Urmia Lake Watershed Restoration in Iran: Short- and Long-Term Perspectives

Khatami, Sina; Berndtsson, Ronny

Published in:
[Host publication title missing]

2013

Urmia Lake Watershed Restoration in Iran: Short- and Long-Term Perspectives

Sina Khatami[1] and Ronny Berndtsson[2]

[1] Graduate Student, Department of Water Resources Engineering, Lund University, Box 118, SE-221 00, Lund, Sweden
[2] Professor, Center for Middle Eastern Studies & Department of Water Resources Engineering, Lund University, Box 118, SE-221 00 Lund, Sweden

Abstract

Urmia Lake (also known as Oroumieh Lake) is a shallow terminal lake located in northwest Iran and one of the largest permanent lakes in the Middle East. Due to its biodiversity it has been designated as a Biosphere Reserve by UNESCO and a National Park under the 1971 Ramsar Convention. At present, the entire lake's watershed is threatened due to drought and abrupt decline of the lake's water level and the consequent increase of salinity. The rapidly declining eco-environmental conditions have serious impacts on the socio-economy of the whole region. In this paper we review the environmental state of art and suggest measures to improve the lake's ecology by short- and long-term restoration possibilities. There are indications that the hydrology of the area could be described by a chaotic climate and a low-dimensional dynamical system. However, also the human impact is strong due to mismanagement of water resources. It is concluded that a multidisciplinary integrated approach is needed to tackle the current critical situation.

Keywords: Urmia Lake, lake restoration, watershed restoration, watershed management, chaos, phase diagram

1. Introduction

Urmia Lake is one of the largest permanent lake in Middle East with a catchment area of 51,876 km^2 comprising 3% of the country area and 7% of total surface water in Iran (Eimanifar & Mohebbi, 2007). It is one of the largest salt lakes in the world in terms of surface area. This terminal lake is situated in the northwestern corner of Iran, near Turkey. It is located in the heart of two provinces of West Azarbaijan and East Azarbaijan at latitude 37°00' to 38°12' N, and longitude 44°40' to 45°50' E (UNESCO, 2001) at the west of the Iranian Plateau. The Urmia Lake catchment has a population of about two million (West Azarbayejan Regional Water Authority, 2012a). The lake's basin has a continental climate that is affected by its surrounding mountains (Kelts & Shahrabi, 1986). The lake is divided into southern and northern parts by Martyr Kalantari causeway constructed across the lake for facilitation of communication between east (Tabriz City) and west (Urmia City) of the lake (Figure 1). The brine shrimp, *Artemia Urmiana*, is the dominant invertebrate and a central factor of the food chain and food availability. As a hypersaline lake, it plays a central role in the socio-economy and ecology of the region and the life of about more than two million people, directly or indirectly. Due to its unique ecological environment, Urmia Lake is one of the 610 Biosphere reserves in 117 countries recognized in 1976 under UNESCO's Man and the Biosphere (MAB) Program (UNESCO, 2012). The lake is registered as a Biosphere Reserve and a Ramsar Wetland (UNESCO, 2009). Unfortunately, during the last 17 years, there has been a rapid decline of the lake's water level (Figure 2).

Figure 1. The map above shows the location of Urmia Lake in Iran. The other presents the Urmia Lake's general shape. The bold line in the middle of the lake is the Martyr Kalantari causeway and the vertical line over the lake is the border between two provinces of East and West Azarbaijan (Google Earth, 2012)

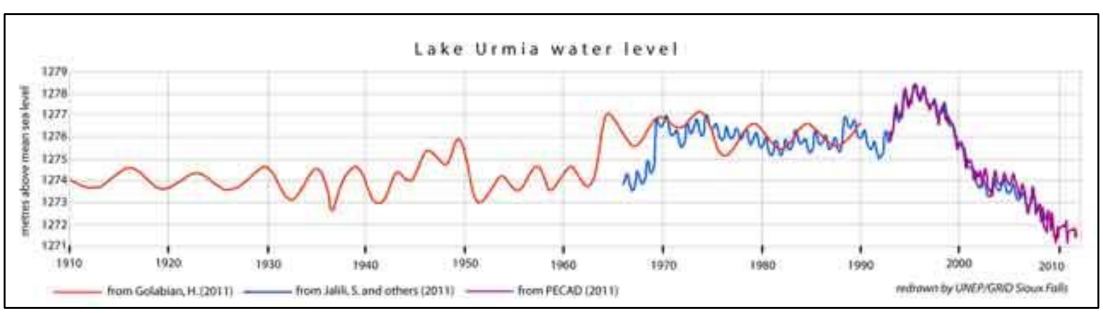

Figure 2. Urmia Lake's water level using various data (UNEP and GEAS, 2012).

The objective of this paper is present a state of art of the lake's eco-environmental situation and a general analysis of hydrology and water resources utilization. We discuss suggested measures that could be taken in the short-term and long-term in order to improve the situation. After the short analysis we address restoration measures from a sustainable and integrated approach.

2. Previous research

As a terminal lake, inflows to the lake are precipitation and inflowing rivers. Consequently, there are no outflows from the lake other than evaporation. The lake is fed by 14 permanent and 7 seasonal rivers together with 39 episodic ones. Annually, 4900 million cubic meters (MCM) water come from rivers, 1500 MCM precipitation, and 500 MCM from floodwaters are flowing to the lake; hence the total inflow to the lake is about 6,900 MCM (Ghaheri et al., 1999). Although these figures are somewhat outdated and have changed due to human activities and climate change, still they represent a general picture of the lake's water balances. The rivers are the main water supply for agricultural activity in the region which is the main source of income. Most of the rivers flow into the southern part of the lake. Thus, there is an expected continuous flow from its south end to the north. The groundwater situation is unclear. In general, groundwater discharge would be from the catchment areas to the lake. Due to the large plane areas, however, and influence from seasonally high evaporation, it is unclear how and what amounts that flow into the lake. Pumping is also extensive over the catchment and that possibly also affects the total inflow of groundwater to the lake. Groundwater withdrawal is estimated to be around 1200 MCM per year. Due to this extensive withdrawal permission to drill new wells and groundwater pumping has been ceased in many regions within the lake's basin (West Azarbayejan Regional Water Authority, 2012b).

2.1. Causeway

The lake is divided into southern and northern parts by Martyr Kalantari causeway constructed across the lake for facilitation of communication between east (Tabriz City) and west (Urmia City) of the lake. The project was initiated in 1979 (Teimouri, 1998). A floating bridge was constructed in 1989. On January 21, 2004, ground operational performance was started and on January 21, 2005, in-lake operations were launched. As seen from Figure 2, there is a coincidence between the operation date of the causeway and decrease of water level below the average water level (1275.5 m amsl). Although, simulation studies (Zeinoddini et al., 2009) claim that the causeway has no significant influence on the lake's flow and salinity regime. However, further studies are needed to verify these results.

2.2. Ecology

After Anzali lagoon, Urmia Lake National Park is the most important natural fauna habitat in Iran. The Urmia lake wildlife is composed of about 27 mammal species, 212 bird species, 41 reptile species, 7 amphibian species, and 26 fish species (Rezvantalab & Amrollahi, 2011). They are all dependent on the lake and its surrounding wetlands. Also, Urmia Lake is the habitat of a unique brine shrimp called *Artemia Urmiana*. The most predominant eco-environmental feature of the lake is the dependence of migratory birds such as flamingoes and pelicans on the lake as their seasonal habitat. These migratory birds feed to a major extent on *Artemia Urmiana*. The shrimp itself, feeds on diatoms and the green algae (Ghaheri et al., 1999). Unfortunately, during recent years due to increase in salinity and its consequent impacts on the shrimp reproduction and also pollutants the lake has been subjected to an environmental phenomenon known as red tide and literally turned red (Najafia et al., 2011). This is another indication of intensification regarding the environmental crisis of the lake. There is an extensive nutrient load from agricultural and industrial activities and also human wastewater without regulation and monitoring.

Although designated biosphere reserves remain under national sovereign jurisdiction, they should share their experience and ideas nationally, regionally, and internationally within the World Network of Biosphere Reserves (WNBR). Unfortunately, there is only a general international discussion regarding the Urmia Lake ongoing deterioration. Much of recent research has only been reported in Farsi that indirectly limits the international awareness about this environmental crisis. Even for national scholars it is not easy to access data about the lake. Locally, East Azarbaijan State Water and Wastewater Company and West Azarbaijan Regional Water Authority, are the responsible authorities regarding the lake's condition. These organizations are operating under the supervision of Ministry of Energy. Accessing data such as climate, water level, salinity, pollutants, etc., requires intense bureaucratic procedures that are time consuming and exhausting. On the other hand, free access Lake data could contribute to a better knowledge regarding the lake's state of art and possible remediation.

2.3. Dams

Population growth raises the need for food. The main reason of damming inflowing rivers to the lake is supply to irrigation and agriculture. Agriculture is the main source of income in the region. In order to address the future food demand of the increasing population, dam construction and water diversion projects are increasing. At present, there are 275 projects under study and 231 of these have been approved and will be initiated in near future (Figure 3) (Hassanzadeh et al., 2011). Until 2006, the total amount of water regulated by dams, pump stations, flood control, weirs and conduction facilities, etc. was about 1712 MCM. Within 20 years, due to newly approved projects, about 2157 MCM will be added to the regulated water (Ministry of Energy, 2007). It is evident that these projects will intensify the environmental crisis if they do not consider water for the ecosystem. These projects will likely have a major impact on the natural circulation of water in this basin and more specifically desiccation of the lake.

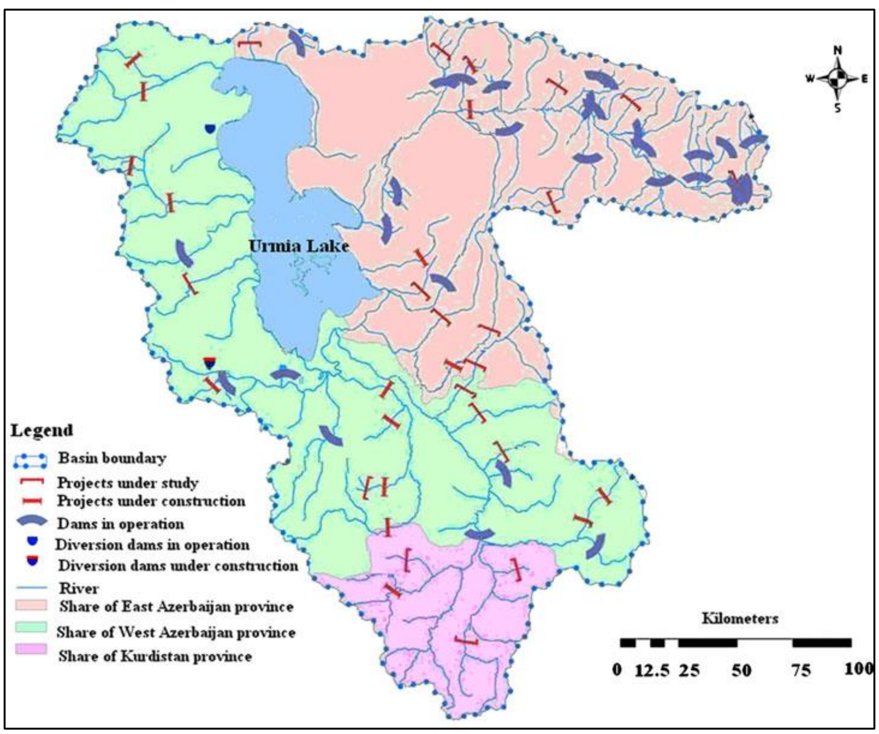

Figure 3. Schematic map of inflowing rivers and most important projects in Urmia Lake's catchment (Hassanzadeh et al., 2011).

2.4. Salinity

In terms of hydrochemistry, the lake is a sodium-chloride-sulfate type oceanic lake (Eugster & Hardie, 1978). During the last decade, the ecology of entire lake's watershed has been threatened due to drought and consequent increase of salinity. Salinity fluctuation of the lake's water is not a recent phenomenon. During 1967 to 1995, the salinity of the lake varied between 166 and 280 g/l (Karbassi et al., 2010). From 1995 to 2008, the salinity of the lake increased from 166 g/l to 340 g/l due to abrupt decline of the lake's water level. Since the Saturation Index (SI) of all major salts in the lake is greater than zero (dolomite 4.49, calcite 1.29, aragonite 1.14, anhydrite 0.19, gypsum 0.17 and halite 0.09), lake's water is supersaturated and salt precipitation is likely (Karbassi et al., 2010).

2.5. Climate and lake water level

Monthly lake water levels from 1965 to 2009 varied between 1272.2 to 1278.4 m amsl (Figure 2). From about 2000 the water level has reduced dramatically. Figure 4 shows a monthly lake water level phase diagram for the period 1965 to 2009 with a lag of 3 months. As seen from the figures, the historical climatic influence has made the water level fluctuate between two states, namely a wet higher lake water level and a dry low lake water level. The human influence, however, is now pushing the lake water level well below these two extremes. Figure 4 indicates that the lake water level is naturally chaotic in nature and thus cannot be predicted in the long-term. However, the recent trend indicates that human influence now is changing the lake water level into a state that has no historical similarity. Khatami (2013) has applied a nonlinear chaotic analysis to the lake water level fluctuations. Similar studies have been made for other terminal lakes such as the Big Salt Lake in Utah (Sangoyomi et al., 1996; Lall et al., 1996).

As discussed above the recent decline of the lake's water level has both climatic as well as human influence. The human influence has decreased the water level below historical records, however. A decrease in mean annual precipitation by 19% during 1997 to 2006 and increase of 17% in mean annual temperature during 1996 to 2006 have been recorded (Hassanzadeh et al., 2011). At the same time, human withdrawal of water for agriculture has increased. In line with new water withdrawal projects the water level is expected to continue to decrease in the near future. Thus, the current mismanagement of water and the uncontrollable increasing demand for irrigation water that authorities are over-seeing will eventually back-lash in terms of a degraded eco-environment.

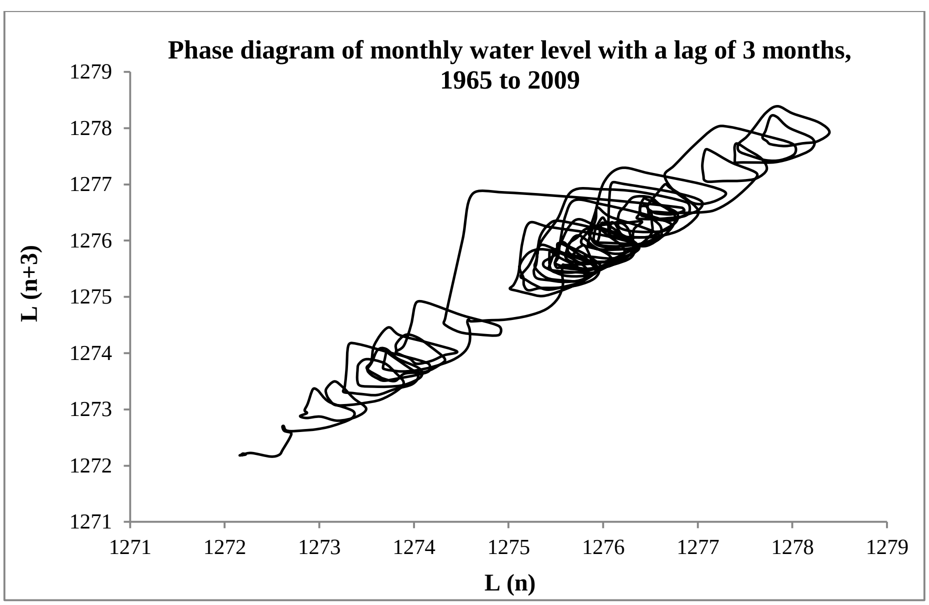

Figure 4. Phase diagram of Urmia Lake's monthly water level (L) from 1965 to 2009

Stakeholders and researchers from different disciplines are responsible for high-lighting the possibly collapsing environment in the area if current mismanagement continues. Recent reports indicate a high water consumption per capita in the area (Mehr News Agency, 2009) This demand of water has to be seen in view of inefficient irrigation techniques and leaking water supply pipes for domestic water use. At the same time pollutant management needs to be improved by waste water treatment and control of industrial effluents. Improving sustainability by increasing public awareness and a participatory process are some of the most important immediate measures.

3. Improving water management

It is evident that continued decline of water level in the lake will lead to irreversible damage to environment and possible collapse of the regional ecosystem (specifically *Artemia Urmiana* as the key link of the food chain and consequently fauna and migratory birds). Decline of the water level may lead to migration of the major part of local population since their life is mainly dependent on agricultural activity. Thus, the ongoing environmental decline will also negatively affect the socio-economy of the region (Hassanzadeh et al., 2011; Delju et al., 2012). The extent and concrete effects of a continued declining water level are still under debate. However, regardless of its details, the current situation calls for an extensive national as well international discussion on how to improve the current situation.

3.1. Previously proposed solutions

Previous studies have arrived at quite different management options to restore the lake (Khatami & Berndtsson, 2012). Three main solutions have been suggested by previous studies in order to tackle the current crisis, namely; desalination, inter-basin water transfer (specifically water transfer from Caspian Sea), and releasing water from dams to inflowing rivers.

Two major desalination methods that have been considered for desalination of the lake’s water are reverse osmosis (RO) and multistage flash evaporation (MSF). In general, costs of desalination depend on various site-specific variables. Considering the size of the lake and the fact that it is a hypersaline lake, costs associated with desalination will be substantial. Karbassi et al. (2010) estimated that the cost for desalination of Urmia Lake by a combination of the RO and MSF would equal about US$ 6.7/m^3. It has to be noted that the performance of these methods of desalination has not been tested for hypersaline waters and their potential performance is regarded for desalination measures. Together with the high costs of desalination, another important environmental challenge is the disposal problems of the brine. Thus, desalination does not seem to be a viable alternative at present (Karbassi et al., 2010)

Although some previous studies has suggested the inter-basin transfer of water as a promising solution (Golabian, 2010; UNEP and GEAS, 2012) it is not an eco-friendly plausible solution. Water transfer from the Caspian Sea is not economically plausible due to a large height difference (1316 m). In addition, common sense would suggest that for solving a problem one should not introduce new problems. Transferring water from Caspian Sea through a man-made river is likely to cause international tension. Also, the transfer of water from Caspian Sea would affect the whole ecosystem through its path to Urmia Lake. Previous experiences from large-scale water transfer include water logging, increased salinization, and water intrusion to groundwater aquifers (Mamaev & Inc., 2002).

The most realistic and plausible suggestion in previous studies for addressing the issue of Urmia Lake drought, is perhaps water allocation adjustment and increase in discharge of water from dammed rivers to the lake. One study (Abbaspour & Nazaridoust, 2007) estimated the ecologically required water for restoration of Urmia Lake as 3085 MCM of inflow per year. Despite the fact that this study is fairly outdated due to changes of salinity and other conditions during the few past years and also considering the extent of the problem and the lake’s size this volume does not seem to be a sustainable volume of water needed for the lake. Probably instead, it has to be seen as a minimum amount of water needed for restoration of the lake. Fortunately, the Ministry of Energy has agreed upon allocation of 2 to 3 MCM per year to restore the lake's salinity to previous condition of 166 g/l (Karbassi et al., 2010). As it was discussed, despite the fact that this volume is fairly low regarding a sustainable perspective it is a promising start for restoration of the lake. It has to be noted that a more thorough comprehensive study is needed to calculate the required amount of water based on updated conditions of the lake and through a holistic approach.

A serious drawback of previous research in the area is the lack of studies on the interaction between the lake and the groundwater. It may be anticipated that groundwater withdrawal may have a significant influence on the lake's water level. Also comparative studies between Urmia Lake and similar lakes could be of interest for future studies.

3.2. Short-term measures

Suggested short-term measures include cloud seeding and weather modification, cessation of dam construction (ongoing project and newly planned), and release of at least 3 MCM per year (required water to attain a salinity of 166 g/l). Since precipitation and rivers are the only source of inflow to this terminal lake cloud seeding and weather modification together with release of water from dams could enhance the eco-hydrological situation of the lake significantly. The main objective of cloud seeding or in general weather modification (WM) programs is to reduce the impact of drought and the consequent water shortage, and enhance reservoir storage within the area. Recent evaluation of different regions exposed to WM programs reveals positive response for precipitation intensification in most cases (Ryan et al., 2005). Cloud seeding and WM could be seen as an acceptable but short-term solution for modifying and improving the precipitation condition within the basin and consequently mitigating the climate changes affecting the region. A study (Acharya et al., 2011) in the arid region of North Platte River Watershed evaluated the impacts of WM programs by developing a hydrological model. The impact was evaluated in terms of streamflow changes. An increase of 0.3% to 1.5% in annual streamflow was the result for an anticipated increase of 1 to 5% in precipitation rate. Besides precipitation enhancement and snowpack increase, WM could lead to other environmental improvements beyond precipitation enhancement. Exploratory analysis of case studies in North Dakota has identified 6% growth in agricultural wheat production together with a decrease of 45% in crop hail loss than what would be expected on the basis of prior experience during operational period (Smith Jr., P.L.; Johnson, L.R.; Priegnitz, D.L.; Boe, B.A.; Mielke, P.W., 1997).

Climatic studies on Urmia Lake shows that during 1997 to 2006 annual average precipitation (204.6 mm) on the lake's basin decreased nearly 17% in comparison to the 30 year average from 1967 to 1996 (246.6 mm) (Hassanzadeh et al., 2011). Other studies (Delju et al., 2012) claim a 9% decrease in the mean annual precipitation during the period 1964-2005. The effectiveness of cloud seeding, 5 to 20%, could help dealing with the climate change in terms of precipitation (Acharya et al., 2011). Due to the fact that cloud seeding may change individual or a group of clouds but not the weather patterns (since they are determined by large-scale atmospheric processes) (Langerud, 2011), it has to be seen only as a short-term solution. It is evident that an effective WM programs by the aim of precipitation augmentation need to be studied based on regional and local conditions and generalization of previous studies at other locations (climate and time period). Hence it is necessary to evaluate and analyze hydrological impact for different scenarios in the given area and catchment. It has to be noted that spatial and temporal variation in annual precipitation distribution is a factor in changes of simulated streamflow that have to be taken into account. Apart from the fact that cloud seeding and WM in general are environmentally friendly, they are also cost effective (WWDC, 2005). For example, KWO (2001) estimated the cost in the range of \$0.8–12 per 1000 m^3 of additional runoff from snowpack in Kansas, which could be considered inexpensive in comparison with building new infrastructure.

Also, it is highly recommended to initiate new research and simulation studies in order to investigate different uncertainties about the lake. Most importantly, groundwater interaction with the lake and lake circulation pattern has to be investigated from different aspects and of course with updated conditions of the lake. Together with scientific studies on the lake the Ministry of Environment could design an urgent Environmental Protection Law for this specific region.

3.3. Long-term measures

The ultimate goal for solving the current issue of the lake and its watershed is a long-term integrated approach towards sustainability. Eco-friendly solutions are needed that contain a set of actions done in parallel and under a greater plan of restoration. It is important to stress solutions that are integrated with all parts of society and where local participation can guarantee sustainable solutions in the long-term. A major local economic issue is a sustainable agricultural activity as the main source of income. Increasing population that increase the demand of food on one hand and traditional methods of irrigation on another hand, increase the threats for water resources and environment of the region. New sources of income have to be introduced within the lake's catchment. For example, the lake's salinity has a potential for salt industry. In addition, its unique ecosystem has a great potential for tourism industry. Previous initiatives in this direction from private sector have mainly failed. However, new initiatives with the support from authorities may lead to successful results.

Another example is sustainable energy development that both improves the economy of the region and also could be seen as an environmental protection measure. Due to the fact that about 50% of algae weight is lipid oil that can be used in biodiesel production and its capability of yielding oil is about 30 times more than the currently used crops in biodiesel production, it has a good chance to be considered in a longer term. The recent phenomenon of red tide has a potential for a new source of energy. Algae could be directly converted into energy like biodiesel, bioethanol, and biomethanol (Najafia et al., 2011). This high potential of biofuel energy has to be more investigated in future studies in terms of its feasibility for this specific catchment.

Currently, there is a great need for improving water infrastructure in the watershed. For example, within the province of East Azarbaijan there are 8 running wastewater treatment plants with the annual capacity of 94.96 MCM that is operating for 71.23 MCM. First of all this capacity is not even capable of addressing the current population of the province (3,6 million) nor is it for the future population. In addition, the efficiency of 74% is not satisfactory. Also these treatment plants have the potential of improvement in terms of chemical and biological treatment processes (East Azarbaijan State Water and Wastewater Company, 2012)

Authorities have initiated different water infrastructure projects including water and wastewater treatment plants. For instance, there are four wastewater treatment plants with the annual nominal capacity of 14.32 MCM under construction in the province of East Azarbaijan (East Azarbaijan State Water and Wastewater Company, 2012). Similar projects could be of a great positive influence for the environmental condition of the basin in a long term period but it seems that these types of projects are slow in implementation. Also, the efficiency of these plants is always a matter of question. It is highly important that authorities prioritize these projects and do their best effort to speed up the physical progress together with the improvement of their efficiency. There are 6 cities of the province of East Azarbaijan that are adjacent to the lake with the total population of 0.62 million. It simply shows that an increasing population is influencing, directly and indirectly, the lake's environmental conditions.

For social sustainability, which is widely neglected by scholars and authorities, the most significant issue is the participatory approach that has a great potential influence on environmental systems as well. For example, according to a national news agency, consumption pattern shows that a typical resident of this watershed is consuming about 183 L per capita and day (Mehr News Agency, 2009). This shows that demand is too high in relation to supply and that measures are needed to improve efficiency of distribution systems. Hence, for approaching a more sustainable consumption it is necessary to improve the public awareness together with improvement of irrigation efficiency and implementing advanced irrigation methods, waste water treatment, stormwater management, and re-use in agriculture that requires larger investment from authorities.

As mentioned above sustainable development is the essence of a long-term perspective. It is necessary to integrate factors affecting the environment to enable improvement of the region towards a more sustainable position. Researchers and scholars dealing with the lake play a central role in providing authorities and society with the real image of the lake's condition. A greater consideration from authorities and government is required in terms of environmental support and access to data bases. Hydrological and hydraulic data for the area are quite limited with short records not easily accessible for researchers. Providing a comprehensive database, both in Farsi and English, would catch the attention of international researchers for further studies and better interdisciplinary solutions. Further hydrological modeling studies are highly needed to study the combined effect of climate change, groundwater exchange, and dam construction on the lake ecology. The output of these studies would be the basis for long-term management and decision making for the authorities.

References

Abbaspour, M. & Nazaridoust, A., 2007. Determination of environmental water requirement of Lake Urmia, Iran: an ecological approach. *International Journal of Environmental Studies*, 64 (2), pp.161-69.

Acharya, A., Piechota, T.C., Stephen, H. & Tootle, G., 2011. Modeled streamflow response under cloud seeding in the North Platte River watershed. *Journal of Hydrology*, 409, pp.305-14.

Delju, A.H., Ceylan, A., Piguet, E. & Rebetez, M., 2012. Observed climate variability and change in Urmia Lake Basin, Iran. *Theoretical and Applied Climatology*, doi: 10.1007/s00704-012-0651-9.

East Azarbaijan State Water and Wastewater Company, 2012. [Online] Available at: http://www.abfa-azarbaijan.com/fa/index.php?page_id=215&menu_id=7&menu_item_id=198 [Accessed 18 September 2012].

Eimanifar, A. & Mohebbi, F., 2007. Urmia Lake(Northwest Iran): a brief review. *Saline Systems*, 3(5).

Eugster, H.P. & Hardie, L.A., 1978. *Saline lakes. In Lakes, Chemistry, Geology, Physics*. New York: Spriger.

Ghaheri, M., Baghal-Vayjooee, M.H. & Naziri, J., 1999. Lake Urmia, Iran: A summary Review. *International Journal of Salt Lake Research*, 8, pp.19-22.

Golabian, H., 2010. Urumia Lake: Hydro-Ecological Stabilization and Permanence Macro-engineering Seawater in Unique Environments. (pp. 365-397). Berlin: Springer-Verlag. doi: 10.1007/978-3-642-14779-1_18.

Google Earth, 2012. [Online] Urmia Lake 37°00' to 38°12' N, 44°40' to 45°50'E Available at: http://maps.google.se/maps?hl=sv&bav=on.2,or.r_gc.r_pw.r_qf.&biw=1366&bih=673&wrapid=tlif134902120274310&q=urmia+lake&um=1&ie=UTF-8&hq=&hnear=0x401ab691484226e9:0xa3bcb751ad9dec7a,Lake+Urmia&gl=se&sa=X&ei=IG5oUM_AN7SK4gSkpoCoCA&ved=0CD0Q8gEwAw [Accessed 20 September 2012].

Hassanzadeh, E., Zarghami, M. & Hassanzadeh, Y., 2011. Determining the Main Factors in Declining the Urmia Lake Level by Using Dynamics Modeling. *Water Resources Management*, 26(1), pp.129-145, doi: 10.1007/s11269-011-9909-8.

Karbassi, A., Nabi Bidhendi, G., Pejman, A. & Esmaeili Bidhendi, M., 2010. Environmental Impacts of Desalination on the Ecology of Lake Urmia. *Journal of Great Lakes Research*, 36(3), pp.419-24.

Kelts, K. & Shahrabi, M., 1986. Holocene sedimentalogy of hypersaline Lake Urmia, northwestern Iran. *Paleogeography, Paleoclimatology and Paleoecology*, 54, pp.105-30.3

Khatami, S. & Berndtsson, R., 2012. *Integrated Watershed Management to Save the UNESCO Biosphere Reserve Lake Urmia, Iran*. AWRA Annual Water Resources Conference, Jacksonville, Florida.

Khatami, S., 2013. *Nonlinear Chaotic and Trend Analyses of Water Level at Urmia Lake, Iran*. M.Sc.

Thesis report: TVVR 13/5012, ISSN:1101-9824, Lund University, Lund, Sweden.

KWO (Kansas Water Office), 2001. *Weather Modification Program, Fact Sheet No. 18*. (access NAIWMC FAQs, www.naiwmc.org).

Lall, U., Sangoyomi, T. & Abarbanel, H.D.I., 1996. Nonlinear Dynamics of the Great Salt Lake: Nonparametric Short-Term Forecasting. *Water Resources Research*, 32(4), pp.975–985, doi:10.1029/95WR03402.

Langerud, D., 2011. *North American Interstate Weather Modification Council*. [Online] Available at: http://agriculturedefensecoalition.org/sites/default/files/file/plumas_co/71W_2011_NAIWMC_Cloud_Seeding_Facts_Brochure_Q_A_Website_April_4_2011.pdf [Accessed 18 September 2012].

Mamaev, V. & Inc., W.H.G., 2002. *Seas around Europe, The Caspian Sea*. European Environment Agency.

Mehr News Agency, 2009. *Water Use per capita in West Azarbaijan*. [Online] Available at: http://www.mehrnews.com/fa/newsdetail.aspx?NewsID=854091 [Accessed 16 September 2012].

Ministry of Energy, 2007. Water allocation for the development projects in Urmia Lake basin. *Technical report of Water and Wastewater Planning Office*.

Najafia, G., Ghobadiana, B. & Yusaf, T.F., 2011. Algae as a sustainable energy source for biofuel production in Iran: A case study. *Renewable and Sustainable Energy Reviews*, 15(8), p.3870–3876.

Rezvantalab, S. & Amrollahi, M.H., 2011. Investigation of Recent Changes in Urmia Salt Lake. *International Journal of Chemical and Environmental Engineering*, 2, No.3, pp.168-71.

Ryan, T., Busto, J., Huggins, A.W. & Hunter, S.M., 2005. Weather modification for precipitation augmentation and its potential usefulness to the Colorado River Basin States. *A report for Metropolitan Water District of Southern California*, Available at: http://www.nawmc.org/4dcgi/GetContentPDF/PB-1052/WxMod%20Basin%20States%20rev.pdf [Accessed 15 September 2012].

Sangoyomi, T.B., Lall, U. & Abarbanel, H.D.I., 1996. Nonlinear Dynamics of the Great Salt Lake: Dimension Estimation. *Water Resources Research*, 32(1), pp.149–159, doi:10.1029/95WR02872.

Smith Jr., P.L.; Johnson, L.R.; Priegnitz, D.L.; Boe, B.A.; Mielke, P.W., 1997. An Exploratory Analysis of Crop Hail Insurance Data for Evidence of Cloud Seeding Effects in North Dakota. *Journal of Applied Meteorology*, 36, p.463–473.

Teimouri, B., 1998. Urmia golden gate highway (known as Martyr Kalantari Highway) after two decades of uncertainty. *Sanat Haml-o Naql (Transportation Industry)* , 173, pp.18-23.

UNEP and GEAS, 2012. The drying of Iran's Lake Urmia and its environmental consequences. *Environmenta lDevelopment*, 2, pp.128-37.

UNESCO, 2001. *MAB Biosphere Reserves Directory, Lake Oromeeh*. [Online] Available at: http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?code=IRA+07&mode=all [Accessed 18 September 2012].

UNESCO, 2009. *List of Biosphere Reserves which are wholly or partially RAMSAR Wetlands*. [Online] Available at: http://www.unesco.org/mab/doc/brs/brs_ramsar.pdf [Accessed 18 September 2012].

UNESCO, 2012. *Global list of Biosphere reserves*. [Online] Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/sc_mab_BR2012.pdf [Accessed 18 September 2012].

UNESCO, n.d. *Ecological Sciences for Sustainable Development*. [Online] Available at: http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/ [Accessed 18 September 2012].

West Azarbayejan Regional Water Authority, 2012a. [Online] Available at: http://www.agrw.ir/Farsi/AreaF.asp?Id=3 [Accessed 16 September 2012].

West Azarbayejan Regional Water Authority, 2012b. [Online] Available at: http://www.agrw.ir/Farsi/UsageF.asp?Id=5 [Accessed 29 September 2012].

WWDC (Wyoming Water Development Commission), 2005. *WWDC (Wyoming Water Development Commission), 2005. Wyoming level II weather modification feasibility study: Executive summary*. Weather Modification, Inc. for the WWDC.

Zeinoddini, M., Tofighi, M.A. & Vafaee, F., 2009. Evaluation of Dike-Type Causeway Impacts on the Flow and Salinity Regimes in Urmia Lake, Iran. *Journal of Great Lakes Research*, 35, pp.13-22.