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Classification of hydrological conditions to assess water allocation schemes for Lake Baiyangdian in North China

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SUMMARY

In this study an assessment framework based on analysis of water level fluctuations (WLFs) is presented to classify hydrological conditions and investigate the effect of recent water allocation to the lake of Baiyangdian. Good, moderate, and bad hydrological conditions in dry and wet periods are identified respectively using this framework. Annual average water level (AAWL) of moderate hydrological conditions is considered as the annual minimum water level (AMWL). The trend and determined range of intra-annual WLFs are estimated based on monthly optimum water level (MOWL) and monthly minimum water level (MMWL). Both estimated AMWL and intra-annual WLFs are compared respectively with AAWL and intra-annual WLFs observed in the corresponding year in order to assess recent water allocation schemes. Results show that in Lake Baiyangdian, a 16-year periodic component with alternation of dry and wet periods is found in the time series of water levels for 55 years. In dry period, the AMWL is 7.50 m with the determined range of intra-annual WLFs from 0.93 m to 1.04 m. While in wet period, the AMWL is 7.76 m with the determined range varying from 1.35 m to 1.56 m. The trend of intra-annual WLFs deduced by MMWL indicates that in both periods the maximum and minimum values of water levels appear in September and June, respectively. Assessment results suggest that recent water allocations for Lake Baiyangdian are irrational. Although, in some years, AAWL is higher than AMWL, ignorance of trend and determined range of intra-annual WLFs undermine the effects of water allocation. This framework can be used as a preliminary management tool for water allocation in degraded lakes.

Introduction

Water level is a useful indicator in lake management practices (O'sullivan and Reynolds, 2004). Low water level often results in reduction of marginal zones around the lake and leads to serious damages to aquatic species. Sellinger et al. (2008) found that the decline of water level could deteriorate the whole lake and lead to serious ecological degradation. In addition, some researchers (Riis and Hawes, 2002; Chow-Fraser, 2005; Hofmann et al., 2008; Wang and Yin, 2008) reported that water level fluctuations (WLFs), varying from short-term to intra-annual, and long-term (e.g. inter-annual, inter-decadal) time scale, affected the composition and diversity of aquatic species. Lakes with little range of intra-annual WLFs tend to have narrow, poor fringe habitat with low biodiversity. Fringe areas of this kind of lakes often transforms rapidly from aquatic ecosystems to terrestrial ones which lead to significantly negative impacts on lake ecosystems (Coops and Hosper, 2002; Coops et al., 2003; Hawes, 2003; Hudon, 1997; Wei and Chow-Fraser, 2006). A New Zealand study (Riis and Hawes, 2002) also reported that long-term WLFs played the same role in maintaining high level of species richness as intra-annual WLFs did. As a result, a scheme considering the effects of water level and WLFs (both in intra-annual and long-term scale) for water allocation is required to improve the hydrological and ecological conditions of degraded lakes.

Water allocation for a lake is to allocate water as closely as possible to its natural regime to maintain particular ecological characteristics which are able to provide important goods and services (Ramsar Convention Secretariat, 2007). It is widely recognized that water allocation for aquatic ecosystem should take natural variability of hydrological conditions into consideration because they are deterministic factors influencing geomorphology, habitat quality, water quality, as well as biodiversity of lakes (Smakhtin et al., 2004; Mitsch and Gosselink, 2007). Methodologies initially developed for rivers were employed to calculate the amount of water allocated to lakes. These approaches include relative simple and rapid ones such as Tennant method and more comprehensive ones (e.g., Desktop Reserve Model) (Tennant, 1976; Hughes and Hannart, 2003; Tharme, 2003; Kashaigili et al., 2007; Mazvimavi et al., 2007; Shang, 2008; Smakhtin and Eriyagama, 2008). Recently, there is an increasing awareness of the necessity of

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restoring hydrological conditions in restoration of wetlands and lakes. Sima and Tajrishy (2006) classified water allocation for wetlands into three levels. These levels corresponded to hydrological conditions represented by wetland water surface at the probability exceedance of 90%, 80%, and 60%, respectively. Dunn and Roach (2001) concluded that water level in wetlands should be maintained at an appropriate level to preserve or create desired hydrological conditions. Munson et al. (2005) and Neubauer et al. (2008) recommended that the concept of minimum water levels was required to protect lake and wetland systems from significant damage. By assuming that the time series were stationary in long-term scales, they determined the minimum water levels based on water levels, duration (days) and return interval (years). However, since water level has multi-scale and non-stationary characteristics in the entire time series (Chow-Fraser, 2005), this method fails to consider the fact that minimum water levels may vary due to long-term WLFs.

A new methodology is required to analyze WLFs over different time scales in order to better analyze available information to assess and optimize water allocation for degraded lakes and wetlands. This method should take into account the management of water levels over a certain time scales or at a certain time period. Wavelet analysis is considered as an efficient tool for detecting temporal characteristics of hydrological time series (Labat et al., 2000, 2005; Labat, 2008; De Jongh et al., 2006; Pasquini et al., 2006, 2008; Lane, 2007). It provides useful scale-frequency decomposition for hydrological time series and the observed variations (i.e. waveform at an individual time scale) in different time scales. Thus, it can be used in hydrological condition classification.

Hydrological conditions in this paper are described by water level, inflow, outflow, rainfall, as well as evaporation. Among these components, water level is the one that can reflect hydrological conditions directly (Coops et al., 2003; O'sullivan and Reynolds, 2004). Recently, abrupt falling of water level in Lake Baiyangdian was observed, indicating possible damages to aquatic ecosystem (Zhong et al., 2008). In this study, WLFs are systematically analyzed to reflect hydrological condition change based on wavelet method. This research can provide a description of characteristics of WLFs in depth, and determine appropriate hydrological conditions for water allocation and management. Compared with traditional method in water allocation in which goals were set subjectively, this study uses natural hydrological conditions associated with ecological information to assess and direct water allocation practices, which can be handled more scientifically and efficiently. The assessment framework developed in this study can be used in water management of degraded aquatic ecosystems in the future.

The objective of this paper is to assess different water allocation schemes for Lake Baiyangdian based on classifications of hydrological conditions obtained from wavelet analysis. Sub-objectives of this research are to (1) analyze natural WLFs at temporal scales and then classify hydrological conditions using wavelet analysis; (2) determine the annual minimum water level (AMWL) and appropriate intra-annual WLFs for water allocation management; and (3) develop an effective assessment method for water allocation.

Methodology

Study area

Lake Baiyangdian is one of the biggest lakes in North China (Fig. 1). It is located in the middle of Hebei province, with a surface area of 366 km^2 and an average water depth of 2.5 m (CCLCAC, 2000). The climate in this region is characterized as temperate continental monsoon climate with an annual average rainfall of 510 mm and evaporation of 1690 mm. The major water source of this lake comes from upstream of the Daqinghe watershed.

Over last decades, human activities significantly deteriorated hydrological conditions in this area. High water level of the lake occured in 1950s and provided a suitable habitat for a variety of species. After that, due to construction of dams and reservoirs upstream, water level was greatly influenced by human activities, resulted in the decline of water levels and deterioration of ecosystem in Lake Baiyangdian (Zhong et al., 2008). Lowest water level of the lake was recorded in 1980s. In order to restore degraded ecosystem, great amounts of water (about 6.83×10^8 m^3 over 16 times from upstream reservoirs) was allocated to the lake by local government from 1992 to 2005.

Data sources

Monthly average water level (MAWL) data in Lake Baiyangdian from 1951 to 2005 were obtained from Anxin Water Conservancy Bureau. Data for annual rainfall and evaporation from 1954 to 2005 were recorded by Anxin Meteorological Station. Annual inflow (annual surface water inflow into the lake) and outflow data between 1951 and 2005 were collected from Anxin Annals. The time series of water levels was analyzed using wavelet analysis to characterize temporal fluctuation and classify hydrological conditions. Mean value, standard deviation (SD), and coefficient variation (CV) of aforementioned data were calculated in order to compare characteristics of different hydrological classes. Since only few ecological data were available in the study area, species richness, represented by total number of species obtained from previous studies (Jin et al., 1995; Zhang et al., 1995; Cao et al., 2003; Gao, 2008), was classified as high, moderate and low levels to reflect ecosystem conditions and verify the rationality of hydrological condition classification.

Assessment framework of water allocation to a lake

A flow chart to assess water allocation is illustrated in Fig. 2. Considering the water level associated with inflow, outflow, rainfall and evaporation time series, as well as species richness, hydrological conditions of Lake Baiyangdian were classified into good, moderate, and bad ones in both dry and wet periods. Recent water allocation practices were assessed in this framework. The first step is to determine hydrological conditions of the lake according to the fluctuation of real part of wavelet coefficient in dominant periodicity component obtained from wavelet analysis. Hydrological factors in corresponding period will be identified after that. For annual average water level (AAWL) and intra-annual WLFs in one study year, if one of them fails to meet the corresponding estimated values, the water allocation scheme will be considered as an irrational one (Fig. 2). The related step given in Fig. 2 will be explained in the following sections.

Classification of hydrological conditions

Hydrological conditions were classified based on WLFs over a long period. The continuous wavelet transform, which is a basic tool of wavelet methods, was used to analyze the temporal variability of water levels by deducing wavelet coefficient at different temporal resolutions (Labat et al., 2000; Lafrenière and Sharp, 2003; Labat, 2005). Morlet wavelet, as a common used function in the continuous wavelet transform, was applied to detect both location-dependent amplitude and phase for different frequencies exhibited in time series, since it can better describe the variance of hydrological time series and provide good frequency resolution as well as temporal resolution compared with other wavelets (Chou, 2006; Cazelles et al., 2008; Si, 2008).