's water issues comprehensively and apply strategic solutions for restoring Urmia Lake, rather resorting exclusively to the reduction of agricultural water use. Consideration of improving the efficiency of irrigation systems and the type of cultivated crops is also called for in this case. Furthermore, reduction of other water uses impacting on the volume of Urmia Lake, such as industrial and human water use, must be entertained.

Construction of different dams and water allocation (agriculture, domestic, industry and environment) have had negative effects on downstream water resources in the basin. This study considered the reduction of agricultural water use, known to be the largest user, met by the Bukan Dam, as the main strategy for improving the volume of Urmia Lake. Future research will consider the impacts of climatic change and domestic, industrial and environmental demands as well as agricultural ones.

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