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Preserving the world second largest hypersaline lake under future irrigation and climate change

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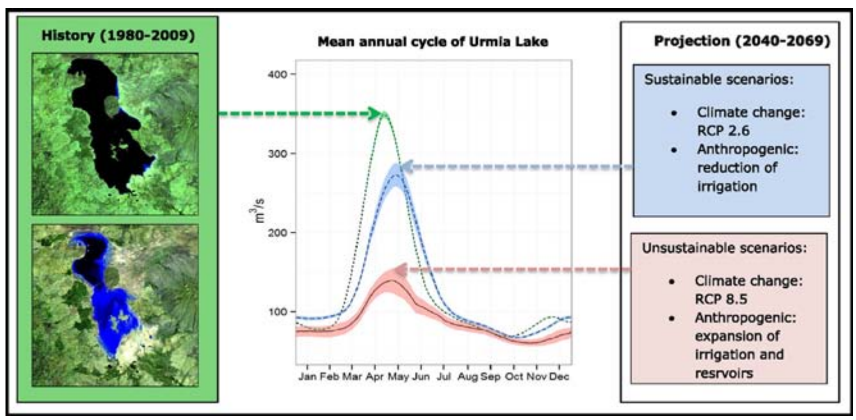
HIGHLIGHTS

- To restore drying Urmia Lake, the new official policy aims to increase inflow by cutting of irrigation water use substantially.
- Inflow to the lake was projected under the different climate and anthropogenic scenarios.
- Water availability in the basin will decrease under all climate change scenarios.
- The new policy can help to preserve the lake only under a very limited future climate change.
- To face all other climate and anthropogenic scenarios more drastic measures are needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Iran Urmia Lake, the world second largest hypersaline lake, has been largely desiccated over the last two decades resulting in socio-environmental consequences similar or even larger than the Aral Sea disaster. To rescue the lake a new water management plan has been proposed, a rapid 40% decline in irrigation water use replacing a former plan which intended to develop reservoirs and irrigation. However, none of these water management plans, which have large socio-economic impacts, have been assessed under future changes in climate and water availability. By adapting a method of environmental flow requirements (EFRs) for hypersaline lakes, we estimated annually $3.7 \cdot 10^9$ m^3 water is needed to preserve Urmia Lake. Then, the Variable Infiltration Capacity (VIC) hydrological model was forced with bias-corrected climate model outputs for both the lowest (RCP2.6) and highest (RCP8.5) greenhouse-gas concentration scenarios to estimate future water availability and impacts of water management strategies. Results showed a 10% decline in future water availability in the basin under RCP2.6 and 27% under RCP8.5. Our results showed that if future climate change is highly limited (RCP2.6) inflow can be just enough to meet the EFRs by implementing the reduction irrigation plan. However, under more rapid climate change scenario (RCP8.5) reducing irrigation water use will not be enough to save the lake and more drastic measures are needed. Our results showed that future water management plans are not robust under climate change in this region. Therefore, an integrated approach of future land-water use planning and climate change adaptation is therefore needed to improve future water security and to reduce the desiccating of this hypersaline lake.

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1. Introduction

To supply food and energy for growing populations, humans have developed reservoirs and extract water for irrigation (Biemans et al., 2011). Furthermore, climate change has a significant impact on the natural hydrological cycle and amplifies water scarcity in (semi)-arid regions (Haddeland et al., 2014; Fernandes et al., 2011; Santos et al., 2014). Consequently, managing water for a growing population without harming natural resources is becoming a serious challenge. In this paper, we assess this challenge in Urmia basin, where the second largest permanent hypersaline lake in the world is drying up (Karbassi et al., 2010).

Urmia Lake, in north-western Iran, is an important internationally recognized natural area designated as a RAMSAR site and UNESCO Biosphere Reserve (Eimanifar and Mohebbi, 2007). It is a home to many species along with a unique brine shrimp species (Asem et al., 2012). Urmia Basin supports a variety of agricultural production systems and activities as well as livestock. The basin is located in a politically tensed region bordering both Iraq and Turkey. It is linguistically and culturally diverse area dominated by two ethnic groups, Azeri Turks and Kurdish (Henareh et al., 2014).

Over the last 40 years, the water level and surface area of Urmia Lake have declined (Rokni et al., 2015) by 80% (AghaKouchak et al., 2015). As a result, the salinity of the lake has sharply increased which is disturbing the ecosystems, local agriculture and livelihoods, regional health, as well as tourism. (UNEP, 2012). Several studies have warned that the future of Urmia Lake could become similar to the Aral Sea, which has dried up over the past several decades and severely affected the surrounding people with windblown salt storms (Torabian et al., 2015). The population around Urmia Lake, however, is much denser compared to the Aral Sea and many more people are at risk (UNEP, 2012). Local reports have indicated that thousands of people around the lake have already abandoned the area (RadioFarda, 2014). It has been estimated that people living within 500 km^2 of the Lake location, are at risk (Torabian et al., 2015), which could amplify economic, political and ethnic tensions in this already volatile region (Henareh et al., 2014).

Previous studies have indicated that the lake desiccation is probably caused by a combination of human activities and climate change (AghaKouchak et al., 2015; Fathian et al., 2014; Hamzekhani et al., 2015; Hassanzadeh, 2010; Jalili et al., 2015). The area of the agricultural lands has more than tripled over the last 40 years supported by a considerable number of reservoirs and a large irrigation network (Iran Ministry of Energy et al., 2014). There has also been a significant decrease in precipitation and an increasing trend in average maximum temperature during the same period (Fathian et al., 2014; Delju et al., 2013). This has caused the most extreme droughts in the basin over the last few decades during the mid-1990s (Tabari et al., 2013). These trends have affected the inflow into the lake (Fathian et al., 2014) which has been recognized as the main reason of the lake shrinkage (Hassanzadeh et al., 2012). Some studies have estimated how much water is needed to restore and protect the ecology, water quality and quantity of the lake (Abbaspour and Nazaridoust, 2007). However, they have not included the important role of climate change which is likely to reduce the precipitation and run-off in both near-term (Kirtman et al., 2013) and long-term future (Collins et al., 2013).

To secure enough food and income for a growing population in the basin, the initial government water resources plan intended to increase the irrigated area by 25% supported by additional dams and reservoirs. More recently, a new plan has been proposed aiming to restore and preserve Urmia Lake. This plan proposes to stop all reservoir developments and reduces irrigation water allocation by 40%. However, it is still unclear if the water use reduction plan, which is about to start and has large socio-economic impacts, is able to restore and preserve the lake under future climate change.

The main objective of this study was to assess the impacts of future water resources management plans under climate change on the water inflow into Urmia Lake during the 21st century. To address this objective we first developed a method to estimate the annual and monthly environmental flow requirement (EFRs) to preserve vulnerable hypersaline lake ecosystems especially in a lack of precise ecological data. By applying the method, we quantified how much water is needed to preserve Urmia Hypersaline Lake. Then, we developed future projections of total inflow into the lake, using the Variable Infiltration Capacity (VIC) hydrological model (Liang et al., 1994), including an irrigation and reservoir module (Haddeland et al., 2006; Haddeland, 2006). The model was forced with statistically bias-corrected General Circulation Models (GCMs) outputs from a low and high representative concentration pathways (RCPs) (Moss et al., 2010). In addition, to study the impact of the water resources plans on the future inflow, the two proposed plans plus the current, and the naturalized (without any irrigation and reservoirs) situations were applied in the model. The simulated inflow was compared with the annual and monthly estimated EFRs to assess the possibilities of Urmia lake restoration and preservation under different climate change and anthropogenic scenarios.

2. Study area

Urmia Lake is formed at the lowest point within the closed Urmia basin (UNDP, 2014). The area of the lake has reduced from ~6100 km^2 in 1995 to ~1500 km^2 in 2014 (Fig. 1) followed by >7 m decline in the water level (Supplementary Information S1). The lake is relatively shallow (maximum depth 16 m) and thus vulnerable to evaporation (Meijer et al., 2012). There are 17 permanent rivers and 12 seasonal rivers which terminate at Urmia Lake. The average inflow into the lake has declined from around 12,000 to $2400 \cdot 10^6$ m^3 over the last five decades. The mean annual precipitation is 341 mm $year^{-1}$ which has decreased by 9.2% over the last 40 years (Delju et al., 2013).

3. Materials and methods

The methodological framework for this study is shown in Fig. 2. Future scenarios for daily flow into the lake were calculated using the VIC hydrological model forced by bias-corrected outputs from five GCMs, using the representative concentration pathway (RCP) 2.6, lowest; (Van Vuuren et al., 2011) and 8.5, highest; (Riahi et al., 2011), for 2010–2099 and for 1971–2000 (control) in combination with four different anthropogenic scenarios (40 simulations). Historical naturalized inflow from the control period was used to estimate annual and monthly environmental flow requirements (EFRs). To assess the significant impact of water resources plans and the climate change impact, the paired two-tailed Student's t-test was used, P values of <0.05 were considered significant.

3.1. Hydrological model

The VIC model is a grid-based soil–vegetation–atmosphere transfer schemes model (Liang et al., 1994; Nijssen et al., 2001b; Nijssen et al., 1997). The input data are daily precipitation, maximum and minimum temperature and wind speed. Each grid cell is divided into multiple vegetation types and into multiple soil layers. Evapotranspiration is calculated using the Penman-Monteith equation. The simulated surface streamflow and baseflow, combined referred as inflow in this paper, are routed from each grid cell to the basin as described by Lohmann et al. (1998a, 1998b)). The VIC model, like most land surface models, does not consider deep groundwater withdrawals (Haddeland et al., 2007), which therefore are not taken into account in this study. The model has been widely used for streamflow studies globally (Nijssen et al., 2001a; Vliet et al., 2013) and for major river basins, as well as for other basins of the world like Europe, the US, and China (Hurkmans et al., 2008; Vliet et al., 2012; Wu et al., 2007; Xie et al.,