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Commentary

Aral Sea syndrome desiccates Lake Urmia: Call for action

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ABSTRACT

Lake Urmia, one of the largest saltwater lakes on earth and a highly endangered ecosystem, is on the brink of a major environmental disaster similar to the catastrophic death of the Aral Sea. With a new composite of multi-spectral high resolution satellite observations, we show that the area of this Iranian lake has decreased by around 88% in the past decades, far more than previously reported (~25% to 50%). The lake's shoreline has been receding severely with no sign of recovery, which has been partly blamed on prolonged droughts. We use the lake basin's satellite-based gauge-adjusted climate record of the Standardized Precipitation Index data to demonstrate that the on-going shoreline retreat is not solely an artifact of prolonged droughts alone. Drastic changes to lake health are primarily consequences of aggressive regional water resources development plans, intensive agricultural activities, anthropogenic changes to the system, and upstream competition over water. This commentary is a call for action to both develop sustainable restoration ideas and to put new visions and strategies into practice before Lake Urmia falls victim to the Aral Sea syndrome.

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Introduction

Lake Urmia, one of the largest saltwater lakes on earth and a highly endangered ecosystem, is on the brink of a major environmental disaster similar to the catastrophic death of the Aral Sea. Once with a surface area of approximately half a million hectares, Lake Urmia's shoreline has been receding severely with no sign of recovery, leading to a significant shrinkage in the lake's surface area. Situated ≈ 1273 m above the sea level, this shallow terminal lake is surrounded by a range of high mountains (UNEP, 2012; Ghaheri et al., 1999). A unique feature of this UNESCO designated Biosphere Reserve and National Park is its hypersaline environment, with salinity ranging from 217 to more than 300 g/l, approximately eight times higher than sea water (UNEP, 2012; Ghaheri et al., 1999; Ahmadzadeh Kokya et al., 2011). Unique and rare types of diatoms, phytoplankton and bacteria can survive in such a hypersaline environment. The lake is the world's largest habitat of brine shrimp *Artemia* (*Artemia urmiana*), which is a major food source for migratory birds such as flamingos, pelicans, ducks and egrets (Barigozzi et al., 1987; Vahed et al., 2011; Ahmadi et al., 2011). The intensity of bird migration to the

area largely depends on the primary production of Lake Urmia, and particularly on availability of salt-adjusted brine shrimp (Karbassi et al., 2010; Eimanifar and Mohebbi, 2007).

In the past decade, the lake's average water level has decreased significantly, endangering this unique ecosystem (Hasanzadeh et al., 2012; WRI, 2006; Tisseuil et al., 2013; Abbaspour and Nazaridoust, 2007; Farzin et al., 2012; Sima and Tajrishy, 2013; Jaafari et al., 2013; Tourian et al., 2014). While the current status of Lake Urmia 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 (UNEP, 2012; Micklin, 2007; Small et al., 2001). 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 inflow from Amu Darya and Syr Darya rivers for ill-conceived irrigation development in the Soviet era (Micklin, 2007; Gaybullayev et al., 2012; Micklin, 1988), causing severe economic, environmental, and health consequences (Whish-Wilson et al., 2002).

Drastic changes in Lake Urmia: causes and consequences

Composite multi-spectral high resolution (30 m) satellite observations show drastic changes in lake area since 1972 (Fig. 1). The area of

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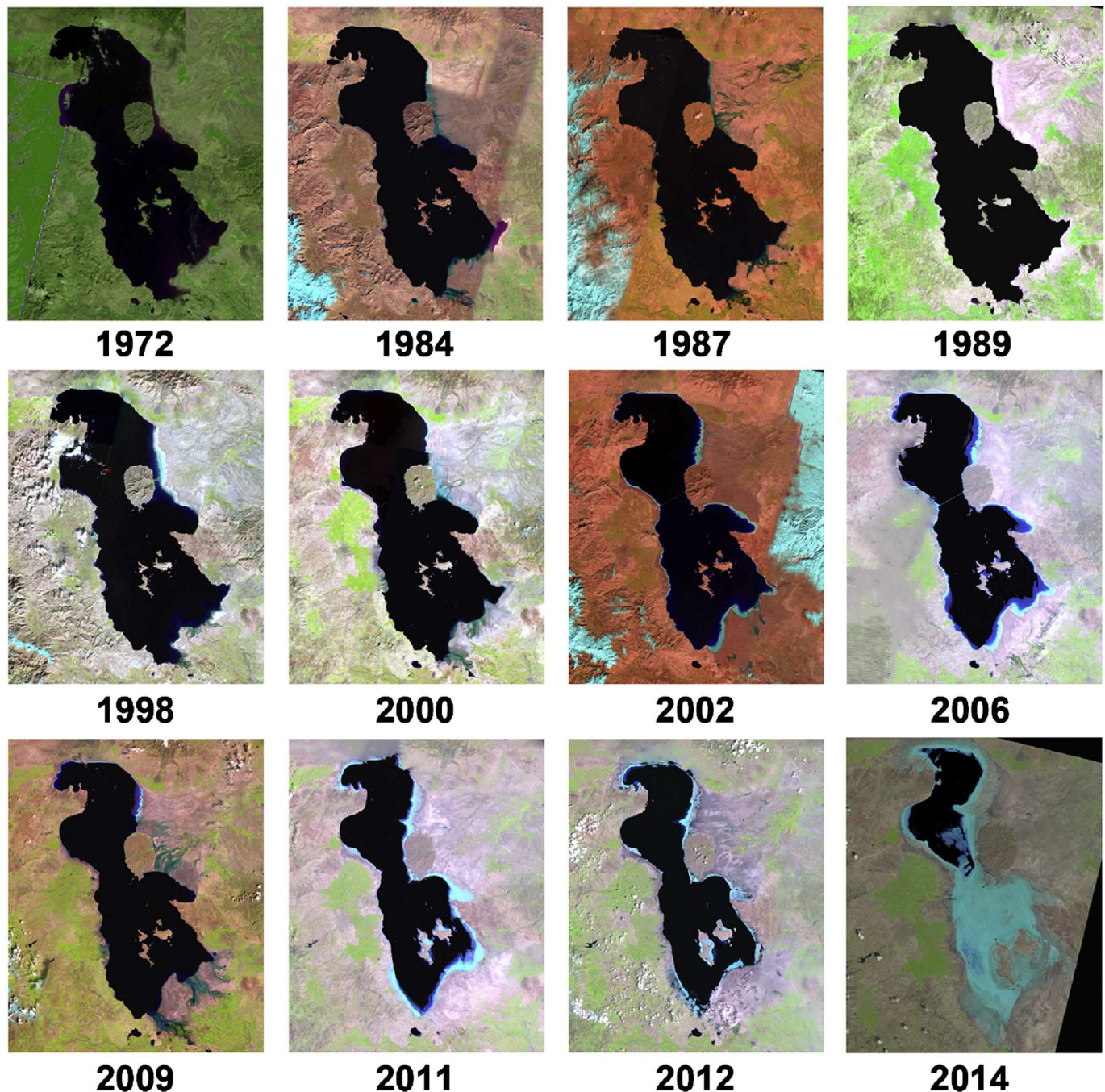


Fig. 1. Changes in area of Lake Urmia from October 1972 to August 2014, derived from LandSat imagery.

Lake Urmia, with detectable water from space, has decreased by around 88% (Fig. 2a), far more than previously reported ($\approx 25\%$ to 50% ; (Hassanzadeh et al., 2012; WRI, 2006)). Consequently, the volume of Lake Urmia is at a record low in August 2014, approximately 80% less than in 1972 (Fig. 2b). A time series of the volume of the lake was derived using the lake's Area–Volume–Height curve available from WRI (2006). It should be noted that in determining the area of the lake in different years, we relied on detectable remotely sensed water. Therefore, our estimates are subject to some uncertainties as areas with negligible water or mud may have not been accurately detected given the resolution and accuracy of satellite images.

The lake's shoreline retreat has exposed the former lake-bed (Fig. 1), which consists of salt crusts ($\approx 400 \text{ km}^2$ of sodium chloride-covered salt flats), to wind forces (Golabian, 2010). The resulting salt storms increase

the risk of irreversible ecosystem regime shifts, diminish fertility of nearby agricultural lands, and cause biotoxicity and chronic human health consequences (Cook et al., 2005; Yamaguchi et al., 2012). To the best of our knowledge, risks of potential diseases from Lake Urmia salt storms have not been explored at local or regional scales.

During the unfolding of this environmental catastrophe which has heightened public and political sensitivity (Madani, 2014), extended drought periods and climatic changes have been blamed by local authorities as one of the causes of the lake's shrinkage. Indeed, changing hydrologic patterns due to climatic changes and increase in the frequency and intensity of droughts are important factors that can affect the variability of the lake's surface (Tabari et al., 2012; Abbaspour et al., 2012; Nikbakht et al., 2013; Damberg and AghaKouchak, 2014; Delju et al., 2013; Golian et al., 2014; Tabari et al., 2014). Nonetheless, a

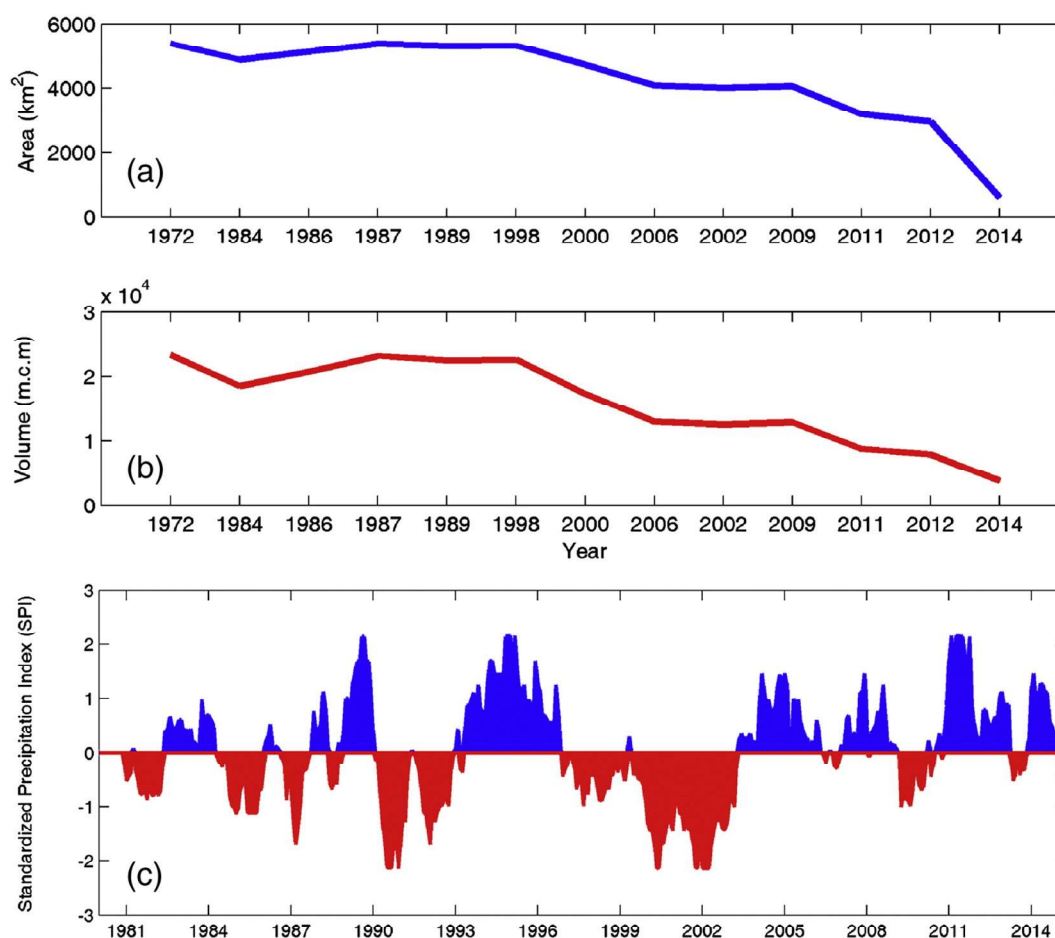


Fig. 2. Area (a), and volume in millions of cubic meters (b) of Lake Urmia, and meteorological drought conditions (c) in Lake Urmia basin based on Standardized Precipitation Index (SPI) in the past decades.

satellite-based gauge-adjusted climate record (AghaKouchak and Nakhjiri, 2012) of Lake Urmia basin's Standardized Precipitation Index (SPI (McKee et al., 1993)), obtained from the Global Integrated Drought and Monitoring System (GIDMaPS (Hao et al., 2014)), indicates no significant trend in droughts over the past three decades at the 0.05 significance (95% confidence) level (Fig. 2c). In fact, the region has experienced more severe drought events in the past (e.g., 1997–2002) that did not lead to a substantial change in the lake's surface area. Thus, we caution against overrating the role of droughts in the disruption of the lake's water balance to the extent that would cause such a massive shrinkage. In fact, the lake's retreat cannot be blamed solely on droughts because it has survived several multi-year droughts in the past. It is acknowledged that a warming climate can intensify the effect of droughts (AghaKouchak et al., 2014). However, ground-based observations do not indicate a substantial increase in evaporation in the region (Farzin et al., 2012).

The paucity of irrigation and water demand data for the region is a severe constraint which hinders the investigation of all the components of the water budget and quantification of the anthropogenic influence. With this caveat in mind, our analysis leads us to believe as in the case of the Aral Sea, over-exploitation of input water to the lake may be the main driver of Lake Urmia's desiccation. Unfortunately, the data for water demand and irrigation water consumption for the Lake Urmia basin is not available to the public for detailed water budget assessment of the region and quantification of the anthropogenic influence.

Lake Urmia is fed by a total of 60 (21 seasonal or permanent, and 39 periodic) rivers with the Zarrine-rud and Aji Čay being the main inputs (Ghaheiri et al., 1999). In the past decade alone, several new dams and irrigation districts have been developed in the lake basin across three

western Iranian provinces, increasing the consumptive use of tributary river waters. As of 2012, there are over two hundred approved new dams and irrigation projects that are either under construction or in the final phases of design (Hassanzadeh et al., 2012; WRI, 2006). Considering no significant trend in the drought pattern, Lake Urmia's observed physiographic changes may be attributable to the construction of dams, irrigation projects and overuse of surface water and groundwater (Hassanzadeh et al., 2012; Khatami, 2013).

The aggressive hydro-economic development plans in the upstream provinces which cause overallocation of Lake Urmia's inflows, along with the construction of a 15-km causeway, with a gap of 1.2 km to facilitate regional transportation, are severely aggravating the lake's condition. High agricultural water demand in the area due to low irrigation efficiency, cultivation of water intensive crops, and extensive agriculture drive this environmental catastrophe (Hassanzadeh et al., 2012; Madani, 2014). The shrinkage of Lake Urmia is a clear indication that the natural supply capacity of the water resources in the lake basin is not sufficient to meet the dramatically increasing water demand, making the lake biophysically and ecologically dysfunctional. Without any serious change (e.g., giving regulatory priority to sufficient environmental flows) in the current unsustainable, supply-oriented water management schemes in the basin, Lake Urmia will not recover, and the lake's condition is expected to worsen with completion of ongoing upstream development projects.

Toward a sustainable restoration plan

Lake Urmia's looming tragedy is a culminating manifestation of the consequences of uncoordinated, disintegrated water resources

management driven and aggravated by managerial and socioeconomic myopia (Madani, 2014). The lake's management problem involves complex trade-offs putting the economy and ecosystem at odds. Further desiccation of the lake fueled by development plans intended to boost the regional economy creates a pernicious feedback effect. Irreversible changes to land productivity and health issues are likely due to salt blowouts (estimated at 12×10^9 t stored in the lake (Ghaheri et al., 1999)), triggering environmental out-migration and substantial economic losses. Climate change adds additional pressure to the system. The combination of the current management policy with natural variability and climate change could increase the risk of reaching a 'tipping point' (Hansen et al., 2007) such that large additional changes are possible with little additional anthropogenic perturbation.

The drying of Lake Urmia can become a turning point for implementing proactive water resources management (Madani, 2014) based on deep regional understanding of the social, economic, and environmental pillars of sustainability in a synergistic lake restoration effort. The grave situation has cropped up at the national level as the most pressing environmental issue, alerting environmentalists and the general public in the region who demand restoration actions. To this effect, the Iranian government has recently founded the Urmia Lake Restoration Program (ULRP) to re-establish the lake's ecological water level (1274 m above sea level) within a 10-year timeframe. A range of promising restoration strategies and action plans are being considered within the ULRP, including stopping new dam construction projects and those in the early construction phase, managing some of the newly built reservoirs for the lake restoration only, re-establishing the hydraulic connection between the tributaries and the lake, limiting additional surface water and groundwater withdrawal in the basin, rent-for-fallowing the surrounding agricultural lands, and trying to mitigate salt blowouts and sand storms, among others. Furthermore, a number of supply-oriented solutions have been proposed, including major water transfers from international trans-boundary river basins, as well as from the Caspian Sea (UNEP, 2012; Zarghami, 2011).

The lack of sustainable adaptive governance approaches (Alipour and Olya, 2014) that engage the public sector and local stakeholders, and are facilitated by coordination among different institutions is a principal contributor to the dominance of operating in crisis management mode (Madani, 2014). Lack of proper institutions can result in incomplete or even wrong implementation of the restoration plans, which can exacerbate the current status. For example, increasing the efficiency of irrigation is considered to be one of the evident solutions to the Lake Urmia problem. However, without regulating, controlling and limiting water uses, improving irrigation efficiency has the potential to increase the water uses in the area as with better irrigation technologies farmers will have the opportunity to grow higher value crops that have higher water needs. It is necessary to actively engage the various stakeholders, experts, and decision makers in order to put the attractive restoration ideas of the action plans into real and effective actions while recognizing the potential conflicts between the public and individual interests and developing compensatory programs. Furthermore, in order to avoid destructive criticisms and loss of faith in the restoration process, the side-effects and limitations of the proposed top-down technological and institutional action plans must be clarified to the local stakeholders to facilitate consensus about the objectives and planning horizons. The positive effect of the solutions that quickly relieve the symptom of the problem will indeed be short-lived unless they incorporate the local knowledge of the stakeholders who share the sense of urgency about the restoration, although concerned about the livelihood of their community members in impacted areas.

Despite their attractiveness to the public as potential "quick" fixes to the problem, supply-oriented solutions such as water transfers to the basin can entail unintended ecological side-effects, and socioeconomic consequences that may intensify the original water shortage problem (Madani and Mariño, 2009). From an ecological standpoint, the consequences of transporting non-native organisms

and biogeochemical impacts of mixing water from donor basins require in-depth analysis to ensure the ecological side-effects of the proposed water transfers will not cause more harm than good. The supply-oriented fixes in the Lake Urmia basin may promote further development of the basin due to a false perception of water availability (Mirchi et al., 2012), exacerbating the lake's situation in the long-run. Although the water transfer projects may temporarily conceal the symptom of the problem (water shortage), they cannot address its root cause, i.e., increasing upstream water demand due to aggressive development. Thus, *water transfer as a solution to water shortage* has been recognized as *a fix that backfires* (Gohari et al., 2013). Besides technical and economic difficulties associated with transferring the Caspian Sea water over Alborz Mountain Range, the post-Soviet legal regime of the sea which is shared by five littoral states of Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan is still in dispute (Madani et al., 2014), which can potentially pose a formidable geopolitical obstacle to the water transfer initiative.

The bottom line is that sustainable development and water management plans for the region must re-establish a balance between the health of Lake Urmia and economic development. An effective recovery plan for Lake Urmia must emphasize water demand reduction in the lake basin, especially the irrigation water demand. Future adaptation strategies may consider providing farmers with incentives for cropping change and water conservation to reduce agricultural water demand and irrigation losses (Pimentel et al., 2004), development of socio-economic strategies for improving the efficiency of water use through water pricing (Rogers et al., 2002) and market mechanisms (Griffin and Hsu, 1993), establishing environmental water accounts, increasing water and energy prices, revising land use and regional development plans, and empowering farmers (Madani, 2014). While water demand reduction policies targeting the agricultural sector may cause economic losses in the short-term, they are essential to sustain environmental and economic productivity of the Lake Urmia basin in the long run. Policy instruments compensating for the economic losses incurred by the agribusiness and supporting the industries to provide alternative employment opportunities can help alleviate the immediate socio-economic impacts of restoration efforts.

A call for action

Drastic changes to lake health are primarily consequences of aggressive regional water resources development plans, intensive agricultural activities, anthropogenic changes to the system, and upstream competition over water. This underscores the urgent need for in-depth understanding of the anthropogenic alteration of the lake's water balance and implementing reactionary restoration measures rather than attributing the drastic physiographic changes to prolonged droughts and climate change which may justify no-action. Lack of reliable data on water demand and irrigation in the region prevents direct water budget assessment and quantification of the anthropogenic influence on the water cycle. The shrinkage of Lake Urmia bears important similarities to the desiccation of the Aral Sea in central Asia. Based on what has already been witnessed in the Aral Sea basin, we argue that the current condition of Lake Urmia requires immediate action to prevent or reverse an environmental disaster in the basin and beyond while there is time. To our consternation, however, a veil of political conservatism coupled with a knowledge gap between the scientific community and decision makers about the anthropogenic changes to the water cycle and associated socio-ecological consequences has obscured the urgency of Lake Urmia's situation.

This commentary updates the information about the extent of Lake Urmia's areal shrinkage, underscoring the anthropogenic threat to the lake's existence. The impending collapse of Lake Urmia's unique ecosystem requires immediate international attention in order to prevent the catastrophic socio-ecological repercussions. Extensive research is necessary to develop a comprehensive restoration plan. To this end,

involvement of international organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Development Programme (UNDP), and World Meteorological Organization (WMO) can foster a creative dialogue between physical and social scientists and political decision makers on how to address this environmental crisis. This commentary is a call for action to both develop sustainable restoration ideas and to put new visions and strategies into practice before Lake Urmia falls victim to the Aral Sea syndrome.

Appendix A. Data sources

Multi-spectral high resolution (30 m) Landsat images of the Lake Urmia region from 1972 to 2014 were acquired to derive the area of the lake. The composite maps of the lake were created for the time steps in which the geo-referenced Landsat scenes covered the entire lake region. Only high quality cloud-free images without SLC-off (Scan Line Corrector-off) were utilized in this study. A Bayesian Maximum Likelihood classification technique was used to classify land and water in the composite maps (Tom and Miller, 1984). The lake areas are then computed based on the 30 m water-classified pixels of each image. The trend analysis is based on the 12-month Standardized Precipitation Index (SPI) data of the lake's basin, obtained from a satellite-based gauge-adjusted climate record (AghaKouchak and Nakhjiri, 2012), standardized using an empirical approach outlined in (Farahmand and AghaKouchak, 2014).

References

- Abbaspour, M., Nazaridoust, A., 2007. Determination of environmental water requirements of Lake Urmia, Iran: an ecological approach. *Int. J. Environ. Stud.* 64 (2), 161–169.
- Abbaspour, M., Javid, A., Mirbagheri, S., Givi, F.A., Moghimi, P., 2012. Investigation of lake drying attributed to climate change. *Int. J. Environ. Sci. Technol.* 9 (2), 257–266.
- AghaKouchak, A., Nakhjiri, N., 2012. A near real-time satellite-based global drought climate data record. *Environ. Res. Lett.* 7 (4), 044037. <http://dx.doi.org/10.1088/1748-9326/7/4/044037>.
- AghaKouchak, A., Cheng, L., Mazdiyasi, O., Farahmand, A., 2014. Global warming and changes in risk of concurrent climate extremes: insights from the 2014 California Drought. *Geophys. Res. Lett.* 41. <http://dx.doi.org/10.1002/2014GL062308>.
- Ahmadi, R., Mohebbi, F., Hagigi, P., Esmaili, L., Salmazadeh, R., 2011. Macro-invertebrates in the wetlands of the Zarrineh estuary at the south of Urmia Lake (Iran). *Int. J. Environ. Res.* 5 (4), 1047–1052.
- Ahmadzadeh Kokya, T., Pejman, A., Mahin Abdollahzadeh, E., Ahmadzadeh Kokya, B., Nazariha, M., 2011. Evaluation of salt effects on some thermodynamic properties of Urmia Lake water. *Int. J. Environ. Res.* 5 (2), 343–348.
- Alipour, H., Olya, H.G.T., 2014. Sustainable planning model toward reviving Lake Urmia. *Int. J. Water Resour. Dev.* 1–21. <http://dx.doi.org/10.1080/07900627.2014.949636> (ahead-of-print).
- Barigozzi, C., Varotto, V., Barattelli, L., Giarrizzo, R., 1987. The Artemia of Urmia Lake (Iran): mode of reproduction and chromosome numbers. *Atti. Acc. Lincei. Rend. Fis.* 8, 87–90.
- Cook, A., Weinstein, P., Centeno, J., 2005. Health effects of natural dust. *Biol. Trace Elem. Res.* 103 (1), 1–15.
- Damberg, L., AghaKouchak, A., 2014. Global trends and patterns of drought from space. *Theor. Appl. Climatol.* 117 (3), 441–448. <http://dx.doi.org/10.1007/s00704-013-1019-5>.
- Delju, A., Ceylan, A., Piguet, E., Rebetez, M., 2013. Observed climate variability and change in Urmia Lake basin, Iran. *Theor. Appl. Climatol.* 111 (1–2), 285–296.
- Eimanifar, A., Mohebbi, F., 2007. Urmia Lake (northwest Iran): a brief review. *Saline Syst.* 3 (5), 1–8.
- Farahmand, A., AghaKouchak, A., 2014. A generalized framework for deriving nonparametric standardized drought indicators. *Adv. Water Resour.* <http://dx.doi.org/10.1016/j.advwatres.2014.11.012>.
- Farzin, S., Ifaei, P., Farzin, N., Hassanzadeh, Y., Aalami, M., 2012. An investigation on changes and prediction of Urmia Lake water surface evaporation by chaos theory. *Int. J. Environ. Res. Public* 6 (3), 815–824.
- Gaybullae, B., Chen, S.-C., Kuo, Y.-M., 2012. Large-scale desiccation of the Aral Sea due to over-exploitation after 1960. *J. Mt. Sci.* 9 (4), 538–546.
- Ghaheeri, M., Baghal-Vayjooee, M., Naziri, J., 1999. Lake Urmia, Iran: a summary review. *Int. J. Salt Lake Res.* 8 (1), 19–22.
- Gohari, A., Eslamian, S., Mirchi, A., Abedi-Koupaei, J., Bavani, A.M., Madani, K., 2013. Water transfer as a solution to water shortage: a fix that can backfire. *J. Hydrol.* 491, 23–39.
- Golabian, H., 2010. Urmia Lake: hydro-ecological stabilization and permanence macro-engineering seawater in unique environments. 10. Springer-Verlag, Berlin, pp. 365–397 (978–3).
- Golian, S., Mazdiyasi, O., AghaKouchak, A., 2014. Trends in meteorological and agricultural droughts in Iran. *Theor. Appl. Climatol.* 1–10.
- Griffin, R.C., Hsu, S.-H., 1993. The potential for water market efficiency when instream flows have value. *Am. J. Agric. Econ.* 75 (2), 292–303.
- Hansen, J., Sato, M., Ruedy, R., Kharecha, P., Lacis, A., Miller, R., Nazarenko, L., Lo, K., Schmidt, G., Russell, G., et al., 2007. Dangerous human-made interference with climate: a GISS modelE study. *Atmos. Chem. Phys.* 7 (9), 2287–2312.
- Hao, Z., AghaKouchak, A., Nakhjiri, N., Farahmand, A., 2014. Global integrated drought monitoring and prediction system. *Sci. Data* 1, 140001. <http://dx.doi.org/10.1038/sdata.2014.1>.
- Hassanzadeh, E., Zarghami, M., Hassanzadeh, Y., 2012. Determining the main factors in declining the Urmia Lake level by using system dynamics modeling. *Water Resour. Manag.* 26 (1), 129–145.
- Jaafari, S., Shabani, A.A., Danehkar, A., 2013. Investigation of coastline change of the Urmia Lake using remote sensing and GIS (1990–2012). *Int. J. Aquat. Biol.* 1 (5), 215–220.
- Karbassi, A., Bidhendi, G.N., Pejman, A., Bidhendi, M.E., 2010. Environmental impacts of desalination on the ecology of Lake Urmia. *J. Great Lakes Res.* 36 (3), 419–424.
- Khatami, S., 2013. Nonlinear Chaotic and Trend Analyses of Water Level at Urmia Lake, Iran. M.Sc. Thesis report: TVVR-13/5012. Lund University, Lund, Sweden (ISSN-1101-9824).
- Madani, K., 2014. Water management in Iran: what is causing the looming crisis? *J. Environ. Stud. Sci.* 1–14. <http://dx.doi.org/10.1007/s13412-014-0182-z>.
- Madani, K., Mariño, M.A., 2009. System dynamics analysis for managing Iran's Zayandehrud River basin. *Water Resour. Manag.* 23 (11), 2163–2187.
- Madani, K., Rouhani, O.M., Mirchi, A., Gholizadeh, S., 2014. A negotiation support system for resolving an international trans-boundary natural resource conflict. *Environ. Model Softw.* 51, 240–249.
- McKee, T., Doesken, N., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference of Applied Climatology*, 17–22 January 1993. American Meteorological Society, Anaheim, CA, pp. 179–184.
- Micklin, P.P., 1988. Desiccation of the Aral Sea: a water management disaster in the Soviet Union. *Science* 241 (4870), 1170–1176.
- Micklin, P., 2007. The Aral Sea disaster. *Annu. Rev. Earth Planet. Sci.* 35, 47–72.
- Mirchi, A., Madani, K., Watkins Jr., D., Ahmad, S., 2012. Synthesis of system dynamics tools for holistic conceptualization of water resources problems. *Water Resour. Manag.* 26 (9), 2421–2442.
- Nikbakht, J., Tabari, H., Talaei, P.H., 2013. Streamflow drought severity analysis by percent of normal index (PNI) in northwest Iran. *Theor. Appl. Climatol.* 112 (3–4), 565–573.
- Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., Clark, S., Poon, E., Abbott, E., Nandagopal, S., 2004. Water resources: agricultural and environmental issues. *Bioscience* 54 (10), 909–918.
- Rogers, P., Silva, R.D., Bhatia, R., 2002. Water is an economic good: how to use prices to promote equity, efficiency, and sustainability. *Water Policy* 4 (1), 1–17.
- Sima, S., Tajrishy, M., 2013. Using satellite data to extract volume–area–elevation relationships for Urmia Lake, Iran. *J. Great Lakes Res.* 39 (1), 90–99.
- Small, I., Van der Meer, J., Upshur, R., 2001. Acting on an environmental health disaster: the case of the Aral Sea. *Environ. Health Perspect.* 109 (6), 547.
- Tabari, H., Abghari, H., Hosseinzadeh Talaei, P., 2012. Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran. *Hydrol. Process.* 26 (22), 3351–3361.
- Tabari, H., AghaKouchak, A., Willems, P., 2014. A perturbation approach for assessing trends in precipitation extremes across Iran. *J. Hydrol. Part B* (0), 1420–1427.
- Tisseuil, C., Roshan, G.R., Nasrabadi, T., Asadpour, G., 2013. Statistical modeling of future lake level under climatic conditions, case study of Urmia Lake (Iran). *Int. J. Environ. Res.* 7 (1), 69–80.
- Tom, C., Miller, L., 1984. An automated land-use mapping comparison of the Bayesian maximum likelihood and linear discriminant analysis algorithms. *Photogramm. Eng. Remote. Sens.* 50.
- Tourian, M.J., Elmi, O., Chen, Q., Devaraju, B., Roohi, Sh., Sneeuw, N., 2014. A spaceborne multisensor approach to monitor the desiccation of Lake Urmia in Iran. *Remote Sens. Environ.* 156, 349–360.
- UNEP, 2012. The drying of Iran's Lake Urmia and its environmental consequences. Tech. rep. United Nations Environment Programme (UNEP) Global Environmental Alert Service (GEAS).
- Vahed, S.Z., Forouhandeh, H., Hassanzadeh, S., Klenk, H.-P., Hejazi, M.A., Hejazi, M.S., 2011. Isolation and characterization of Halophilic bacteria from Urmia Lake in Iran. *Microbiology* 80 (6), 834–841.
- Whish-Wilson, P., et al., 2002. The Aral Sea environmental health crisis. *J. Rural Remote Environ. Health* 1 (2), 29–34.
- WRI, 2006. Synthesis report. Integrated water resources management of Urmia Lake. Tech. rep. Water Research Institute, Tehran, Iran.
- Yamaguchi, N., Sakotani, A., Ichijo, T., Kenzaka, T., Tani, K., Baba, T., Nasu, M., 2012. Break down of asian dust particle on wet surface and their possibilities of cause of respiratory health effects. *Biol. Pharm. Bull.* 35 (7), 1187–1190.
- Zarghami, M., 2011. Effective watershed management; case study of Urmia Lake, Iran. *Lake Reserv. Manag.* 27 (1), 87–94.