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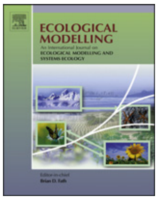

Impacts of climate change/variability on the streamflow in the Yellow River Basin, China

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ABSTRACT

Changes of streamflow reflect combined effects of climate, soil and vegetation in the basin scale. This study was conducted to investigate the response of streamflow to the climate changes/variability in different scales of the Yellow River Basin (YRB). The spatial distribution and temporal trends were explored for precipitation and potential evapotranspiration (PE) during 1961–2000 to illustrate climate change/variability and impacts of climate change/variability on streamflow were explained by investigating the relationship of precipitation, PE and streamflow in the YRB. The results presented that: (i) precipitation and PE exhibited different spatial distribution patterns and temporal trends in different regions, and most stations showed negative trends for precipitation in the basin; (ii) the relationship of streamflow with precipitation and PE showed high nonlinearity, and the magnitudes and patterns of streamflow response to precipitation and PE displayed different patterns varied with the dry conditions in different region or years; and (iii) the precipitation elasticity of streamflow (ε_P) was 1.80, 1.08, 1.78 and 1.95 in Lanzhou, Toudaoguai, Huayuankou and Lijin respectively, while the PE elasticity of streamflow (ε_{ET}) was −3.41, −4.40, −4.52 and −4.20 in above four scales, respectively, from which can be seen that streamflow was more sensitive to precipitation in wet region than in arid region and inversely it was more sensitive to PE in arid regions than in wet regions. Furthermore, precipitation elasticity of streamflow calculated from the partial correlation presented a reasonable result to show the combined effect of precipitation and PE on streamflow.

1. Introduction

According to definition provided by Ramsar Convention, wetland is “the areas of marsh, fen, Pearland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt including areas of marine water, the depth of which at low tide does not exceed 6 meters” (Mitsch and Gosselink, 2000). Climatic change/variability combined with human activities (e.g. land reclamation, soil and water conservation engineering) results in massive changes in the eco-hydrological pattern, which in turn, leads to changes of hydrological processes in many basins, having caused a series of water resources problem, especially in all kinds of wetlands all over the world (Zalewski et al., 1997; Zalewski, 2000; Zhang et al., 2001; Mitsch, 2005; Li et al., 2007; McVicar et al., 2007a; Harper et al., 2008). Up to now, half of the original wetlands in the world were lost from 1900s and it is estimated that the remained area of the wetlands is only $5.73 \times 10^8\,\mathrm{h\,m}^2$ (Mitsch and Gosselink, 2000). In order to protect the vulnerable wetland ecosystem, we should elucidate the response of hydrological processes to climate change/variability, which has been regarded as one of most important aspects to understand the hydrologic mechanisms which underlie ecologic patterns and processes (Rodriguez-Iturbe, 2000). All of these will be helpful to solve water resources declining problem and have drawn a great attention (Rodriguez-Iturbe, 2000; Rodriguez-Iturbe et al., 2001; Rodriguez-Iturbe and Porporato, 2005). The concept of elasticity in economics used to express the ratio of the percent change in one variable to the percent change in another variable, which was introduced by Schaake (1990) to evaluate the sensitivity of streamflow to changes in climate. As it is easy to be understood, much research has been conducted on this topic (Dooge et al., 1999; Sankarasubramanian et al., 2001; Niemann and Eltahir, 2005; Fu et al., 2007a,b,c). Up to now, two approaches have been developed to investigate impact of climate change/variability on hydrological processes. One approach is using the conceptual watershed models (CWM) to assess the impact of climate change/variability on hydrological processes. Although it could be able to model the complex spatial and temporal variations in evapotranspiration, soil moisture and streamflow (Sankarasubramanian et al., 2001), its validation still remains a fundamental challenge. Sensitivity of streamflow to climatic variability revealed by the CWM can obtain remarkable different results even using identical CWM on the same basin

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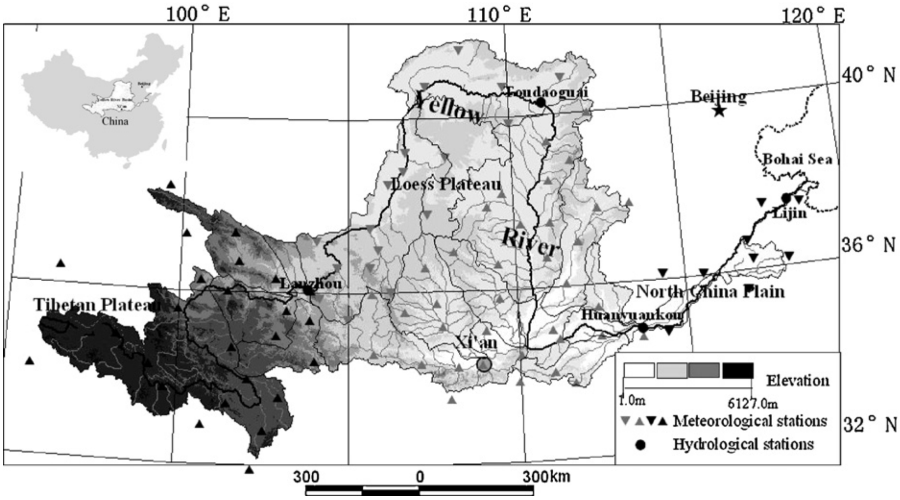

Fig. 1. Location of the Yellow River Basin, the meteorological and hydrological stations used in this study. Meteorological stations in the Lanzhou scale (▲), Toudaoguai scale (▲ and ▼), Huanyuankou scale (▲, ▼ and ▲) and Lijin scale (▲, ▼, ▲ and ▼) show in the figure.

(Sankarasubramanian et al., 2001; Fu et al., 2007c). In order to solve the paradox resulted from the CWM, Sankarasubramanian et al. (2001) provided the other approach to investigate the response of streamflow to climate variable. The streamflow elasticity of climate variable revealed by the Sankarasubramanian's method has been suggested by Chiew (2006) as an intrinsic property of a catchment. Several studies have been conducted on different basins using this method (Sankarasubramanian and Vogel, 2003; Fu et al., 2007c; Novotny and Stefan, 2007). As the method, provided by the Sankarasubramanian et al. (2001), can use to compare the response of streamflow to the climate change/variability in different basins or in different scales of the same basin, it will be helpful to assess the impact of climate change/variability on the water resources and provide suitable water resource regulating project to protect the health of the wetland. However, little research has been conducted to reveal the response of climate change/variability in different scales of the basin. Furthermore, using the climate elasticity of streamflow to address the effect of the combined influence of climate variables on the streamflow remains a challenge.

The objectives of this study are: (i) to explore the spatial distribution and temporal trends for annual precipitation and potential evapotranspiration (PE) during 1961–2000 and expressions of the climate change/variability in Yellow River Basin (YRB); (ii) to investigate the relationship of precipitation, PE and streamflow in different scales of YRB; and (iii) to analyze climate elasticity of streamflow to reveal the response of streamflow to precipitation and PE at different scales of YRB.

2. Study area and data processing

2.1. The Yellow River Basin

The Yellow River is about 5400 km long with a drainage area of 7.95×10^5 km^2 (Fig. 1), which directly supports a population of 107 million people (McVicar et al., 2007b). Originating from the Tibetan Plateau, the river flows through Loess Plateau and North China Plain, finally reaching the Bohai Sea. The headstream of the Yellow River is covered by snow and frozen soil for the whole year, the area from upstream to Lanzhou is the main source of water resources, and about 54% of the river runoff is from this area (Jia et al., 2006). From the Lanzhou to Toudaoguai station, the river runs through the influx region in the Loess Plateau and little flow runs into the river. While from Toudaoguai to Huayuankou station, runoff increases with several tributaries flowing into the river. When the river runs through Loess Plateau, most of the sand of the basin produces in this region because of the rainstorm frequently occurring in flood season besides the loose soil texture and spare vegetation. In the Loess Plateau severe soil erosion rates ranging from 20,000 to 30,000 t km^{-2} year^{-1} are commonly reported (e.g. Xu et al., 2004), and extremely high rates (59,700 t km^{-2} year^{-1}) have also been documented (Shi and Shao, 2000). In the North China Plain, the sand carried by the river deposits and has formed the famous suspended river (i.e. where the bottom of the river bed is, in places, some 20 m above the surrounding plain) in the lower reach of the YRB. For these special catchment characteristics, climate change/variability combined with human activities has led to a series of environmental problems in wetlands of the YRB. For example, the increase of the agricultural and industrial water use, combined with decrease of precipitation, has contributed to the decrease of the runoff and drying-up in the lower reach of the Yellow River, which is experiencing more zero-flow days and some wetland degraded in recent decades (Liu and Cheng, 2000; McVicar et al., 2002; Liu, 2004).

2.2. Data processing

The time series of the monthly wind speed, sunshine hours, relative humidity, air temperature and precipitation at 89 meteorological stations were used from 1961 to 2000. They were provided by the National Climatic Centre (NCC) of the China Meteorological Administration (CMA). The annual precipitation and potential evapotranspiration (PE) were obtained by summing the monthly precipitation and PE at 89 stations from 1961 to 2000. The monthly PE was calculated using the monthly wind speed, sunshine hours, relative humidity and air temperature by the FAO recommended P-M method (Allen et al., 1998; López-Urrea et al., 2006; Xu et al., 2006; McVicar et al., 2007b). The average annual precipitation and PE for Lanzhou, Toudaoguai, Huayuankou and Lijin scale (which was defined in below) respectively was calculated from the averaging precipitation and PE in different scales of YRB. Furthermore, in order to reduce the influence of human activities such as irrigation, industry, and domestic uses, the "naturalized runoff", instead of the observed runoff, was used to investigate the change of streamflow in Lanzhou, Toudaoguai, Huayuankou and Lijin stations, which were provided by the Yellow River Conservancy Commission (YRCC). According to YRCC (1977), the difference between observed runoff and naturalized runoff generally results from the following factors: (i) the amount of water directly abstracted from the