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Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model

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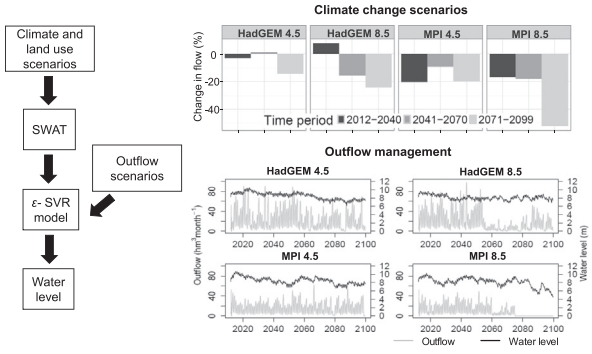
HIGHLIGHTS

- Climate change would augment water scarcity problems in Mediterranean catchments.
- Future water level changes was simulated by linking SWAT model to ε-SVR model.
- Climate change has a major impact on hydrology while effects of land use are minor.
- Outflow management is critical to prevent Mediterranean lakes from diminishing.

GRAPHICAL ABSTRACT



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ABSTRACT

Inter- and intra-annual water level fluctuations and changes in water flow regime are intrinsic characteristics of Mediterranean lakes. Additionally, considering climate change projections for the water-limited Mediterranean region, increased air temperatures and decreased precipitation are anticipated, leading to dramatic declines in lake water levels as well as severe water scarcity problems. The study site, Lake Beyşehir, the largest freshwater lake in the Mediterranean basin, is – like other Mediterranean lakes – threatened by climatic changes and over-abstraction of water for irrigated crop farming. Therefore, implementation of strict water level management policies is required. In this study, an integrated modeling approach was used to predict the future water levels of Lake Beyşehir in response to potential future changes in climate and land use. Water level estimation was performed by linking the catchment model Soil and Water Assessment Tool (SWAT) with a Support Vector Regression model (ε-SVR). The projected increase in temperature and decrease in precipitation based on the climate change models led to an enhanced potential evapotranspiration and reduced total runoff. On the other hand, the effects of various land use scenarios within the catchment appeared to be comparatively insignificant. According to the ε-SVR model results, changes in hydrological processes caused a water level reduction for all scenarios. Moreover, the MPI-ESM-MR General Circulation Model outputs produced the most dramatic results by predicting that Lake Beyşehir may dry out by the 2040s with the current outflow regime. The results indicate

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that shallow Mediterranean lakes may face a severe risk of drying out and losing their ecosystem values in the near future if the current intensity of water abstraction is not reduced. In addition, the results also demonstrate that outflow management and sustainable use of water sources are vital to sustain lake ecosystems in water-limited regions.

1. Introduction

Global warming is expected to increase the frequency of extreme climatic events such as droughts, floods, and heat waves in Europe (Beniston et al., 2007; Kovats et al., 2014; Lehner et al., 2006). The Mediterranean region already suffers from water scarcity and episodes of droughts due to intensive water use and the natural intrinsic climatic characteristics (Chenini, 2010). Additionally, significant changes in freshwater availability are expected to occur with the ongoing climate change. Climate projections for the Mediterranean region predict a significant decrease in precipitation (Christensen et al., 2013; Erol and Randhir, 2012) and enhanced temperatures, which would result in an increase in the number of dry days and more frequent heat waves (Christensen et al., 2013; Giannakopoulos et al., 2009). Evaporation from water surfaces and evapotranspiration from land surfaces caused by higher temperatures may lead to a further decrease in water availability (Calbó, 2010) and thus reinforce the existing water scarcity problems in the region.

Apart from climate forcing, land use influences the water and energy balance in watersheds through its effects on infiltration, evapotranspiration, and surface runoff (Liu et al., 2014; Mao and Cherkauer, 2009). Disruption of natural vegetation (for instance, forests) and an increase in urbanized areas generally trigger an increase in surface runoff (Foley et al., 2005), whereas an extension of agricultural areas often decreases surface runoff (Calder, 2007; Hibbert, 1967). With the substantial changes in land use since 1900, noticeable increase in surface runoff has been observed worldwide (Piao et al., 2007). In addition to the direct effects of land use change, increased water abstraction for agriculture is one of the major threats to the freshwater ecosystems, rendering them highly vulnerable to the effects of climate change (Erol and Randhir, 2012). In Southern Europe, agriculture is the major water-using sector with a total freshwater abstraction share of 80% (EC, 2009). Thus, increased abstraction may lead to significant water level reductions (Beklioglu et al., 2007; Beklioğlu et al., 2006; Stefanidis and Papastergiadou, 2013). This may have a particularly strong effect on shallow lakes due to their high surface area/depth ratio (Coops et al., 2003). The ultimate result may be a complete drying out as exemplified by the drying out of one of the largest freshwater lakes in Turkey, Lake Akşehir (343 km^2), due to a major water diversion of its inflows for the purpose of intensive irrigation of croplands (Bahadır, 2013; Çatal and Dengiz, 2015; Sener et al., 2010). Further threats to the lakes are expected due to climate change-induced reduced water availability in summer, leading to increased irrigation in Southern Europe (Kalogeropoulos and Chalkias, 2013; Kovats et al., 2014). In addition, the projected demographic changes in the Mediterranean region, including increased population growth, summer tourism (Rico-Amoros et al., 2009) and urbanization, are expected to intensify the water usage by expanding the demands for agricultural products.

Water scarcity and frequent drought periods are likely to have high economic costs (Milano et al., 2013). During the last 20 years, droughts have created a significant economic deficit in the Mediterranean catchments (Erol and Randhir, 2012). This emphasizes the need to implement measures that maintain water sources and ensure sustainable water usage in order to meet the future water demands from different sectors (agriculture, human settlement, ecosystem need, energy, etc.) (Kovats et al., 2014). The cost of inaction and/or taking reactive actions would be much higher than those associated with adopting proactive measures (Collet et al., 2015; Palmer et al., 2008).

In this study, Lake Beyşehir, which is the largest freshwater lake in the Mediterranean basin and situated in the Western Taurus karstic region, was chosen to function as a model for Mediterranean lakes subjected to intense water use and climate change. Since the Mediterranean region is one of the most vulnerable regions in the world and its freshwater ecosystems are highly regulated, sustainable water management is crucial to preserve the water bodies and meet the water demand of society. Water scarcity issues are not limited to the Mediterranean basin; other parts of the world with a Mediterranean-type climate, such as south-west Australia (Reisinger et al., 2014), South Africa (Niang et al., 2014), and California (Romero-Lankao et al., 2014), all face similar issues, preventing water demands from being met in a projected future warmer climate. Hence, the aim of this study is to elucidate how multiple stressors – like climate change, land use, and water abstraction – will impact the future water availability and water levels in Mediterranean water bodies. This study not only contributes to the still limited number of climate change impact studies on Turkish and Mediterranean catchments, but it also presents a modeling framework for assisting water managers in planning mitigation strategies in the region. The knowledge gathered may provide insight into the development of sustainable systems for lake and reservoir management, bearing in mind the uncertainties in climatic predictions and how these relate to water availability and lake levels.

The main objectives of this study are: i) to quantify the effects of the projected changes in climate and land use on the water availability in the catchment of the largest freshwater Mediterranean lake, Lake Beyşehir, ii) to evaluate the effects of the projected climate and land use scenarios on the lake water level, iii) to offer outflow management options by predicting the maximum outflow (maximum abstraction loss) permitted for maintenance of natural lake water levels as a viable adaptation measure to climate change.

2. Material and methods

2.1. Study site

Lake Beyşehir (area: 650 km^2, max. depth: 8–9 m, mean depth: 5–6 m) is located in Isparta and Konya provinces in the southwestern part of Turkey (between 31° 17′–31° 44′ E, 37° 34′–37° 59′ N). The lake has had a Natural Site protection status since 1991 and is surrounded by two National Parks (the Beyşehir and Kızıldağ National Parks, Republic of Turkey, Ministry of Forestry and Water Affairs). The lake is also an "Important Bird Area" (BirdLife International, 2015), an "Important Plant Area" (PlantLife International, 2015), and it hosts the endemic fish species *Chondrostoma beysehirense* Bogutskaya, 1997 and *Pseudophoxinus anatolicus* Hankó, 1925. Until recently, it also functioned as a habitat for the extinct endemic species *Alburnus akili* Battalgil, 1942 (Yeğen et al., 2006).

The catchment area of the lake is 4704 km^2 and includes an upstream area of the Konya Closed Basin (area: 49,805 km^2, population size: 2.6 million) (Ayaz, 2010) (Fig. 1). The lake is the main water source for irrigated crop farming in the Konya Closed Basin. The catchment is situated in the transition zone between the Mediterranean and continental climates (average temperature: 11 ± 0.7 °C, yearly precipitation 490 ± 94 mm, calculated from measurements conducted by the Turkish State Meteorological Service in the Beyşehir district during 1960–2012). The catchment has a highly variable topography and land use characteristics. The elevation ranges between 1027 and 2958 m.a.s.l., with an

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