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Spatiotemporal monitoring of Bakhtegan Lake's areal fluctuations and an exploration of its future status by applying a cellular automata model

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ABSTRACT

Recent developments of geospatial technologies and models have provided environmentalists and naturalists with a wide variety of facilities and approaches for improved monitoring and management of environmental resources. Rich temporal remote sensing datasets, e.g., Landsat imagery as well as geospatial modeling techniques, facilitate the process of monitoring and modeling environmental phenomena. The main objective of this paper is to monitor the spatiotemporal patterns of fluctuations of a dynamic lake in the south of Iran – Bakhtegan Lake – which has been influenced by extreme climate change conditions. To do so, a temporal coverage of 12 Landsat images from 1973 to 2013, was used to delineate the boundaries of the lake over time and analyze the occurred changes. Next, a cellular automata (CA) approach was adopted for simulating two main processes: 'lake expansion' and 'lake shrinkage'. The CA model was then calibrated based on a statistical comparison of the simulated and actual images of one timestamp. Application of Kappa index analysis measures the performance of the model at a value of 83 percent. The calibrated CA model was then applied and the future status of the lake (by 2017) was modeled; this suggested a further 45 percent shrinkage in addition to its recent 42 percent shrinkage. In conclusion, the socio-ecological impacts and consequences of the lake's fluctuations are discussed in detail and some complementary recommendations are proposed.

1. Introduction

Surface water bodies are a key component of a wide variety of ecosystem services, e.g., water supply and purification, flood regulation and climate balance, and coastal protection (e.g., Baker et al., 2007; Bwangoy et al., 2010). In recent years, these water bodies have been significantly affected by global warming and climate change, and this has been exacerbated by land use/cover changes increasing the speed of decline (Finlayson et al., 2013). Our official records of wetlands and surface water resources are based on previously recorded maps of one timestamp in particular while at their maximum extents (Zedler and Kercher, 2005; Alesheikh et al., 2007; Bai et al., 2012; Ahmet Sesli, 2010; Nath et al., 2010). While researchers, practitioners and planners still rely on the official records, the actual records might be significantly different (Alsdorf, 2003; Dassenakis et al., 2012). This issue is even more crucial when it comes to arid and semi-arid regions of the world (Hui et al., 2008; Hutti and Nijagunappa, 2011; Johnson et al., 2012), as they have recently been greatly influenced by the extreme climate change conditions and the surface water bodies vary greatly (Haas et al., 2009; Deus et al., 2013).

Accessing data relating to the latest status of water bodies in these regions has always been a challenge, because the surrounding environment, climate and biodiversity are all directly influenced. Hence, it is of great importance to acquire a full archive of these changes for environmental management and planning purposes (Hesslerová et al., 2010; Jokar Arsanjani et al., 2014). Certainly, applying surveying techniques for measuring the extent

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of surface water bodies is often time consuming and costly, and therefore limits our ability to update their status on a regular basis (Maillard et al., 2011). Therefore, the importance of satellite images and remote sensing techniques, as an affordable and useful alternative for mapping and monitoring water resources, in comparison with traditional hydrology/surveying-dependent methods, becomes evident (Zhang et al., 2006; Plattner et al., 2006; Tulbure and Broich, 2013). Thanks to advances in remote sensing imageries and signal processing algorithms, accessibility to satellite images (even high spatial/temporal resolution images), along with use case applications, has been widely available (e.g., Maillard et al., 2008). Landsat imagery is one of the most supportive examples in which the full coverage of its archive has been released to the public for any application without restrictions (Vaz and Bowman, 2013; Vaz, 2014). More importantly, this archive, which was created in 1972, has been enriched through the launch of the latest Landsat mission, equipped with the so-called OLI sensor, in mid-2013 (Zhu et al., 2014; Roy et al., 2014). In other words, with the exception of a few time periods, the world has been spectrally and digitally recorded for over 42 years. In addition to the images themselves, a wide variety of products and indices for extracting different features has been provided by several institutions such as the United States Geological Survey (USGS) (Loveland et al., 2012; Irons et al., 2012; Kovalskyy et al., 2013).

The Middle East region, and in particular Iran, has been one of the hotspots most affected by the impacts of global warming, and it has been indicated as one of the most vulnerable areas to climate change augmented by the recent reductions in rainfall (Zarghami, 2011; Pengra, 2012). There has been considerable concern at national, regional and international levels regarding the preservation of significant biodiversity values (Hoseinpour et al., 2010; Pengra, 2012). These evident impacts on the two largest inland lakes of Iran – namely Urmia and Bakhtegan – have been recognized by researchers and practitioners, and local residents (Soltani et al., 2005; Abatzopoulos et al., 2006; Amoozegar et al., 2007; Eimanifar and Mohebbi, 2007; Karbalaei-Heidari et al., 2007; Garousi et al., 2013). While Urmia Lake has become the center of attention, Bakhtegan Lake is also suffering from an extensive reduction in its area, depth, habitats, and ecological heritage (Golabian, 2010; Karimi and Mobasheri, 2011).

Hence, the main objective of this study is to monitor the spatiotemporal patterns of fluctuations in Bakhtegan Lake, Iran, using Landsat images, and to apply a cellular automata model for simulation of the fluctuations over time in order to predict its future status. In order to achieve this aim, the following research questions will be addressed:

- Considering the extreme drought conditions in Iran, how does the temporal evolution of the areal fluctuations of the lake appear?
- How efficiently can the spatiotemporal variations be monitored through satellite images?
- How effectively can the future patterns of the fluctuations be predicted through adopting a cellular automata model?
- Which contributions to the investigation of societal and ecological consequences of such a phenomenon could be given by this study?

The importance of this study can be highlighted through the following issues: (a) while climate change and its extreme impacts on the environment are evidently visible (Nazemosadat et al., 2000; Qiu et al., 2012; Rahmani et al., 2013; López-Moreno et al., 2013; Marquès et al., 2013; Kiem et al., 2013; Akhoond-Ali et al., 2013), a temporal trend analysis of the fluctuations definitely assists in quantifying the pace of change across space and time, specifically when a rich archive of satellite images is utilized; (b) quantitative analysis of the spatiotemporal patterns of changes supports the development of simulation frameworks for modeling the past and future patterns; (c) application of predictive simulation models for projecting the future conditions of the environmental phenomena is sparse, and further attention to model development, calibration, and application should be drawn; (d) in doing so, environmentalists, land-use planners, hydrologists, and ecologists are informed about the impacts and consequences of such a phenomenon as outlined in the United Nations Environment Programme (2012).

The remainder of this paper is organized as follows. Section 2 introduces the materials. Section 3 explains the used methods. Section 4 discusses the empirical results, and finally, Section 5 highlights major conclusions and outlines recommendations for future research.

2. Materials

2.1. Case study

In this study, Bakhtegan Lake is selected, which is the second largest lake in Iran, after Urmia Lake, and is located in the north-eastern part of the Fars Province at an altitude of 1500 m above sea level. This lake is located between latitude N29.24° to N29.55° and longitude E53.55° to E54.17°. It is fed by the Kor River, but the construction of several dams has considerably reduced water input into the lake. From an ecological perspective, along with increasing its salinity, this has also caused the population of migratory bird species to become endangered. Furthermore, the generated humidity from the lake plays a vital role in the surrounding dry farming. Bakhtegan Lake is part of the protected Bakhtegan National Park – in which a diverse range of birds and animals live. Fig. 1 illustrates the study area.

2.2. Data source

A query regarding the availability of Landsat satellite images was delivered to its official data provider – the USGS – and 10 images of wet seasons and 2 images of dry seasons, which are cloud free with high signal/noise ratio, were ordered and accordingly collected. An archive of satellite images of Landsat, for 40 years from 1973 to 2013, was collected. Additionally, the digital elevation model (DEM) provided by Advanced Spaceborne Thermal Emission and Reflection (ASTER) within 2002–2006 was ordered and collected. It should be noted that the collected images are geometrically and radiometrically corrected. Table 1 illustrates the characteristics of the images.

3. Methods

As outlined in Fig. 2, the workflow consists of two main parts. While the first stage attempts to provide a time series of the spatiotemporal patterns of the lake's areal extent, and to analyze its historical patterns, the second stage comprises the CA model for predicting the future status of the lake's fluctuations.

Within the first step, a temporal coverage of satellite images (Path: 162, 174, Row: 39, 40), at 30-m pixel size, along with ASTER DEM, at 30-m pixel size, were collected and stored. The extent of the study area was clipped from the images. Thereafter, the tasseled cap analysis was applied in order to produce the following indices: *greenness, wetness,* and *brightness*. The reasons for applying the tasseled cap transformation are as follows: (a) it has been widely used for the mapping of vegetation and water bodies and the detection of land-cover change (Cohen and Spies, 1992; Collins