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Examining the influence of river–lake interaction on the drought and water resources in the Poyang Lake basin

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SUMMARY

In recent years, the Poyang Lake basin is in a prolonged drought which has placed immense pressure on the water resources utilization. In this paper, we explore the spatial and temporal distributions of extreme droughts in the Poyang Lake basin by using the methods of SPI (Standardized Precipitation Index) and EOF (Empirical Orthogonal Function) for the period of 1956–2009, which are influenced by regional precipitation anomalies and river–lake interaction due to water impounding of the Three Gorges Dam (TGD). The results show that: (1) the Poyang Lake basin experienced six extreme droughts during the past 60 years, which lead to decreases in streamflow from five tributary rivers down to the Poyang Lake. The droughts in the 1960s and the 2000s were the most serious ones. However, there was an increasing trend of streamflow in the upper and middle Yangtze in the 1960s, and a decreasing trend appeared in the 2000s. The decline of streamflow in the upper Yangtze reaches has lowered the water level of lower Yangtze River which has caused more outflow from the Poyang Lake to the Yangtze River; (2) the operation of the Three Gorges Dam (TGD) has altered the seasonal pattern of flow regimes in the Poyang Lake and significantly reduced the water level in the lower Yangtze River during the TGD impounding period from late September to early November; and (3) the conjunction of extreme droughts in the Poyang Lake and the upper Yangtze reaches coincided with the impounding of the TGD is the main cause of the low water level in the Poyang Lake. Although the impact of the recent droughts in the Poyang Lake and upper Yangtze reaches has played a crucial role in the low water level of Poyang Lake, more attention should be paid to its sensitivity to the influence of the large dam-induced changes in the interaction between river and lake, particularly during impounding periods.

1. Introduction

"Drought" as a natural hazard is mainly caused by large-scale climatic variability while water scarcity is more a result of human influence. Making the distinction between them is not trivial because they often occur simultaneously (Van Loon and Van Lanen, 2013). Evaluation of drought conditions in a particular area is the key step for planning water resources. Numerous drought indices have been developed to monitor droughts (Rossi et al., 2007), including the worldwide used indices of the Standardized Precipitation Index (SPI, e.g. Mckee et al., 1993; Zhang et al., 2012; Portela et al., 2015), the Normalised Flow Index (NFI, e.g. Gosling, 2014), the Reconnaissance Drought Index (RDI, e.g. Takiris and Vangelis, 2005; Rahmat et al., 2015), and the Palmer Drought Severity Index (PDSI, e.g. Palmer, 1965). These indices have been developed to evaluate the water supply deficit in relation to the time duration of precipitation shortage. However, the characteristics of drought in different climate zones may be different. A standardized index is often used to compare drought conditions in different areas. For example, the Standardized Precipitation Index (SPI) is one of the most powerful indices which can be

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computed on different time scales (Bordi and Sutera, 2007). The SPI has been used in many studies (e.g., Hayes et al., 1999; Bordi et al., 2004; Chen et al., 2009; Zhang et al., 2011b) and it has proved to be a useful tool in the estimation of the intensity and duration of drought events (Bordi et al., 2004). SPI was also applied to examine the effects of large dam on hydrological droughts by comparing the drought index before and after the dam construction (Cancelliere et al., 1998; López-Moreno et al., 2009; Lorenzo-Lacruz et al., 2010).

Poyang Lake, China's largest freshwater lake, is located on the southern bank of the lower Yangtze River. The water level of the Poyang Lake depends on watershed runoff from the five tributary river basins and the water exchanges with the Yangtze River (Li et al., 2015a; Zhang et al., 2014). It varies greatly both in area and volume with seasonal and inter-annual changes. The lake level is elevated to the extent that all floodplains are inundated, thus forming a vast lake. In the drier season, lake level declines and lake water recedes into sublacustrine channels and the floodplains are exposed, resulting in the lake surface almost dwindling to a meandering line. At the moment, the Poyang Lake is effectively just a river channel (http://www.jxsl.gov.cn/).

The impact of climate variability and change on the Poyang Lake outflows, particularly on the floods, has been extensively studied (e.g., Jiang and Shi, 2003; Shankman et al., 2006; Guo et al., 2008; Zhang et al., 2011a; Zhao et al., 2010; Li et al., 2015b). Different conclusions have been drawn by previous studies which were undertaken at different time and used different methods and data. The river–lake interaction related to flood storage ability of the lake and TGD was investigated by Nakayama and Shankman. (2013a), and they pointed out that the TGD will increase flood risk during the early summer monsoon, in contrast to the original justifications for building the dam, due to complex river–lake–groundwater interactions. Hu et al. (2007) reported that basin effect (basin discharge generated by rainfall) has played a primary role influencing the water level of Poyang Lake and development of severe floods, while the Yangtze River played a complementary role of blocking outflows from the lake. Zhang et al. (2011a) also found that the occurrence of water intrusion from the Yangtze River to the Poyang Lake was heavily influenced by hydrological processes of the Poyang Lake basin. Guo et al. (2011) found that the Poyang Lake has the largest outflow to the Yangtze River and exerts a strong pressure on the mainstream during April–June, and the Yangtze River's blocking and/or reversed flow to the Poyang Lake are the strongest during July–September.

Currently, the most severe droughts in the Poyang Lake basin have drawn people's attention to the water resources shortage problem along the lower reaches of the Yangtze River. The lower reaches of the Yangtze River, covering eight provinces of both Central and Southern China, are usually considered to be an area with relatively abundant water resources. However, the continuous droughts in this region have changed this situation and the Poyang Lake is facing the danger of water shortage. The precipitation in this region during November 2010–May 2011 was the lowest in the past 60 years. The Poyang Lake shrank to its smallest area of 1326 km^2 in May 2011, reducing about two-thirds of its normal surface area of 3585 km^2. Meanwhile, the prolonged drought in the Yangtze River basin coincides with the water level rising of the Three Gorges Dam (TGD) from 135 to 175 m. Recently, low water levels in the drier season of the lower Yangtze River have started earlier and lasted longer, which aroused a debate over whether the TGD contributed to the decrease in water level of the Poyang Lake (Zhang et al., 2014). Some researchers suggested the TGD, along with the droughts, had caused the water level decline in the Poyang Lake in the drier season (Dai et al., 2008; Guo et al., 2011, 2012). Guo et al. (2011) reported that the influence of the TGD has resulted in less than 10% of the variation in the Yangtze River flow in most of the seasons. Dai et al. (2008) pointed out that 54% of the water flux was lost at Datong station during September 20–October 27, 2006, in comparison with the same period in 2005. It can be estimated that the impounding of TGD and the extreme drought in 2006 contributed 9% and 45% of this loss, respectively. Meanwhile, Guo et al. (2012) suggested that the impacts of large dams in the Yangtze River should alter from the previous studies in the dam-river setting to a new dam-river–lake construction. Nevertheless, Lai et al. (2014) also suggested that the effects of the TGD on downstream rivers and lakes will be intensified in the foreseeable future when many ongoing and planned large-scale dams located in the upstream tributaries in the Yangtze River, with a combined water storage capacity far larger than the TGD, will be put into operation in the near future. On the other hand, the Government of Jiangxi province situated in Poyang Lake area has stirred up another controversy by pushing to build a dam at the outlet of the Poyang Lake to prevent water from flowing into the Yangtze River. So water shortage is becoming one of the most serious problems in the Poyang Lake.

Although there are some studies about the influences of drought and TGD impounding on the lower Yangtze River (e.g. Chen et al., 2001; Dai et al., 2008; Guo et al., 2011), question like, "How do the droughts in the Poyang Lake basin together with the associated streamflow of the upper Yangtze River affect the water resources of Poyang Lake?", has not yet been analyzed thoroughly, which is of great scientific merit in understanding the causes of current water shortage in the Poyang Lake. The scientific problems to be investigated in this paper include: (1) Are there any regularity of the extreme droughts in the Poyang Lake basin and how do they affect the water resources? (2) To what extent does the low streamflow of the Yangtze River affect the water resources in the Poyang Lake? (3) Are there any differences in the interaction of the Yangtze River and the Poyang Lake before and after the impoundment of the TGD? In this study, we attempt to address these problems based on a thorough analysis of long-term hydrological and precipitation datasets across the Yangtze River basin. This study is of importance in further understanding the impacts of the droughts coincided with the dam-induced river–lake interaction on hydrological processes of the Poyang Lake.

2. Data and methodology

2.1. Study area and data

Poyang Lake basin, located in Jiangxi province, has an area of 162,200 km^2, occupying 9% of the Yangtze River basin. The water balance at the Poyang Lake is mainly dominated by five main tributary rivers: Ganjiang River, Fuhe River, Xinjiang River, Raohe River and Xiushui River, and several smaller rivers (as shown in Fig. 1). In addition, inflow from the Yangtze River to the Poyang Lake also plays an important supplementary role in maintaining the water resources stability of the Poyang Lake (Hu et al., 2007). Thus, the inflow of the Poyang Lake should include two parts: the inflow from the five tributary rivers and inflow from the Yangtze River. The Hukou station is the junction of the Poyang Lake basin with the Yangtze River, and streamflow from this station is regarded as the outflow of the Poyang Lake. The highest recorded lake level at Hukou hydrological station is 22.59 m. The corresponding lake area is approximately 4500 km^2 with the lake volume reaching 34 billion m^3. The lowest lake level at the same station is 5.90 m, and its corresponding lake area and lake volume are 146 km^2 and 450 million m^3, or rather, 1/32 and 1/76 of the largest area and volume, respectively.

Daily mean streamflow and water level data from 16 hydrological stations during the period of 1956–2009 and 215 daily