Journal of Hydrology 494 (2013) 83–95

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Distinguishing the relative impacts of climate change and human activities on variation of streamflow in the Poyang Lake catchment, China

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ARTICLE INFO

Article history:
Received 18 January 2013
Received in revised form 8 April 2013
Accepted 20 April 2013
Available online 3 May 2013
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Ashish Sharma, Associate Editor

Keywords:
Climate change
Human activities
Hydrological response
MK test
Poyang Lake catchment

SUMMARY

Under the background of global climate change and local anthropogenic stresses, many regions of the world have suffered from frequent droughts and floods in recent decades. Assessing the relative effect of climate change and human activities is essential not only for understanding the mechanism of hydrological response in the catchment, but also for local water resources management as well as floods and droughts protection. The Poyang Lake catchment in the middle reaches of the Yangtze River has experienced significant changes in hydro-climatic variables and human activities during the past decades and therefore provides an excellent site for studying the hydrological impact of climate change and human activities. In this study, the characteristics of hydro-climatic changes of the Poyang Lake catchment were analyzed based on the observed data for the period 1960–2007. The relative effect of climate change and human activities was first empirically distinguished by a coupled water and energy budgets analysis, and then the result was further confirmed by a quantitative assessment. A major finding of this study is that the relative effects of climate change and human activities varied among sub-catchments as well as the whole catchment under different decades. For the whole Poyang Lake catchment, the variations of mean annual streamflow in 1970–2007 were primarily affected by climate change with reference to 1960s, while human activities played a complementary role. However, due to the intensified water utilization, the decrease of streamflow in the Fuhe River sub-catchment in 2000s was primarily affected by human activities, rather than climate change. For the catchment average water balance, quantitative assessment revealed that climate change resulted in an increased annual runoff of 75.3–261.7 mm in 1970s–2000s for the Poyang Lake catchment, accounting for 105.0–212.1% of runoff changes relative to 1960s. However, human activities should be responsible for the decreased annual runoff of 5.4–56.3 mm in the other decades, accounting for −5.0% to −112.1% of runoff changes. It is noted that the effects of human activities including soil conservation, water conservancy projects and changes in land cover might accumulate or counteract each other simultaneously, and attempts were not made in this paper to further distinguish them.

1. Introduction

Climate change and human activities are the two factors that affect the change of catchment hydrology. According to the IPCC (2007), the average global surface temperature increased by 0.74 °C over the last 100 years. One of the most significant potential consequences of climate change may be alterations in regional hydrological cycles (e.g., Huntington, 2006). General consensus have revealed that global warming and related changes to the hydrological cycle are likely to enhance the frequency and severity of extreme climate events, causing more severe floods and droughts (e.g., Milliman et al., 2008; Bates et al., 2008; Déry et al., 2009; Jung et al., 2012; Thompson, 2012; Li et al., in press; Xiong et al., in press). In addition to global climate change, increases in human activities such as cultivation, irrigation, afforestation, deforestation and urban construction have also introduced changes to flow regime, especially large scale changes of land cover or its management (e.g., Yang et al., 2004; Brown et al., 2005; Jiang et al., 2012; Yang et al., 2012a,b). Depending on the study region,

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http://dx.doi.org/10.1016/j.jhydrol.2013.04.036

impacts of human activities on streamflow may be different. Reduction in streamflow has been shown in several arid and semi-arid catchments in north China due to implementation of conservation practices and increased water utilization (e.g., Li et al., 2007; Wang and Meng, 2008; Liu et al., 2009a). However, studies in Iowa's rivers noted that increasing agricultural intensity may increase stream discharge but reduce its variance due to the decreasing surface runoff and increasing baseflow (e.g., Tomer et al., 2005; Schilling, 2004). Moreover, water utilization for agricultural and industrial development can also lead to significant change in the water cycle and affect the variation of surface or sub-surface runoff (e.g. Du et al., 2012).

Within the last decades, water quantity and quality have become increasingly serious issues for water resources management at catchment and/or regional scale (e.g., Kizza et al., in press; Li et al., in press; Ren et al., 2002; IPCC, 2007; Tomer and Schilliing, 2009; Lakshmi et al., 2012). Therefore, understanding the influence and relative importance of climate change and human-induced change on hydrology and water resources has recently drawn considerable concerns (e.g. Siriwardena et al., 2006; Ma et al., 2008; St. Jacques et al., 2010; Jin et al., 2012; Carless and Whitehead, in press; Zhan et al., in press). Lahmer et al. (2001) indicated that climate change is the dominant factor that affects the change of streamflow in wet regions, while human activities such as some extreme land-use change only resulted in comparatively small impacts on regional water balance. Similar result was also revealed by Legesse et al. (2003) for tropical Africa. However, the study by Raymond et al. (2008) suggested that land use change and management were more important than climate change for explaining the increasing water export from the Mississippi River. In northern China, increasing water shortage is very common in recent years due to significant regional precipitation variation as well as rapid development of local economy (e.g., Piao et al., 2010). A quantitative assessment revealed that local human activities since the 1970s led to a decrease of the water diverted into the main stream of the Tarim River catchment, which has been aggravated in the 2000s (Tao et al., 2011). In Haihe River catchment, an important economic center of China, human activities were estimated to be responsible for the decline in annual water discharge, which accounts for over 50% of runoff reduction, while the contribution of climate change is relatively small (Wang et al., 2012). In a recent study conducted by Zhang et al. (2011a), the trends of the annual streamflow and precipitation and the relationship between them were analyzed in nine large river basins of China during 1956–2005. The results indicated that annual runoff has the same changing trend as precipitation in humid regions revealing a stationary rainfall–runoff relationship is still held. However, in arid and semi-arid regions of north China the decline in streamflow is faster than the decreases of precipitation since 1970s, indicating that the relationship between the annual precipitation and streamflow presents a non-stationary state. This non-stationary relationship is strongly influenced by human activities, especially by the increase of irrigation water use.

Poyang Lake, the largest fresh water lake in China, is located in the middle reaches of the Yangtze River with a catchment area of 162,225 km^2. The Lake and its surrounding catchments have suffered from frequent droughts and floods in recent decades, especially in 1990s and 2000s (e.g., Wang et al., 2008; Min et al., 2011). These severe drought and flood events have raised concerns for the lake ecology and local water resources management. Studies on hydrological response suggested that the changes of annual streamflow in the catchment were primarily caused by climate anomalies in the Yangtze River catchment, while human activities such as land-use change and modifications to river systems including the Yangtze River also exerted some impacts (e.g., Min, 2002; Guo et al., 2008, 2011; Zhang et al., 2012). Several studies showed that the variations of streamflow is much more strongly related to regional climate especially precipitation, but this is insufficient to explain all the changes (e.g., Guo et al., 2007; Zhao et al., 2009; Ye et al., 2009). For example, the increased vulnerability of the lake to floods is further elevated by deforestation and change of landscape in the basin. In addition, the construction of large-scale water conservancy facilities (reservoir and irrigation system) in the catchment is another important factor altering the annual hydrograph and increasing the water utilization (e.g., Zhang et al., 2011b; Liu et al., 2009b). Large amount of water demand severely decreased the catchment discharges to Poyang Lake and elevated the drought in the lake area, especially in dry years.

Effects of climate change and human activities on runoff variation are significantly sensitive, especially in arid and semi-arid regions, and these effects have resulted in severe environmental degradation and water crises. However, previous studies revealed that the relative importance of the influence of climate variability/change and human activities varies from region to region. To our knowledge, the relative contribution of climate change and human activities to runoff change in the Poyang Lake catchment has not been well investigated. Further studies are needed in order to provide a generalized and conclusive interpretation of the changes observed. The answer to this is essential not only for an improved understanding of the mechanism of hydrological response in the catchment, but also for local water resources management as well as floods and droughts protection and mitigation in the Poyang Lake catchment and the lower reaches of the Yangtze River. The purposes of this study are: (1) to investigate the variability of long-term historical records of climate and hydrological data in the Poyang Lake catchment; and (2) to evaluate the relative impacts of climate change and human activities on catchment-scale streamflow response under different spatial and temporal scales.

1.1. Overview of the Poyang Lake catchment

The Poyang Lake, connected to the Yangtze River, lies on the northern border of the Jiangxi Province, China. The lake receives water flows mainly from five rivers: Ganjiang, Fuhe, Xinjiang, Raohe and Xiushui, and discharges into the Yangtze River from a narrow outlet in the north (see Fig. 1). Among the five major rivers, the Ganjiang is the largest river in the region extending 750 km and contributes almost 55% of the total discharge into the Poyang Lake (Shankman et al., 2006). The topography of the Poyang Lake catchment varies from highly mountainous regions (maximum elevation of about 2200 m above sea-level) to alluvial plains in the lower reaches of the primary watercourses. Headwater of these rivers are located in boundaries of the east, south and west of the Jiangxi Province that surrounded by high mountains. Stream gradient decreases as these rivers flow onto the relatively flat region surrounding the Poyang Lake. The wide alluvial plains surrounding Poyang Lake and the broad alluvial valleys of the tributary streams are important rice growing regions in Jiangxi Province as well as in China; most notably the lower reaches of Ganjiang and Fuhe subcatchments have large irrigation areas over 10,000 ha (see in Fig. 1).

The Poyang Lake catchment belongs to a subtropical wet climate zone with an annual mean precipitation of 1680 mm and annual mean temperature of 17.5 °C. Annual precipitation in the catchment shows a wet and a dry season and a short transition period in between (see Fig. 2). Water inputs from the five subcatchments are particularly important during the wet season from April through June when heavy rainfall produces large surface flows from the sub-catchments to the lake (Shankman et al., 2006). Rainfall decreases sharply from July to September, while evapotranspiration is still very strong in these months (Fig. 2). After September, the dry season sets in and lasts through