Assessment of main findings on Urmia Lake research and restoration efforts

M. Soudi¹*, H. Ahmadi¹, M. Yasi² and S.A. Hamidi³
¹ Department of Water Engineering, University Urmia, Urmia, Iran
² Department of Irrigation & Reclamation Engineering, University of Tehran, Karaj, Iran
³ Department of Physics, College of Natural Sciences and Mathematics, Indiana University of Pennsylvania, USA
*e-mail: soudi_mina@yahoo.com

Abstract: The natural and human-induced processes are currently major threats to aquatic ecosystems and water bodies, all over the world. Urmia Lake, the world’s second largest saline lake, is located in the Northwest of Iran, is being drying up mainly due to the mismanagement of water use in the basin and the reduction of inflow to the lake. The lake water level has rapidly declined since the mid-1990s. Construction of more than fifty dams and diversion structures, along with the effects of climate change, are the main causes. Construction of a 15 km long causeway in the middle of the lake is an additional cause, which eliminates the natural circulation in the lake. The situation has turned to critical over the past two decades, and the need for restoration is an urgent priority for the region. The contribution of the principal rivers for flowing water into Urmia Lake is considered an ultimate solution to this crisis. However, the most challenges for any restoration plan are to be public awareness and general knowledge on the environmental values of the lake to local communities. This paper addresses the major causes to the desiccation of Urmia Lake, and presents an overview on the restoration plan and strategies that have been setup for the next years. Major threats and challenges are also highlighted in terms of the public awareness and community benefits in order to secure the feasibility of the plan for preservation of this internationally recognized wetland at a sustainable environmental status.

Key words: Causeway Urmia Lake; restoration plan; water management; drought; lake causeway.

1. INTRODUCTION

The Urmia Lake Basin is one of the most valuable ecosystems that is located in the northwest of Iran, between the provinces of West and East Azerbaijan. As an endorheic or terminal lake, water leaves the lake only by evaporation. So it is a closed-basin and the only outlet is evaporation (UNEP, 2012), but the inlets consist of precipitation, rivers, runoff flow and groundwater inflow (Ghaheri, 1999).

Because of its unique natural and ecological features, such as existence of exclusively a kind of Artemia (Urmiana Artemiana) as an exclusively parthenogenetic population (Barigozzi et al., 1987), this hypersaline lake was declared as a Wetland of International Importance by the Ramsar Convention in 1971 (Ramsar Site) and in 1976 as designated a UNESCO (UNESCO Site) Biosphere Reserve (ULRC, 2015a).

Since 1979 a dike type causeway gradually has been constructed in the middle of the lake and divided the lake into north and south parts, where connects the city of Urmia (West Azerbaijan Province) to city of Tabriz (East Azerbaijan Province) and limits the exchange of water within just 1.25 km long opening that covered by a bridge (Teimouri, 1998). Results of hydrodynamic numerical modeling of Urmia Lake reveal that flow regime have been effected by wind input as a climate and hydrologic factor, but river discharge, evaporation and rainfall were main parameters affecting salinity distribution in the lake models. Therefore, the causeway has no significant effect on the lake flow and salinity regime (Zeinoddini et al., 2009). However, the influence of the causeway on exchanging of flow between these two parts is unassailable, and needs much more hydrodynamic studies to have a better knowledge about it. The location of Urmia Lake and the causeway as well as mouth of its major input rivers are shown in Figure 1.
2. CAUSES AND CONSEQUENCE OF DRYING

During the last two decades (since 1995) some parameters have severely been declined the water level of Urmia Lake. Based on precipitation measurement stations in the lake basin, the average of the basin precipitation from 1995 to 2013 has been decreased about 18%, about 68 mm (ULRC, 2015a). Investigations result by Hassanzadeh et al. (2011) revealed that four dams (Alaviyan, ZarinehRoud, Mahabad and Nahand) have been responsible for 25% of the lake. Furthermore, last assessment of water demand in the Urmia Lake Basin revealed that 70% consumption of renewable water resources of the basin, whereas, according to stable development index of United Nations Commission, the amount of secure and acceptable consumption of renewable water resources have been determined between 20 and 40%. Therefore, 30% overuse from the Urmia Lake Basin (because of development of agriculture) has affected stability of the water resources of the basin (ULRC, 2015a). Nonetheless, reduction of the water level of the lake through the two recent decades, whether in monthly or yearly scales was more harsh and different than changes of precipitation and temperature, so anthropogenic factors impacts rather than natural variability (Jalili et al., 2016a, b; Zoljoodi and Didevarasl, 2014).

In the Urmia Lake Basin, population growth leads to increasing in the need for food as well as demand for water (Khatami and Berndtsson, 2013). Agriculture activities in the basin consume about 90% of water of the whole basin and more than 60% of the renewable water. Based on recently published data by Ministry of Energy (MOE), in 2011 annual water volume consumption for agriculture purpose was 4.3 MCM. In spite of that, agriculture consists of 30% of whole basin incomes (ULRC, 2015a). It seems that developing industrial activities in Urmia Lake basin can decrease, depending on the economy of the region to agriculture and may decrease water demand.

Drop in the lake water level increase the salinity of the lake. Artemia Urmiana tolerate a salinity range of 40 to 250 g/l (Csavas, 1996) so continuation of this trend in recent years treat the life of Artemia, and confront it with extinction danger. Since Artemia is the main food resource of birds, especially flamingos, which spawn in the basin, a severe decrease in number of birds have been occurred (Abbaspour et al., 2012).

Furthermore, drying of Urmia Lake leaves the majority of the lake converted by salt, especially
in southern part. Based on experience from Aral Sea, this change leads to numerous problems in the ecosystem and the climate of the area such as salt storm and subsequently refractory diseases for child and other health hazards (Zetterstrom, 1999). Unfortunately, converting the lake to an active region of saline dusts can be significantly threatening for the population of the lake basin.

In Figure 2, some examples of consequences of drop in the Urmia Lake water level are shown. Other impacts are rising of the lake bed level and change it to flatter bed because of settling salts. Based on satellite images and remote sensing observations of the bed level of the lake, there has been an increase from 4 up to 108 cm since 2013 to 2015 (WRI, 2015).

3. ADMINISTRATIVE ACTION PLANS OF URMIA LAKE RESTORATION NATIONAL COMMITTEE

Urmia Lake Restoration National Committee (ULRC) has proposed management and structural policies for the restoration of the lake. As the programs have had pros and cons, professional investigation of cost - benefit of projects is essential. Mentioned action plans consist of below actions (ULRC, 2015b):

I. Enhancement of inflow volume in watercourses ending to the Urmia Lake.
   - Connecting two major rivers, ZarinehRoud and SiminehRoud, for facilitating water delivery into the lake.
   - Dredging of SiminehRoud, Godarchai, Mahabadchai and Ajichai Rivers

II. Increase in input water volume to the lake by extrication of stored water of the constructed dams

III. Inspection of illegal overusing of surface and ground waters.

IV. Protection actions for decreasing to salt storm disasters

V. Inter basin water transfers plans
   - from Zaab River subbasin
   - from Silve Dam in Southern part of the lake

VI. Increasing the efficiency of irrigation water by using new irrigation methods.

Some of the mentioned action plans have high cost such as dredging of major rivers and inter basin water transfers plans. So those restoration plans so far have had multi millions dollars expenses for government but implementation process is slow and the efficiency of them in restoration of the lake water level is a matter of question (Khatami and Berndtsson, 2013).

Transferring of water from other basins to Urmia Lake, because of long distance between two basins has had much more expenses, and cause problems for the water balance and ecosystem of the other basins. Thus, inter basin water transfer plans are expensive and time consuming, and at least cannot be considered as a short-term solution.
4. MAIN FINDINGS AND IMPLICATIONS

Results of the sensitivity analysis of different parameters declared that the lake water level is highly sensitive to river input, so that the water development projects implementation in the Urmia Lake Basin will disturb the lake ecosystem (Abbaspour et al., 2012).

Japan International Cooperation Agency, JICA et al. (2016), in collaboration with Water Resources Management Company (WRMC) and MOE has been modelled the projects effect and the hydrological cycle of Lake Urmia Basin by MIKE-SHE and GETFLOWS numerical models respectively.

Based on the result of the MIKE-SHE model, the water level of Urmia Lake was simulated for the condition that the selected hydrological situation will continuously occur every year from the beginning to the end of the sequential simulation. The results of sequential simulation are summarized in Figure 3. As a result, it can be seen that only the Project 3 (P3) can achieve the target water level (1,274.1 m), even though all projects except No. 1 have the possibility to recover the lake water level to some extent (JICA et al., 2016). It seems that there is essential to design an appropriate dams operation schedule.

From the result of the simulation, it became clear that the river inflow volumes of approximately 2,050 MCM is necessary for around 10 years to adjust the in target water level. However, in case of the project prepare of over 2,100 MCM/year, the water level will also rise to more than the target water level of 1,274.1 m in the future. Other studies estimate inflow volumes as 3085 MCM of inflow per year for restoration of the lake (Abbaspour and Nazaridoust, 2007). Thus, to adjust the water level to the target, after the achievement of the target water level, the total river inflow volume should be controlled to approximately 2,100 MCM/year (JICA et al., 2016).

If all projects are implemented, the river inflow volume will increase to approximately 3,177 MCM/year and the lake water level is likely to rise to around 1,276.78 m (higher than the target water level). In this case, it takes around 6 years to reach the target water level (1,274.1 m) (JICA et al., 2016).

One of the solutions proposed for reducing the salt content of Urmia Lake is using desalination techniques, but desalination in hypersaline waters is a high cost projects.

![Figure 3. Project effects (change of yearly average water level). P1: Prohibition against any increase of water use (maintenance of status quo); P3: Stop of whole water supply; P4: Water Transmission from Zaab River to Urmia Lake Basin; P6: Controlling and reducing water consumption in agriculture section; P9: transferring Rivers’ water into the body of the Lake; P11: Transferring from Aras River in West Azerbaijan merely into Urmia Lake. Including No. 3, 4, 9, 11 (in this case No. 6 contain in No.3) (JICA et al., 2016).](image-url)
Its seems be better to allow the rivers flow to reach the lake for reducing salinity and increasing aquatic life rather than creating fresh water through reverse osmosis and distillations processes (Karbasi et al., 2010). Fortunately, authorities of the Ministry of Energy have agreed with this policy. During dry seasons, Southern part of the Urmia Lake was dry in the last two years (Figure 4). An emergency action was to release 136 MCM water from three reservoir dams (Bukan, Sarough, and Hassanlou) to the lake during February and March 2015. In 2016, extra precipitation over the Urmia Lake Basin resulted in the overflow of flood flows from the most of the basin dams to the lake. So, the lake water level approached to 1270.55 m in February 15, 2016. Figure 5 shows the effectiveness of natural water inflows on the lake surface area. At the same time, other actions such as dredging of the rivers mouths, connecting ZarinehRoud and SiminehRoud Rivers, and controlling the illegal overuse of surface waters facilitated the recovery of the lake.

So far, most numerical modeling efforts on the Urmia Lake dealt with simulating the effect of the causeway on salinity and flow circulation, planning scenarios to improve current conditions of causeway. Examples of these studies are: Sadra (2003), Fallah (2004), Abrari (2003), Tarhe Noandishan (2004), Zeinoddini et al. (2009), Damanafshan et al. (2011) and Pirani et al. (2017). Their main findings have been reported in the following list:

- Numerical modeling of the Urmia Lake indicates the wind energy as the main environmental parameter influencing water flow regime in the lake. River discharges, evaporation and rainfall have been found to be the key parameters effecting salinity in the lake (Zeinoddini et al., 2009; Pirani et al., 2017). Water level is highly sensitive to river discharges (Abaspour et al., 2012).

- Spatial salinity difference over the lake area has been found to have an insignificant impact on the water flow regime (Zeinoddini et al., 2009; Pirani et al., 2017). Results of 3D modeling showed that the velocity and direction of flow vary along the depth (Tofighi et al., 2006). This is consistent with the observations by Ab-Niroo (1995). 3D modeling also showed that variations in water density along the depth are insignificant (Tofighi et al., 2006), also consistent with observations (Sima and Tajrishi, 2015). Therefore, the observed changes in direction and magnitude of flow velocity along the vertical are not due to density difference (Pirani et al, 2017; Zeinoddini et al., 2009), rather being the product of other forces such as bathymetry, wind and river discharges (Tofighi et al., 2006). Results of 3D models (Zeinoddini et al., 2009; Tarhe Noandishan 2004), have been found to better correlate with field data than those from 2D models (Abrari 2002; Zeinoddini et al., 2009; Tarhe Noandishan 2004).

- The effects of adding an extra opening in the causeway have been examined with 3D models. An insignificant variation of water salinity in the lake compared to the current situation is obtained (Zeinoddini et al., 2009; Pirani et al., 2017, Marjani and Jamali, 2014). Compared to the conditions prior to the building of the causeway, salinity transport from the Southern to the Northern part decreased by 49%, vice versa from the Northern to the Southern basin by 49.4% (Pirani et al., 2017).

- The North to South and South to North flows through the opening balance out during a year. However, northbound flow prevails in spring, due to the head difference between the two parts of the lake, caused by major river discharges (Marjani and Jamali, 2014; Pirani et al., 2017). Owing to the causeway, the flow exchange between the North and South parts decreased (Ab-Niroo 1995; Sadra 2003; Pirani et al., 2017) Compared to natural conditions prior to the causeway, northbound and southbound flow dropped by 48% and 50% respectively (Pirani et al., 2017; Sadra 2003).

- In case a new opening is built, it should be 500 m long and placed in the western arm of the causeway. This solution would allow a 40% increase in water exchange between the Southern and North basins (Sadra, 2003).

- Salinity changes in the Northern and Southern basins of the lake do not have steady trends. Their change rather reflects the evolution of the environmental factors, as also evident from field observations (Tarhe Noandishan, 2004; Pirani et al., 2017). When river inputs are low,
salinity distribution is inversely proportional to water depth, so that the Northern part is less saline than the Southern one. Instead, during the wet periods, concurrent water discharges from rivers into the Southern basin, cause salinity to decrease there. Such salinity drop is directly proportional to river discharges and inversely proportional to the distance from their mouths (Pirani et al., 2017). The Northern basin is deeper than the Southern one and has a larger water volume. Therefore, salinity factors have less impact over this area than over the shallow Southern part.

Some criticism can be made over the results of the previous studies introduced above, as specified in the next list:

- Researchers tried to simulate the exact conditions of the lake. However, modeling simplifications led to errors in the results. For example, in the two-dimensional results by Tarhe Noandishan (2004), existence of layered flows is mentioned but not simulated due to the limitation of the model. In addition two-dimensional modeling of Ab-Nirou (1995) eliminates the modeling of two-stream flows. Whereas later, three-dimensional simulations (Pirani et al., 2017) have shown that a large volume of waters in the two northern and Southern parts of the lake, especially in the end of winter and spring are transmitted through two-way currents around the causeway, which ultimately have a positive effect on the mixing of the entire water of the lake and its general homogeneity.

- Numerical modeling for studying Urmia Lake in which the continuity and momentum equations have been analyzed, using hydrological data with mean or extreme conditions (studies by Ab-Nirou, 1995; Tarhe NoAndishan, 2004; Sadra 2003; Abbaspour et al., 2012) have provided calculations and conclusions, and modeling hasn’t used real time analysis for a given period. Also, in the study by Pirani et al. (2017), exhaustive model calibration and validation of salinity distribution could not be performed, as data were available for a single year only. In addition, the density and flow velocity were not investigated and the water level elevation was simulated for the 2003-2004 period only.

- In the modeling study performed by Marjani et al. (2007) with the COHERENCE model, river inflows were assumed as fresh water. Precipitation and evaporation parameters for the Northern and Southern basins were also are assumed coincident, equal to an average value for both regions. Basis on measured data (JICA et al., 2016) evaporation from surface of the lake is more than precipitation on it so both mentioned assumptions are far from reality and create some errors in modeling.

- In the study by Sadra (2003), a continuous wind blowing from one constant direction is assumed. This assumption leads to a significant, unrealistic wind setup. To analyze the actual conditions in the lake and assess its long-term behavior, it is mandatory to apply actual wind data and calibrate the model with them according to field flow velocity measurements.

- MIKE 3 Flow Model adopted by Pirani et al. (2017) and Zeinoddini et al. (2009) uses the UNESCO equation of state to calculate water density as a function of salinity and temperature. However, this equation is valid for salinity below 35 PSU, being reliable under a 45 kg/m$^3$ density range between 992 kg/m$^3$ and 1037 kg/m$^3$. However, according to field studies by Tarhe Noandishan (2004) and Daneshvar and Ashasi (1994), the density fluctuations during a year are more than this range. Hence, the difference between the actual water density of Urmia Lake and the density obtained in the model with the UNESCO equation and also the impact of such error on the flow velocity and other parameters should be evaluated. This was only partially investigated by Zeinoddini et al. (2009) referring to the 1987 density data only. They concluded that the density error does not significantly influence the flow velocity.

- The behavior of Urmia Lake, such as all lakes, depends on the amount of river inflows, rainfall and evaporation. In fact, resulting volume changes directly affect the density and salinity of the lake water. Use of daily data for river discharges, precipitation and evaporation should be strongly preferred to monthly ones in order to obtain accurate results, first of all for
the water level. However, in most previous studies such as Marjani and Jamali (2014) and Zeinoddini et al. (2009), monthly average data of river inflows were used, smoothing out the effects of floods.

- In studies by Zeinoddini et al. (2009), the gradient of salinity was found to be insignificant, while sampling results at the surface and bottom layers indicate a salinity difference.
- There are some agriculture fields between last hydrometric stations and the lake. Because of the easy and low cost access to surface flows in compare with groundwater flows farmers prefer to use river flow by directly pumping from the rivers. Due to water demand for agriculture purpose, refining adjacent lagoons, increasing groundwater level and etc. between the last hydrometric stations and Urmia Lake, the total discharge of the last stations cannot be the actual flow of rivers into the lake and there is remarkable difference between them. But all previews researches for numerical modeling of Urmia Lake (Pirani et al., 2017; Zeinoddini et al., 2009; Abaspour et al., 2012; Tofighi et al., 2006) disregarded it.

![Figure 4. Urmia Lake surface water level trend for last 60 years (black line) and minimum ecological water level (dashed line)(Soudi et al., 2017).](image)

![Figure 5. A satellite image of the storage water extrication action effects in the Urmia Lake, captured on (a) November 28, 2015 (showing the extent of dried regions in the Southern part); and (b) February 15, 2016. (image source: https://earthexplorer.usgs.gov)](image)
5. CONCLUSIONS

Traditional water management will soon result in the drying crisis of Urmia Lake, an internationally recognized hyper-saline wetland, in Iran. The most priority is an action plan to deliver in-basin surface waters into the lake. The restoration of the lake demands the action plan for supplying and delivering water from the major rivers around the lake, in the order of 20% to 40% of potential annual flows from these rivers. The revision of the current water allocation for agricultural uses, emergency plan to reduce 40% of irrigation water, to lease farmers’ water-rights, to prevent illegal water intakes from the rivers, to release 30 to 40% of reserved water from 13 large dams around the lake, and to perform river improvement works to facilitate water delivery are necessary for saving the Urmia Lake. Long life and sustainable solution is to increase the rivers environmental flow allocations from existing 10% to 20 - 40% of their potential annual flows. The change in the volume of water regulation in the 13 operating dams, and the reduction of possible storage of water in the 11 under-construction dams are to be considered for the future restoration of the Urmia Lake.

In recent years, the southern part of the lake was completely dried out. This part of the lake is wide and shallow, and as a consequence of the drying, crystallized salt has been deposited on the lake bed. It is an opportunity for easy and low cost extraction of the deposited salts. The salt at Urmia Lake is a well-known brand with medical values, extraction the huge amount of salt at Urmia Lake (about 8-10 billion tons) with environmental standards could play significant role in the economic development of the West Azerbaijan province, and it can be a replacement of agriculture for livelihoods of native people.

The lake bed has risen, and thereby strategies such as more discharge from dams may not be effective. By releasing stored fresh water in the dams to the southern part of the lake, large quantities of fresh water will be released on a crystalized salt bed and this will waste large amount of water by evaporation.

Therefore it is important to develop models to study the effects of dams’ release in different parts of the lake. A multi-purpose multi-disciplinary project is underway by authors to develop numerical framework to study the hydrodynamic behaviour of the lake under the natural drivers as well as different restoration strategies to analyse the effectiveness of these efforts and predict the future of this precious natural body of water. The output of this research will be useful to improve our understanding about the plans and effective operation of dams and management of water resources.

Processes such as turbulent flow, salinity advection and dispersion, heat layering and wind stress transmission in shallow lakes are actually three-dimensional (Martin and McCutcheon, 1999). Therefore, using three-dimensional hydrodynamic models allows better results than one- or two-dimensional ones, which integrate the governing equations over the width and depth dimensions.

Different possible numerical approaches for simulating the Urmia Lake were evaluated by Tarhe Noandishan (2004) and Zeinoddini et al. (2009). Based on their results and on the problem requirements, the MIKE 3 Flow Model FM code from the Danish Hydraulic Institute (DHI) has been selected for numerical investigation. As was mentioned above, most past numerical modelling research on the Urmia Lake indeed used Mike 3 Flow Model FM, so that it is possible to compare the results of the researches together. In the future study will be tried to correct many of the shortcomings of the past works and will also attempted to calibrate and validate the model against the most accurate available field measurements.

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