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Variations in precipitation and runoff from a multivariate perspective in the Wei River Basin, China

Shengzhi Huang [a,*], Qiang Huang [a], Jianxia Chang [a], Guoyong Leng [b], Yutong Chen [a]

[a] State Key Laboratory Base of Eco-Hydraulic Engineering in Arid Area, Xi'an University of Technology, Xi'an, 710048, China
[b] Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD, 20740, USA

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ABSTRACT

Investigation of the variations in precipitation and runoff and possible breakpoints of their relationship is of great value for local water resources planning and management. The Wei River Basin (WRB), as a typical arid and semi-arid region in China, was selected as the case study. The zonal and meridional moisture transport flux from the National Centers for Environmental Prediction (NCEP) reanalysis dataset were used to explore the possible causes of changes in precipitation variability. A Copula-based method was adopted to examine the changing relations between precipitation and runoff variabilities and identify possible breakpoints of their relationship. Results showed that: (1) a roughly decreasing precipitation trend was found for most months, especially in spring and autumn, which was mainly affected by the joint effects of the weakening East Asian summer and winter monsoons; (2) similar to precipitation changes, the runoff in most months in the WRB exhibited significantly decreasing trends, which are highly correlated with those of precipitation at the 95% confidence level; (3) two breakpoints of the relationship between precipitation and runoff were identified at Linjiacun station in 1972 and 1996 and at Zhangjiashan station in 1988 and 1997, whilst only one breakpoint was detected at Huaxian station in 1995, which were well consistent with the extensive human water use and soil conservation practices.

1. Introduction

The global mean annual surface air temperature had increased by about 0.74 °C during the last century (IPCC, 2007), leading to significant increases in regional precipitation variability and extremes (e.g. floods and droughts) (Easterling et al., 2000; Allen and Ingram, 2002; Mirza, 2002; Alan et al., 2003; Wang et al., 2011; Xu et al., 2015; Leng et al., 2015a). As one of the extremely valuable natural resources, water plays a major role in the sustainable development of society, economy and ecology. Numerous studies have investigated the changes in the availability and variability of water resources within the context of climate change and anthropogenic influence (Vörösmarty et al., 2010; Xu, 2011; Hüseyin and Saffet, 2012; Zhao et al., 2012; Ling et al., 2014; Wang et al., 2015; Leng et al., 2015b; Wu et al., 2016). For instance, Zhang et al. (2011) examined the impacts of climate variability and human activities on streamflow variability for a river basin in northeast China; Tomer and Schilling (2009) applied a simple approach to distinguish land-use and climate-change effects on watershed hydrologic changes in the US Midwest; Yang and Tian (2009) investigated the abrupt changes in runoff and their major driving factors in Haihe River Catchment; Ye et al. (2013) estimated the relative impacts of climate change and human activities on runoff changes in the Poyang Lake catchment in China using a coupled water and energy budgets analysis framework; Xu et al. (2013) assessed the impacts of climate variability and human activities on annual runoff in the Luan River basin in China with a geomorphology-based hydrological model (GBHM); Xu et al. (2014) performed an attribution analysis within the Budyko Hypothesis framework for detecting the dominant cause of runoff declines in the Haihe basin; Yang et al. (2014) investigated the runoff change elasticity to climate change across China.

Although numerous researchers have investigated the responses of water resources to the changing environment, the magnitude and direction of changes usually vary in time and space (Tomer and Schilling, 2009; Zhao et al., 2012; Jiang et al., 2014; Wang et al., 2014). The discrepancy in the detected changes is partly due to fact that most of the previous studies investigated regional

* Corresponding author.
E-mail address: huangshengzhi7788@126.com (S. Huang).

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hydrology from a univariate perspective (Yang and Tian, 2009; Ye et al., 2013). However, there exist complicated interactions among surface water, atmosphere, vegetation, soil and groundwater, (Sadri and Burn, 2012), which complicate the investigations with a univariate analysis approach. Indeed, univariate analysis of changes in single variable of interest (e.g. precipitation or runoff) cannot fully reveal the hydrologic response to climate change and human activities. Hence, it is necessary to examine the variations of precipitation and runoff in a multivariate way.

The Wei River Basin (WRB) is a typical arid and semi-arid area in China, and the Wei River is the biggest tributary of the Yellow River. The available water resources in the WRB are very limited, with per capita and per acre possession of 308 and 174 m^3, which is approximately 13% and 9% of the national average, respectively. The limited water resources have heavily restricted regional agricultural and industrial developments. What's worse, the runoff in WRB has been experiencing a significantly downward tendency (Huang et al., 2014a; Chang et al., 2015), further aggravating the contradictions between water supply and demand. Therefore, it is of importance to comprehensively and efficiently explore the variations of precipitation and runoff in a multivariate way, which help to facilitate local water resources management under the context of changing climate and intensifying human interference in the WRB.

Many previous studied (e.g. Su et al., 2007; Gao et al., 2012; Du and Shi, 2012; Zuo et al., 2012, 2014; Zhao et al., 2014) investigated the effects of climatic change and human activities on the runoff variability in the WRB. However, these studies focused on the causes of runoff changes and neglected the causes of precipitation variations and the changing relationship between precipitation and runoff. Indeed, the relationship between precipitation and runoff is one of the most important relationships in the hydrology and meteorology fields (Zhang and Lu, 2009). Exploring the changes in the relationship between precipitation and runoff helps to understand runoff changes, improve runoff prediction and guide local water resources planning and management. Once breakpoints of the relationship between precipitation and runoff are found, it means that runoff generation mechanism has clearly altered, which has strong impacts on hydrological frequency analysis and hydraulic engineering construction. Therefore, it is an urgent need to detect possible breakpoints of the relationship between precipitation and runoff under the background of the changing environment. To date, none has made such explicit investigations in the WRB. In addition, the typical methods used in identifying the breakpoints of the relationship between precipitation and runoff have been limited to the use of correlation coefficient approach (Hao, 2004), which, however, cannot fully capture their nonlinear correlations. Hyosang et al. (2005) adopted a conceptual model to simulate the changing precipitation and runoff relationship. Apart from the incomplete representation of the underlying land surface processes, hydrological models typically require a large amount of data and parameter calibrations, leading to a certain range of uncertainties. In this study, a Copula-based method, which has been extensively applied in financial field, was introduced to identify possible breakpoints of the relationship, based on the joint probability distribution of precipitation and runoff. Although numerous previous studies such as Zhang et al. (2012, 2015) and Song and Singh. (2010) applied Copulas functions in hydrological field, they were limited to drought risk assessments from a multivariate perspective. However, as far as we know, studies concerning variations of precipitation and runoff relationship from a multivariate perspective are quite rare.

The primary objectives of this present study are: (1) to investigate the spatial and temporal variations of precipitation, with a focus on their possible causes; (2) to analyze the changes in monthly runoff and their relations to precipitation variations; (3) to identify possible breakpoints of the relationship between precipitation and runoff, along with exploring their possible causes.

2. Study area and data

2.1. Introduction of the WRB

The Wei River basin is situated between 103.5°E–110.5°E and 33.5°N–37.5°N, covering a total area of 1.35×10^5 km^2 (See Fig. 1). Topographically, the elevation decreases from the northwestern basin to the southeastern basin. Situated in a monsoon climate

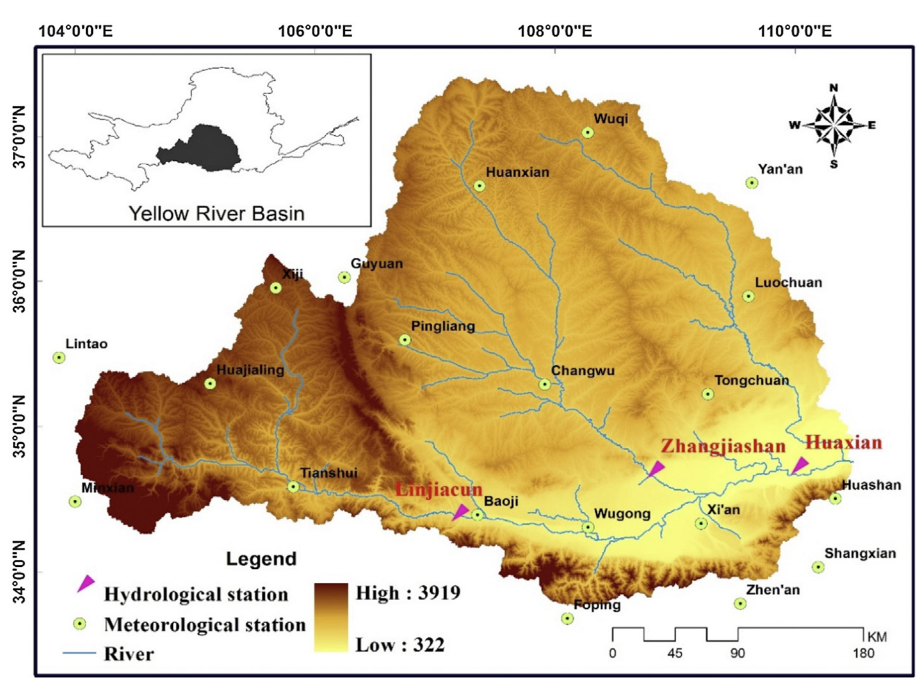

Fig. 1. Location of the WRB and hydro-meteorological station in the Yellow River Basin.