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Advances in Climate Change Research 8 (2017) 37−47

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Review

Documented changes in annual runoff and attribution since the 1950s within selected rivers in China

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Received 18 August 2016; accepted 23 March 2017
Available online 9 April 2017

Abstract

To enable local water resource management and maintenance of ecosystem integrity and to protect and mitigate against flood and drought, it is necessary to determine changes in long-term series of streamflow and to distinguish the roles that climate change and human disturbance play in these changes. A review of previous research on the detection and attribution of observed changes in annual runoff in China shows a decrease in annual runoff since the 1950s in northern China in areas such as the Songhuajiang River water resources zone, the Liaohe River water resources zone, the Haihe River water resources zone, the Yellow River water resources zone, and the Huaihe River water resources Zone. Furthermore, abrupt changes in annual runoff occurred mostly in the 1970s and 1980s in all the above zones, except for some of the sub-basins in the middle Yellow River where abrupt change occurred in the 1990s. Changes in annual runoff are found to be mainly caused by climate change in the western Songhuajiang River basin, the upper mainstream of the Yangtze River, and the western Pearl River basin, which shows that studies on the impact of climate change on future water resources under different climate change scenarios are required to enable planning and management by agencies in these river basins. However, changes in annual runoff were found to be mainly caused by human activities in most of the catchments in northern China (such as the southern Songhuajiang River, Liaohe River, Haihe River, the lower reach and some of the catchments within the middle Yellow River basin) and in middle-eastern China, such as the Huaihe River and lower mainstream of the Yangtze River. This suggests that current hydro-climatic data can continue to be used in water-use planning and that policymakers need to focus on water resource management and protection.

Keywords: Changes in annual runoff; Climate change; Human disturbance; Attribution; Rivers in China

1. Introduction

The hydrological cycle is a complex process affected by climate change and human activities (Ma et al., 2008). Climate change is altering hydrological systems and affecting water resources (in terms of quantity and quality) by causing rising temperatures and changes in the intensity and pattern of rainfall, as well as causing changes in evapotranspiration (IPCC, 2014; Labat et al., 2004). However, in addition to climate change, certain human activities (such as water resource withdrawal and return flow, and hydraulic construction and operations) have had a direct impact on the hydrological cycle and water resources by altering their spatial−temporal distribution. Furthermore, other activities (such as forest disturbance, soil and water conservation projects, and urbanization) have had an indirect impact on streamflow via land use and land cover changes (Song et al., 2013; Zhang et al., 2014). Both direct and indirect impacts on the hydrological process affect natural ecosystems, cultivation, water resource

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Peer review under responsibility of National Climate Center (China Meteorological Administration).

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.accre.2017.03.005

management, land use planning (Dong et al., 2012), and have caused many water-related problems such as water shortages, flooding, water logging, and a deterioration in water quality (Hao et al., 2008) to different extents.

There has been a remarkable decrease in the runoff for many rivers in recent decades in arid and semi-arid regions around the world (Wang et al., 2012a). In addition, there has been a rapid increase in the global human demand for renewable water resources over the past few decades, due to an increase in populations and rapid developments in global economies. In this respect, many regions throughout the world are experiencing water stress (Vörösmarty et al., 2000) and severe challenges in water resource utilization and ecological development. In China, the shortage of renewable water resources is gradually becoming a severe problem (Hao and Zhang, 2013). To enable adaptive management of watersheds in relation to climate change, it is necessary to fully understand the combined impacts thereon (Juckem et al., 2008) and to distinguish between the impact of human activity and climate change in the evolution of a hydrological time series (Wang et al., 2013a).

It is important for local water resource management, ecosystem integrity maintenance, and flood and drought protection and mitigation to detect changes in long-term time series of streamflow and, as mentioned above, to distinguish the roles that climate change and human disturbance play in the changes (Wang et al., 2013a; Ye et al., 2013). For example, if the contribution of human disturbance is determined to be greater than that of climate change, current hydro-climatic data can continue to be used for water use planning, and policymakers can focus on water resource management and projection. However, if climate change is determined to be the major driving factor, it will be essential to study the impact of climate change on future water resources under different climate change scenarios to enable planning and management by relevant agencies (Bao et al., 2012; Fu et al., 2004).

Streamflow is an important hydrological variable that can be used to monitor the possible effects of climate change and human disturbance (Du et al., 2011). During the past several decades, significant research has been devoted to the detection and attribution of changes in river runoff, both in China and internationally. These studies have suggested that the effects of human activities and climate change on alternations in watershed streamflow can vary throughout different geophysical regions (Guo et al., 2014a; Xu et al., 2014), or within different series using differing time-frames (Chen et al., 2011; Xu et al., 2009a) or differing time-scales (e.g., seasonal or annual) (Guo et al., 2008). Such variations thus have distinct implications for integrated land and water resource management (Guo et al., 2014a).

By reviewing previous research pertaining to the detection and attribution of observed changes in annual runoff in China, this paper aims to understand changes in annual runoff and the contribution of climate change and human activities to the changes that have occurred in seven water resource zones in China since the 1950s. This study is potentially valuable and practical for improving our understanding of changes in the hydrologic cycle and promoting water resources planning and management in China.

2. Documented rivers and methods

2.1. Documented rivers

There are 10 first-level water resources zones in China (DWR and CREEI, 2013). Each one consists of a number of second- and third-level zones (or catchments). This study initially reviews the detection and attribution of changes in annual runoff and the main factors causing these changes in seven out of the ten first-level water resources zones as shown in Fig. 1. Further examination is then conducted for smaller zones (or catchments), as listed in Table 1.

2.2. Popular methods

Attribution of human activities and climate change to detected changes in runoff is often documented based on the use of either one-step or two-step methods. One-step methods involve the use of statistical procedures to make a direct evaluation of the relative contribution of climate change and human activities on runoff changes; for example using statistical methods based on indexes of human activities and climate change (Li et al., 2008; Zhang et al., 2012). The advantage of one-step methods is that that they avoid any division between the periods of reference and influence. However, they also have several disadvantages, including the need for a long-term series of climatic variables, runoff, and index of human activities. In contrast, two-step methods involve a statistical analysis of trend in the runoff series and the identification of a theoretical abrupt change point; the results are used to divide the runoff series into a reference period and a period of influence. The relative contribution of human activities and climate change to runoff change is then evaluated for the period of influence. The Mann–Whitney–Pettitt (MWP) test (Pettitt, 1979), double mass curve (Mu et al., 2010), and sequence clustering (Huang and Zhao, 2008) are usually applied to identify any significant change points within a runoff time series. In addition, many runoff simulation methods have been developed; the most frequently used are partial investigation (Xue and Zhang, 2013) and the elastic coefficient model (Dooge et al., 1999; Hu et al., 2012; Zhang,

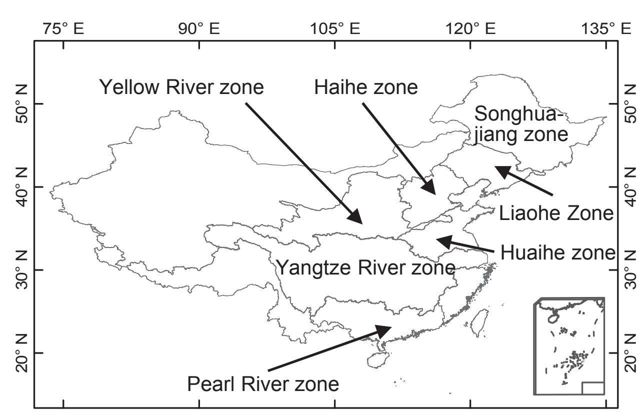

Fig. 1. The seven out of ten first-level water resources zones in China.