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An Overview on Environmental Disturbance and Ecological Tragedy in Urmia Lake: The World's Second Largest Hypersaline Ecosystem

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ABSTRACT

Urmia Lake is the second largest hypersaline lake in the world, covering average 5000 km2 when full. The lake moderates extreme temperatures of the region and many tourists visit it for recreation, swimming and mud treatment during summer. During last two decades, increased demands for agricultural water in the lake's basin and recent droughts have shrunk the lake dramatically, exposing 60-80% of the lake bed. This review indicates that increased water demand in the lake basin, recent droughts and global warming are the main drivers for the Urmia Lake shrinkage. The Iranian government has made restoration of this remarkable ecosystem a crucial priority. Here we concluded the causes and consequences of Urmia Lake shrinkage and provide a brief discussion of the impacts on its fauna and flora, coloration, wetlands and islands. As Urmia Lake shrinking persists, many environmental, economic and social advantages will be completely lost in the lake's basin.

Keywords: *Urmia Lake, restoration, wetlands, shrinking, ecological disaster.*

INTRODUCTION

Hypersaline environments contain crucial environmental, social and economic roles as unique ecosystems due to biogeochemical processes occurring in them, so that, they may be considered as integral and dynamic part of the biosphere (Mohebbi, 2010; Shadrin, 2009).

Urmia Lake, the second largest hypersaline lake on earth, has experienced a significant shrinkage in the last decade. This shallow terminal lake located in northwest Iran at an altitude of 1273 m above sea level, is surrounded by a range of high mountains (Ghaheri et al., 1999). Regarding to its environmental significance and unique biodiversity and the presence of indigenous communities, Urmia Lake was designated a wetland of international importance by Ramsar Conversation and a Biosphere Reserve by UNESCO in 1971 and 1976 respectively (Ghaheri et al., 1999; Eimanifar and Mohebbi, 2007; Chander, 2012; Asem et al., 2014; Nouri et al., 2017). There are five Ramsar sites in the basin, including Urmia Lake and some of its periphery wetlands. The Lake and its periphery wetlands compose nine globally important bird areas in Urmia Lake basin (Karimi, 2013).

The first historical note on Urmia Lake stems from an Assyrian King around 1000 yr B.C. Alexander and Strabo both mention the lake's saltiness (Günther, 1899). Settlement around the lake ranged from 2100 to 800 yr B.C. with some evidence of a precursor Neolithic occupation (Kelts & Shahrabi, 1986). Hasanlu is an archeological site located near the southwest shores only 90 m above the lake surface. Some ruins occur about 50 m above the lake, and a few relicts are near the shore.

The air temperature usually ranges between 0 and -20° C in winter, and up to 40ºC in summer.

In this regard, Urmia Lake is a critical asset for the region, since it acts as a moderator for these extremes (Ghaheri et al., 1999). Mohammadi (2014) showed that temperature decreases with higher altitudes was higher in stations located in south of the lake, which were located more distant from the lake than the west stations, located closer to the lake. There are more than 36 cities and 3150 villages in the Urmia Lake basin with about 6 million people with two different native languages and cultures (Azerian & Kurdish) (Karimi, 2013).

Urmia Lake once had a surface area of about 5000 km^2 (Asem et al., 2012). The lake is the largest natural habitat of a particular brine shrimp *Artemia urmiana*, a major food source for some migratory birds (Ahmadi et al., 2011; Asem et al., 2014, 2016; Agha Kouchak et al., 2015). The lake's water level has declined significantly, endangering this remarkable ecosystem (Abbaspour & Nazaridoust, 2007; Hassanzadeh et al., 2011; Sima & Tajrishi, 2013; Tourian et al., 2015). The continuation of the lake's retreat could result in another major environmental tragedy similar to the fate of the nearby Aral Sea in Eurasia (Aghakuchak et al., 2015; UNEP, 2012), which gradually decreased to less than 10% of its original size after diversion of the lake's major inflow rivers for agricultural irrigation (Gaybullaev et al., 2012; AghaKuchak et al., 2015). The important characteristics of Urmia Lake is summarized in Table 1.

Table1. *Morphometric characteristics of Urmia Lake before and after shrinkage*

Characteristics	High-stand period	Low-stand period	References
Watershed area (km^2)	51876	51876	Marden et al., 2014; Delju et al., 2012
Surface area (km^2)	4800-6100	1730-2200	http://agrw.ir
Mean depth (m)	4.5	0.5	Sima and Tajrishi, 2013
Volume (m^3)	26×10^9	1.5×10^9	http://agrw.ir
Stream flow (m^3/yr)	972×10^6	250×10^6	Nourani et al., 2018
Mean evaporation (mm/yr)	1156	1629	Heidari et al., 2010
Salinity (ppt)	150-180	>300	Eimanifar and Mohebbi, 2007
pH	6-8	6-8	Alipour, 2006

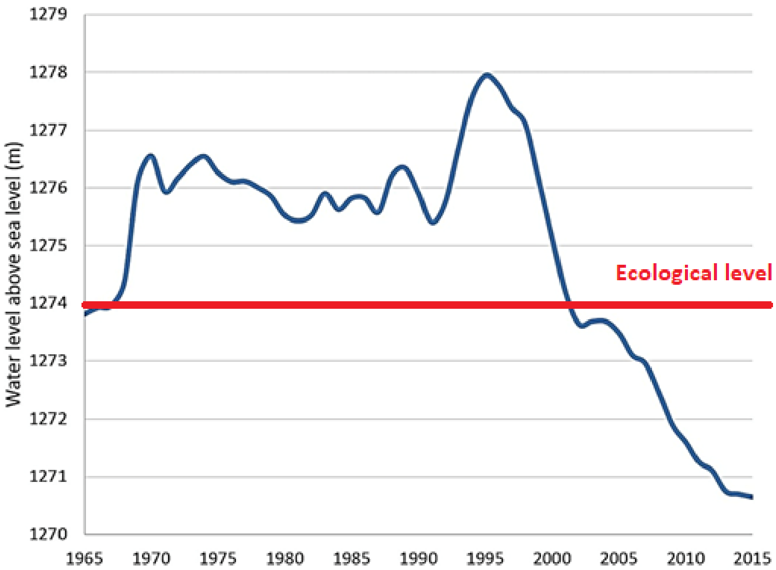

Figure1: *Water level fluctuations in Lake Urmia from1965 to 2015)*

By 2012, Urmia Lake's water level had dropped about 4 m from its ecological level, which is the lowest ever recorded since the start of observation in 1966 (Fig. 1). Vast areas of surrounding lands have been converted to salt marshes and, in southern and southeastern regions, the coastline has retreated several kilometers. Salt crystals can be seen on the Lake Surface year round which has disrupted the water birds feeding and migration (Asem et al., 2012). In spite of rapid growth of industrial activities during the last decades, agriculture and animal husbandry are still the dominant industries within the basin. Prior to shrinking many tourists from Iran and abroad visited Urmia Lake National Park. As the lake has receded from its historical coastline (Jaafari et al., 2013), many tourism sites have been lost. As salinity increased, large amounts of salt precipitated on the lake bed, so wading is very difficult for people who want to swim. As a consequence, tourism jobs in the region have been declined (Bagherzadeh, 2012).

Over-use of surface and groundwater, coupled with frequent droughts has escalated Urmia Lake's water situation to a critical level. Evidence for this includes: a drying lake, wetlands with declined depth; declining groundwater levels; water quality degradation; soil erosion; desertification, and frequent dust storms. The Iranian government has promoted increasing irrigation to increase agriculture productivity which has encouraged an expansion of cultivated areas across the Urmia Lake basin (Madani et al., 2016). Farmers, however, have not employed new technologies and practices, resulting in inefficient irrigation and production.

The decrease in river inflow has severely disrupted the lake ecosystem. The brine shrimp *Artemia* densities have been decreased sharply, so that only cysts can be observed in too low density in the remained lake water (Asem et al., 2012, 2019). Algal communities of the lake have been disturbed remarkably and their diversity and density have been declined. Plants biodiversity of periphery wetlands has been decreased, leaving only a few taxa of aquatic macrophytes, and algal-dominated systems. Mohebbi et al. (2015) has argued that these changes are a consequence of eutrophication. The aim of the present paper is to review the current impacts of lake dewatering on all aspects of the lake, the major restoration plans underway, and to predict the restoration trend of this integrated ecosystem. The shrinking of Iran's great Urmia Lake finally appears to be stabilizing and officials see the start of a revival.

WHY HAS THE LAKE DRIED UP?

Morier (1818) and Curzon (1892) had mentioned the existence of a walk-road across the lake because of a violent drought in early of 19th century. As well as, a historical records document that due to lack of food and freshwater, inhabited herbivorous in the islands abandoned the islands by swimming and migrated into the surrounding mountains (Binder, 1887).

Over the past two decade, Urmia Lake has lost 80% of its area due to severe drought (Asem et al., 2019). During 1997 to 2006, annual average precipitation (205mm) on the lake's basin decreased about 17% compared to the 30 year average from 1967 to 1996 (247mm) (Hassanzadeh et al., 2011). Another study found a 9% decline in the mean annual precipitation during the period 1964 -2005 (Delju et al., 2013). The difference in estimated rate of decline suggests an acceleration in decreased annual precipitation. Recently, Schulz et al. (2020) have shown that variations of Lake's water level during eight decades were substantially caused by climatic changes.

Yarahmadi (2014) indicated that temperature rise and increased evaporation from the lake surface was more important than the decrease in precipitation. It has been reported that about 30% of Urmia Lake water level fluctuations is linked to the increased temperature and the reduction of annual precipitation. However, it has been declared that some 42% of the lake water level reduction was addressed by water input (Yarahmadi, 2014). Additionally, there was the lowest correlation between the Lake water level changes and climatological parameters. The current trend of declining lake water levels is substantially independent of climatic variables (Azizi et al., 2017). They concluded that though ground water levels have highly decreased in the lake basin, but it has a negligible share in the lake water level changes.

Alcott and Steenburgh (2010) suggest that a 2°C increase in the average annual temperature may result in a decrease of 4-12% of water in the Great Salt Lake watershed and a 25% reduction in snowfall. Temperature increases of 1.3°C have occurred in the Urmia Lake basin during 1973-2012 (Doosti Rezaei et al., 2013), and this may have also decreased inflows to the lake. In addition to decreasing trend in precipitation, studies have shown a significant increasing trend of temperature throughout the basin and an area-specific precipitation decreasing trend. The annual increase in temperature in the basin was 0.02 to 0.14°C/year, while, precipitation was annually decreased from -3.8 to -7.5 mm/year range.

Furthermore, the annual decrease of stream flow was -0.01 to -0.4 m^3/s/year. This study showed that the stream flow in the lake basin is more sensitive to changes in temperature than precipitation. Doosti Rezaei et al. (2013)

concluded that the decline in the lake water level is related to both the increase of temperature in the basin and an increasing exploitation of the water resources.

Despite these changes in precipitation and temperature, it appears that water problems in the Urmia Lake basin are mostly man-made and the product of decades of poor management caused by lack of foresight, uncoordinated planning, low irrigation efficiency, extensive agriculture and cultivation of water-intensive crops (Hassanzadeh et al., 2011) which has resulted in water demand being far greater than the available water supply of the basin.

Hesami and Amini (2016) evaluated land and agricultural water use in a 1025 km^2 area in the Miandoab plain located in southeast of the Urmia Lake basin. Their study indicated a 19,000 ha increase in total irrigated area (about 20%) and a 226 million cubic meter increase in water demand (about 35%) for irrigation from 1989 to 2000. Nourani et al. (2018) declared that the main factor influencing the water level at Urmia Lake is decreasing trend in streamflow. They indicated two starting points of significant decreasing trends in water inflow in 1973 and 1998, the latter coincided with decreasing the lake level.

The paucity of data related to water demand and irrigation for the Urmia Lake basin is a severe constraint which hinders the investigation on the components of the water budget and quantification of the anthropogenic influence. However, as in the case of the Aral Sea, over-exploitation of input water to the Lake is very likely the main driver of Urmia Lake's s shrinkage (AghaKouchak et al., 2015; Chaudhari et al., 2018). Although the both natural and anthropogenic reasons have been suggested as causing the desiccation of Urmia Lake (Zarrineh & Azari Najaf-Abad, 2014; Schulz et al., 2020), there is lack of a documentary evidence to evaluate the contribution of each factor with dilates. It seems that human induced drivers are more important than environmental drivers. Industry and domestic consumption are responsible for only 6% and 3% of the water use respectively, whereas agriculture sector is responsible for 91% of the water consumption (Faramarzi, 2012).

As Urmia Lake is a terminal lake, the increasing amounts of water withdrawn from its feeder rivers, in order to expand agricultural lands, are considered a main contributor of the present situation. Since last four decades, Iran's population has more than doubled, from 37 million to around 82 million today (World Bank, 2019). Thus, Urmia Lake basin population has been doubled during last three decades. This led to pressure on the lake by increased water use in agriculture and urban developments. On the other hand, contaminated and waste water produced in these sectors returns into the lake. This high population growth led to an increasing demand for food and water (Madani, 2014). To satisfy the nation's growing needs, dams, groundwater pumping stations and water diversion pipelines have been constructed in the basin. Particularly, since 1995, about 74 dams have been constructed in the Urmia Lake watershed area which had a direct effect on Lu water level decrease correspondences to this period (Ghashghaie & Nozari, 2018).

The availability of huge quantity of irrigation water accumulated behind the dams has in turn led to increasing rates of water withdrawal and evaporation, and these water infrastructure developments have not only reduced direct water inflow into the lake, but they also allowed the overall size of the total cultivated area to triple (Mehrian et al., 2016; Dalby & Moussavi, 2017). In addition, many of the previously rain-fed agricultural lands have become irrigated farmland, growing from 3035 km^2 in 1984 to 5086 km^2 in 2014, an increase of 67.5% (Mehrian et al., 2016). Khazaei et al. (2019) showed that human-driven vegetation cover reduction and associated irrigation expansion are the dominant factor in the Urmia Lake desiccation. Fathian et al. (2016) showed that during last 35 years crop land, horticulture and rain-fed land has increased by 412%, 333% and 627%, respectively. Pasture lands have been substituted by agricultural lands.

Additionally, cultivation strategies have shifted from subsistence farming to intensive agriculture, leading to changed cropping patterns based on more valuable returns, and to thirstier crops such as sugar beet and apples (Zaman et al., 2016; Dalby & Moussavi, 2017; Schmidt et al., 2020). Traditional low water consumer vineyards were aggressively replaced by apples. Thus, apples especially are produced in large quantities around Urmia Lake, which has led to an oversupply of product for food markets and processing industries in the area. Nonetheless, many farmers still build their existence on the production of apples, even though it is barely profitable.

The increase in surface water use has gone together with an aggressive underground water withdrawal campaign, with tens of thousands of deep-wells being drilled. Presently, there are almost 90,000 wells in the Urmia Lake basin, around 50% of which were drilled illegally (ULRP, 2015). Currently, roughly 70% of renewable water resources in the basin are consumed, with the agricultural sector accounting for a minimum of 90% of the total water use (Madani, 2014; ULRP, 2015). Accordingly, a large amount of water consumed by agriculture is not being discharged into Urmia Lake. In fact, according to Urmia Lake Restoration Program (ULRP), during the past two decades the water runoff feeding the lake has decreased by 50% in comparison to its long-term recorded data, amounting to 30 billion cubic meters of ‘‘lost water.’’ Besides, a water pipeline, which has been established in 1999, diverting around 3 billion cubic meters of water annually from the Zarrineh River into the city of Tabriz, thereby greatly reducing the quantity of water coming from one of the most important inflows into the endorheic lake (Khalyani et al., 2014; Alizadeh-Choobari et al., 2016). In this context, the disproportionately high demand for water in the growing urban agglomerations of Tabriz (about 2.2 million inhabitants) and Urmia (about 0.8 million inhabitants) is often suggested as a major cause of increased water consumption. Although the water used in cities is not necessarily lost completely—as some of it returns via the sewage system or diffusing otherwise—it returns to the water cycle in greatly decreased quality (Schmidt, 2018). Furthermore, and rarely discussed in the scientific literature, the construction boom of luxurious weekend houses on the outskirts of urban agglomerations and rural areas is also linked with high water consumption. In many places, farmers cut large plots of gardens to several small pieces in order to gain more returns. Thus, each piece drill well to search of water independently (Sigaroodi and Ebrahimi, 2010; Schmidt, 2018).

It was found that agricultural activity, contamination and salinization from irrigation, fertilizers and up-coming salt water during pumping are among the factors in deterioration of ground water resources in the Urmia Lake basin (Heydarirad et al., 2019). Since 1987 cropland areas doubled at the expense of bare soils and natural vegetation, urban areas increased three folds. On the other hand, regulating and cultural services and biodiversity decreased at the shorelines of the Lake (Rahimi Balkanloo et al., 2020). Briefly, anthropogenic impacts and climatic factors have roughly 80% and 20% effects on the drying up of Urmia Lake, respectively (Alizade Govarchin Ghale et al., 2019).

Causeway Project

A 15.4 Km dike–type causeway was constructed to cross the lake at its narrowest part and to provide a shorter connection road between two large cities in the west and east in the early 2000s. This embankment was equipped with a bridge on a 1.25 Km opening to provide limited water exchange between northern and southern parts of the lake. As most rivers flow into the lake in the southern part, there is speculation that the causeway may have contributed to a higher salinity in the north and lower salinity in the south. However, Khatami and Berndssson (2013) and Zeinoddini et al. (2009) found that the causeway has had no significant influence on the lake's flow and salinity regimes. Following a simulation analysis, Zeinoddini et al. (2009) concluded that the causeway would impact the overall patterns of salinity in the lake during long periods. Causeway construction doesn’t reduce the natural mixing of the water between the north and south parts of the lake (Marjani & Jamali, 2014). However, some authors recommended the widening of the opening to obtain the desired water flow (e.g. Modaresi, 2002; Sadra, 2003). Although there are some disputes referring to the effect of causeway on the Urmia Lake drying, there is no scientific evidence to prove this claim. But certainly the creation of causeway due to abandoned rubbish by passengers and petroleum contamination of vessels for the transportation of vehicles (before the completion of the middle bridge for over a decade) have had a destructive roles on the environment of Urmia Lake.

Hydrology

The deficiency of the data makes difficult the estimating of the water budgets in large basins, particularly in endorheic basins which including of two distinct land and water phases.

The lake water level has declined steeply since 1995 and stakeholders have agreed to allocate 3100 million cubic meters (MCM) of water per year to the lake (Bagheri et al., 2017).

Therefore, it is essencial to monitor water inflow into the lake to achieve the compromise.

Gauging stations have been employed around the lake, but they cannot account for additional water withdrawals below their locations.

The onset of a drought in 2007 over the Urmia Lake basin together with an increase in the rate of groundwater depletion reduced the water storage of the whole basin. The tests also confirmed a general decreasing trend in the basin stream flow that was more pronounced in the downstream stations. On average, the lake has lost 34±1 cm/yr of its water level from 2002 to 2014, equal to a loss of water areal extent at an average rate of 220±6 km^2/yr. In total, the lake has lost about 70-80% of its surface area over the last 14 years (Tourian et al., 2015; Asem et al., 2019). Their results also indicate that the lake volume has decreasing at an alarming rate of 1.03±0.02 km^3/yr.

Based on the analysis of remote sensing data, Chaudhari et al. (2018) found 98% and 180% increases in agricultural lands and urban areas, respectively, in the lake basin from 1987 to 2016. Comparison of river inflow to the lake from 1995 to 2010 suggested that human water management activities together with tripled irrigation requirement caused a reduction in streamflow of about 1.74 km^3/year, which accounted for about 86% of the total depletion in the lake volume during the same period (Chaudhari et al., 2018).

Investigation of interaction between rainfall, stream flow, temperature and humidity and Urmia Lake water level fluctuation during 1971-2013 (Nourani et al., 2018) showed the decrease in streamflow was the main factor in the reduction of the lake water level. Besides, decreased rainfall and humidity and increasing in the temperature were obviously observed during the study period.

The seasonal progress in hydrochemistry of coastal groundwater resources in Urmia plain was studied by Amiri et al. (2016) to understand the temporal and spatial evolution of saltwater intrusion in the coastal alluvial aquifer of Urmia Lake.

Results show that in wet period most of the samples have mixed water type of Ca-Mg-Cl (domain IV) and Ca-Cl (domain V), while in dry period, predominant water type (56.4%) is fresh. Therefore, in spite of some near shore sampling points with the Na-Cl water type, it can be concluded that there is not much interaction between Urmia aquifer and Urmia Lake. Shemshaki and Karami (2016) studied the ratio of Cl^-:Br^- in groundwater at southeast of the lake. They showed that groundwater aquifer in this region was subjected to salt water intrusion from the lake. The change in the groundwater flow direction based on the groundwater level maps was consistent with the results of their study. This is likely a consequence of increased utilization of groundwater in the lake basin. However, only a very small fraction of lake water input comes from groundwater inflow (Okhravi et al., 2017).

Totally, all aquifers of Urmia Lake showed decreasing trend in groundwater level during 2004-2011 (Delshad, 2016). However, there is a large variation on the magnitude of the groundwater level drop (min 0.18 m, max 4.68 m), mostly depending on the volume of water withdrawal for agriculture in different regions. We can find a small discrepancy on the groundwater level drop in this study with that of Mehri et al. (2016) who reported a 2m reduction in the groundwater level in the basin. This may be related either to different time periods of measurement or location of stations investigated in two studies.

HYDROGEOCHEMISTRY AND HYDRO CHEMISTRY

The dominant ions in Urmia Lake are Na, Mg, K, Ca, Cl, So4 and HCO_3, respectively (Sima and Tajrishy, 2015). Aji Chai River as the largest river in eastern part of Urmia Lake, passes through evaporative and erosive structures of Oligomiocene, particularly the salt domes transports a lot of ions into the lake. Annually, 2.2 million tons of ions enters into the lake of which up to 54% (1.18 million tons) come from the Aji Chai River. The Zarrineh River transports 0.46 million tons of salts into the Urmia Lake (Lak & Darvishi Khatooni, 2016). The remaining salts (0.56 million tons) are supplied by other rivers and rain water.

Urmia Lake’s salt composition has changed with water level reduction. This shift was minor during 2007-2010. However, there was a rapid change in anions, cations composition and saline water type of the lake in 2011 (Darvishi Khatooni et al., 2013). The lake’s saline water type was of Na-Mg-Cl type during 2007 to 2010, similar to that of the Great Salt Lake in the United States of America. From 2011 onwards, soluble Na and Cl reached the saturation levels of halite (NaCl). With precipitation of halite in the shores and beds of the lake, the concentration of soluble Na decreased in the water column and Mg increased. Consequently, the lake shifted from a Na-Mg-Cl system to a Mg-Na-Cl type. It was a transition state. By crystallization of more halite and Na_2SO_4, the lake saline water is evolving to a Mg-SO_4-Cl type according to Eugster and Hardie (1978) evolution diagram (Darvishi Khatooni et al., 2015).

IMPACTS

Water level decline of Urmia Lake has had the most negative impact on the physical aspects such as salinization of lands, crops diversity reduction, destruction of orchards and pastures, increased contamination of water resources and rural environment (Anvari & Valaei, 2015). Likewise, the highest negative influence of the lake water level reduction on the socio-economic dimensions including decline of non-agriculture employment, rural income, job diversity etc., was observed. Besides, the probable dryness of Urmia Lake will intimidate ecotourism in the area.

Artemia Production

As evaluated in West Azarbaijan province in 2002, (Mohebbi, 2002) the establishment of a 100 ha *Artemia* farm, an *Artemia* culture in tanks with 9000-m^3 capacity and construction of an *Artemia* cyst processing facility with 210 tons capacity, may create 76, 82 and 21 jobs, respectively. Regarding last decade's drought and the environmental crisis in Urmia Lake, employment opportunities arising from the harvest, production and processing of *Artemia* have completely been lost.

Agh et al. (2008) found that reproductive characteristics of Urmia Lake *Artemia* reduced with increasing salinity. Water level reduction has decreased the *Artemia* density in the lake. In 1898 when salinities were likely near 150 g/L, Günther (1899) found 1200-1600 individuals per cubic meter. Kelts and Shahrabi (1986) reported 3000 *Artemia* per m^3 in their lake expedition in 1977. With dropping the water level (Fig. 1), the density of *Artemia* decreased rapidly, so that there has been reported no *Artemia* in the main lake since 2010 (Asem et al., 2012).

Asem et al. (2010) found a significant negative correlation between salinity and cyst diameter, they have documented that with increase the salinity the diameter of *Artemia* cyst significantly decreased. It has been attributed to decreasing food availability during the drought period.

Additionally, as the lake shrinks, the *Artemia* cysts density drops. Asem et al. (2012) estimated the Urmia Lake cysts density in the upper 50 cm of the water column as 400 cysts/L in 1995, while the density of cysts in the surface 20 cm water layer, based on a stock assessment were 27, 25, 11, 8 and 3 cysts/L in 2003, 2004, 2005, 2006 and 2007, respectively (Ahmadi, 2005, 2007). The decline trend coincided with the start of drought in Urmia Lake. After 2007, no *Artemia* resource assessment was carried out; however, unofficial reports indicated that there was less than 1 cysts/L of *A. urmiana* in Urmia Lake during 2008- 2017 (Fig. 1).

One of the substantial ecological effects of drying of Urmia Lake was on the genetic structure of *Artemia urmiana*. Asem et al. (2019) have evidence that genetic variation of *Artemia* dramatically directed between rainy period (1994) and drought period (2004). Current low genetic variation can make difficult further management to restoration of *Artemia* resource.

Algae and Red Coloration

Enteromorpha intestinalis, a green macroalga has once been reported by Günther (1899) and Saberi (1978), but this alga has not been observed or reported since then. This can be attributed to lower salinities observed in those times.

In summer 2012, an algal bloom occurred at the northwest of Urmia Lake in a relatively small scale (Manaffar & Ghorbani, 2015). Molecular analysis of samples performed by 18srDNA study and ITS region sequencing, indicated a dominance of *Dunaliella tertiolecta* with 1.2×10^6 cells/ ml density. This indicated eutrophication of the lake which was induced by high levels of P and N and may partly be related to the low water level.

In warm and dry season, as the water level drops below 1372 m (Fig. 1), the density of halophilic bacteria in the family of Halobacteriacae rises to more than 10^8 cells/ ml in the lake. These are prokaryotic organisms, so have pigments distributed evenly on the cell membranes. So, are able to absorb light more efficiently than carotenoid of eukaryotic *Dunaliella* as a dominant alga (Mohebbi et al. 2011). In fact, although β-carotene derived from *Dunaliella* is the most abundant carotenoid pigment in the hypersaline water, its dense packaging within granules inside the cell's chloroplast greatly decreases its participation in the overall light absorbance in the water. As for Urmia Lake (e.g. Arash Rad, 2000; Asgarani et al., 2006; Bahari et al., 2009) the presence of Halobacteriaceae family has been reported by Post (1977) and Baxter et al. (2005) in the North Arm of Great Salt Lake, Utah, which shows similar color changes in high salinities. Urmia Lake color changing process has currently a seasonal cycle, as drought and agricultural water overuse persist in the region, ruddy hue may become a more common sight.

Islands

Until the severe drying of the lake occurred, the islands provided reliable water and food availability for these valuable mammals and other biodiversity. However, the mammals now disperse from the islands over the bed of the lake in their search for water and food.

Since the shrinkage of the lake during last decade, Department of Environment have transferred forage to the islands several times. Water sources used for wildlife drinking is finished during dry season. Water has been transferred to the islands in tanks. However, the most limiting factors of wild life population in the islands are still drinking water and poor vegetation. Both are being influenced by the lake low levels. After lake shrinkage, wind lifts salt and dust grains from salt bed that precipitate on the leaves and stems of plants in the islands. These plants may not be grazed by wildlife.

Wetlands

Environmental experts estimate an ecological value for wetlands as 10 times as forests and as 200 times as agricultural lands (Mohebbi, 2007). The wetlands ecosystems have been deteriorated since the start of the lake shrinkage in terms of both water level and hydro periods (Alibakhshi et al., 2017) which had negative impacts on species richness (Ahmadi et al., 2011), aquatic habitats, dynamics of vegetation, plant communities (dominance of invasive plant species), trophic state, salinity, nutrient loading and cyanobacterial bloom (Mohebbi, 2013). The wetlands deterioration is mainly independent event with as similar scenarios as Urmia Lake basin, but in a smaller scale. A minor part of this condition is depended to the connection between the lake and wetlands.

Health Issues

At Urmia Lake region, particularly during dry season, wind could carry on saline dust to adjacent areas as far as hundreds kilometers (Gholampour et al., 2015). Boroughani et al. (2019) found that the number of dust storms increased with a significant inverse correlation to the Lake area. The dried area is the source of many dust storms in regional scale. Sandy-salt surfaces in the east and southeast of the lake are very susceptible to wind erosion with high potential for dust storms generating (Alkhayer et al., 2019). These storms contain toxins and minerals that may be inhaled and have been linked to an increasing cases of health problems such as eye, skin and respiratory issues throat and lung cancer, infant mortality, decreasing life expectancy and increasing child defects in regions adjacent to the lake (Rezaei et al., 2013; Torabian, 2015; Anvari & Valaie, 2015; Pesyan et al., 2017; Maleki et al., 2018; Mohammadi et al., 2019; Samadi et al., 2019).

The occurrence risk of asthma in exposed group (neighboring areas of the Urmia Lake) was 1.85 times higher of non-exposed group (medium distance 65km from the lake) similarly, the risk of disease in exposed group was 1.44 times more when compared to non-exposed group (Musapour et al., 2019). During 2001 to 2016 particulate matter followed an increasing trend, while the adjacent areas have experienced higher pollution compared to far counties mostly in southwestern dominant winds direction (Delfi et al., 2019). Indeed, this observation is consistent with the ULRP's estimates that the more frequent west–east wind direction will increase the pressure on regions on the eastern side of Urmia Lake (ULRP, 2015; 2017).

Suppression of emissions on the Urmia Lake border is critical as the combined area of salt and salty soil bodies around Lu have increased by two orders of magnitude in the past two decades (Mardi et al., 2018). They propose to protect Urmia Lake bordering areas by planting vegetation as a useful strategy for emission control. Furthermore, the decline of available intact water and the increasing amount of contaminated water have caused additional health issues, especially for poor and vulnerable households, whose access to proper nutrition, hygiene and fresh water supply was already low (Torabian, 2015). Therefore, it is very probable that further depletion of the lake will amplify disease outbreaks and health issues for the local population.

Owens Lake in California was desiccated due to water diversion to Los Angeles city. Dust emission from the lake bed contained minerals such as sodium sulfate, sulfur, arsenic, chrome, cobalt, nickel, lead, caused allergy, respiratory diseases, asthma, sinusitis, and cardiovascular problems in the area. The lake was recognized as main source of PM10, annually more than 76000 tons of PM10 is produced in the lake bed. Likely, it is predicted that dried Urmia Lake bed dust could result in 30-60% increase in PM10 of nearby cities during dust episodes (Sotoudeheian et al., 2016).

To gain a better understanding of the significance of salt storms on people's health, the Universities of Medical Sciences in Tabriz and Urmia have begun a comprehensive long-term survey of these effects on people residing in the area (FT, 2017). However, health organizations are currently deal with covid-19 pandemy in 2020. So, health issues induced by lake bed salt storms may be underrated.

Socioeconomic Issues

Environmental deterioration hampers economic development and productivity in the region in various ways. First of all, agriculture and livestock production—the most important source of income for villagers in NW Iran—are under pressure. Salt deposits diminish the fertility of soils and cause a decline in rural agricultural incomes, as farmlands, orchards and pastures are damaged and the water demand for leaching salts from the top soils increases (thereby causing water resource contamination).

More pressure is imposed on the agricultural sector by overall low water availability and quality, due to changes in the regional climate, the overexploitation of groundwater resources and reduced river runoff caused by upstream water withdrawal (Anvari & Valaie, 2015; Azizpour et al., 2015). In fact, the previously vast expanse of Urmia Lake had a balancing effect on the micro-climate throughout the watershed. However, it is evident that due to its progressive and ongoing shrinkage, the daily temperature amplitude has increased, relative humidity has declined and the annual precipitation regime has altered (Ghalibaf and Moussavi, 2014; Azizpour et al., 2015). This coincides with the effects of overall climate change and the experiences of local farmers.

Water quality is decreasing throughout the basin due to fertilizer and pesticide deposits, as well as the overuse of local groundwater, resulting in saltwater intrusions into aquifers (Dalby and Moussavi, 2017). Obviously, the sustainability of present farming systems and livelihoods is under threat, as water shortages and contamination are already critical today and are probably to become more severe in the future.

In response to the continued environmental degradation, many people around the lake have already left their villages. Indeed, households that relied solely on tourism were among the first to be affected by the disaster. As the lake started to shrink, people lost their jobs and the property values of the surrounding lands decreased, thereby creating additional financial problems for many families (Daryani, 2019). In search of other income opportunities, many people moved away or shifted to farming, so increasing the already high pressure on water resources.

However, several farmers also left their home villages in order to adapt to the disaster, which can be blamed on the region's increasing water stress. Almost all men of working age live and work in the city of Urmia. Many farmers reported that due to crop failures and declining incomes they were forced to sell plots of their agricultural land in order to survive. Other immediate adaptation strategies included deepening or digging new wells, to ensure some form of field irrigation and to maintain drinking water supplies, thereby putting further pressure on water resources. As a consequence of environmental degradation, migration had become a common adaptation strategy for rural people. Indeed, if migrating from the adjacent lake areas turns out positively for individuals, remittances can further prompt positive effects for the remaining household members (Warner et al., 2010). Households may choose to send one member to support household livelihoods by transferring remittances.

ULRP was not achieved to its goals in socioeconomic sustainability of local societies close to Urmia Lake so that, in some cases, motivation and life expectancy reduction and increased migration may be observed (Moatamedi et al., 2019). The highest impacts of Urmia Lake shrinkage on local settlements are salinity of drinking water, wells and aqueducts and naked pastures which are strongly linked to their livelihood. Advanced poverty is an ongoing event that occurs in close proximity villages of Urmia Lake. Economy of Urmia Lake basin are basically depended on agriculture, gardening and livestock. The lake crises has challenged these people live and financial condition (Rezaei et al., 2013). Tourism had crucial role in economy of the region and a lot of households were living on incomes from tourism. Almost all tourism activities have been vanished during last two decades. The lake desiccation means no islands, no beaches for swimming and no tourists. Chichest tourism assemblage in western beaches of lake once crowded, at present is converted to a quiet region up to several kilometers you may not see any beach instead a salty desert. Therefore, huge number of unemployed forced to shift to other sectors such as agriculture or service which are already under pressure.

Restoration Measures

Lakes are highly visible feature of the landscape in many parts of the world. Because they are pleasing aesthetically and important economically for recreation, water supply and as a foci for urban development. So, lake deterioration is quickly noticed and demands for remedial action are swift (Winter 1981).

In response to extensive demand in national and international level, in 2013 the Iranian government began the ULRP to re-establish the lake's ecological water level, 1274 m above sea level (Fig. 1), within a 10-year time frame (AghaKouchak et al., 2015). Within the ULRP, a range of restoration strategies and action plans are being considered, including stopping new dam construction projects and those in early construction phase, managing some of the 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 and mitigate salt blowouts and sand storms, among others (UNEP, 2012). Among strategies for the lake revival, the most significant is the establishment of 13 sewage treatment plants in the catchment area financed by ULRP. Once completed, the Tabriz plant will be able to supply 4 cubic meters of water per second to the lake, which equals 125 million cubic meter per year (about 5% of annual water input) to the lake (FT, 2018).

Four different routes of water transfer from Aras River basin in the north of Urmia Lake, was ranked with regard to environmental impacts, simplicity of construction and social acceptance (Zarghami, 2011). Though water transfer solutions are attractive to the public as quick fixes to the crisis, they may create unwanted ecological side-effects and socioeconomic consequences that can intensify the original water shortage problem. Supply – oriented solution may temporarily conceal the symptoms of the water shortage problem, they are not able to address its root cause, i.e., increasing upstream water demand (Gohari et al., 2013). Besides, the ecological consequences of transporting non-native organisms and biogeochemical impacts of mixing water from other basins need in-depth analysis to ensure that the ecological side effects of the water transfers will not cause more harm.

The ULRP implemented 88 projects, with the main goal of restoring the ecological level of the lake, 1274 m above sea level, by 2023 (ULRP, 2015). As part of the programme, several projects have been set up with international help, most notably in the form of cooperation with the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF) (UNEP, 2017). Another international collaboration is the 'Restoration of Urmia Lake via local community participation in sustainable agriculture and biodiversity conservation' project, established through the financial support of the Japanese government (CIWP, 2016). Furthermore, additional dam construction initiatives have been put on hold in the meantime. Currently, water prices are heavily subsidized in Iran, which leaves no incentives for farmers to increase water use efficiency. Furthermore, the government has limited control over groundwater abstraction, as there are huge numbers of illegal wells, highlighting a significant data gap. Current data collected around Urmia Lake do not include water consumption at the field level, and the limited data that exist are either out of date or deposited in inaccessible archives. Relying only on guesstimates for water consumption or availability is not good enough for Urmia Lake restoration purposes (ULRP, 2017). Well depth and pumping capacity are the only limiting factors for groundwater withdrawal. Farmers dig deeper and install larger pumps when the groundwater level drops; however, the groundwater situation in 2018 was extremely critical, with many wells left completely dry. Against this backdrop, a major objective of the ULRP is the enforcement of a 40% reduction in water use in the agricultural sector by revising water management and agricultural techniques over a five year period (ULRP, 2015, 2017); indeed, the agricultural sector utilizes about 90% of the water resources in the catchment area (Madani, 2014). However, to challenge all other climate and anthropogenic scenarios more drastic measures are needed (Shadkam et al., 2016).

Apart from the quantity of water used, local farmers seem to mismanage this valuable resource. For example, Mojarrad-Ashnaabad (2013) pointed out that the amounts of rainfall and water resources accessible in the Urmia Lake basin are higher compared to the required water volume for agriculture, because farmers allocate water according to their cultivation area instead of what is actually required by the crops. At the start of the season, farmers pay a water fee based on predetermined allocation rights, regardless of the actual amount used, and so naturally they consume as much water as possible, even though they might exceed actual crop needs. However, when irrigation water is unavailable, farmers tend to drill wells, whether legal or illegal. In downstream areas, where water is partly even less accessible, farmers pump water from nearby rivers into irrigation channels (ULRP, 2015, 2017), and consequently they are the main focal point for water resource management programs (Valizadeh et al., 2018).

Any restoration program needs field data and dynamic modeling that could predict the Lake response in a more reliable and conservative manner. Also, any practice with the aim of reducing water consumption in the basin is not only environmentally sustainable but also feasible from socioeconomic perspective. Despite the relative success of ULRP in environmental restoration of Urmia Lake in short term, it could not properly handle surface and groundwater resources and cultivation patterns with regard to ecology, water right reduction of croplands and reviving the tourism capacities. Actually, during last 3 years, LURP could not go forward according to predicted program, due to shortage of promised budget (Moatamedi et al., 2019). In May 2020, Urmia Lake water level rose the highest level during last decade; however, this increased level does not mean to stop concerns on this unique natural region in Iran and western Asia. Regarding the occurrence of drought and wet periods in semi-arid regions like Urmia Lake basin, desiccation of lake in the future is predictable, unlike the 2019-20 high precipitations and consequent water level rise.

A part of Urmia Lake shrinkage consequences are immediately visible such as high salinity of water, physical changes, bed appearance, beach strip retarding and tourism reducing. Nevertheless, some issues may be observed in long periods such as salt storms, health and socioeconomic topics. Furthermore, in long term, Urmia Lake water level reduction may affect negatively more distant provinces like Zanjan, Gilan, Ghazvin, Alborz, Tehran, Kermanshah, as well as, neighboring countries such as Turkey, Azerbaijan, Armenia, Iraq and even Syria, particularly via salt storms. Thus, authorities should consider these impacts in their long term national and international programs. Urmia Lake basin data such as soil moisture, snowpack, stream flow, reservoir capacities and climatic data facilitate good decision – making by providing verifiable information and avoiding speculative estimates of water availability. Furthermore, such data can be used to evaluate the current condition and to estimate the future status of the watershed.

Bathymetric data should be coupled with an evaluation of the salt quantities in order to accurately calculate volume to area ratios necessary to achieve optimal levels of salinity for the desired beneficial applications. The main objective should be to distinguish the most critical ecological elements of the lake ecosystem and then to regulate water demand for each element so that the elements may have a sustainable status (Abbaspour and Nazaridoust, 2007). To do so, it is need to construct selective embarkments across the lake for each ecological element to create different salinities for every section. On the other hand, there is a huge body of information and expertise on the *A. urmiana* that can be used to assist in the development of *Artemia* embayment in Urmia Lake.

Briefly, the management should elevate the water level up to 1274m, the ecological level (Fig. 1), to establish the lake ecosystem and to make the wetlands and the islands operate functionally. Major efforts should be directed at reduction of the basin's water demand in order to further deterioration of water resources can be avoided. To reach to such a level, agricultural management should direct the farmers toward to low water consumer crops cultivation and water meters should be installed for all wells in the lake basin. This is a great task and coordination among various sectors and stakeholder engagement are essential to developing sustainable solutions.

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