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Water resource spatiotemporal pattern evaluation of the upstream Yangtze River corresponding to climate changes

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ABSTRACT

The hydrological cycle is sensitive to the driving forces of climate change. Thus, impact assessment of climate change on water resources from the past to the present is of grave concern for basin management. In this study, water resource spatiotemporal patterns exposed to IPCC scenarios A2 and B2 in the upstream Yangtze River are assessed. Statistically downscaled precipitation and temperature are analyzed. Rainfall-runoff processes are modeled using a distributed hydrological model. Results show that the historical downscaled precipitation and temperature are consistent with observations. Mean air temperature increased for both scenarios. Precipitation generally declined over the region. Runoff is predicted to decrease in most rivers, especially in the wet season, and the variation of hydrographs is obvious. An increase in temperature likely caused the reduction of precipitation leading to the consequent rise of evapotranspiration and decline of surface water and groundwater recharge. Generally, surface water and ground water recharge declined faster in the A2 scenario than B2. Water resources will be in a considerable heterogeneous pattern driven by climate changes. Precipitation, surface water generation, and groundwater recharge share identical spatiotemporal patterns but are predicted to show larger spatial variation in future decades. B2 shows a larger future spatial variation, which may add risks for local droughts and floods. This paper emphasizes the evolution of spatiotemporal variations of water resources from 1999 to 2099 associated with discussions on implications and uncertainties in the upstream Yangtze River region.

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1. Introduction

During the past decades, the upstream Yangtze River (UYR) has experienced challenges in water resource management. Changes in water availability have had major impacts on most social aspects, particularly for agricultural, industrial, and domestic water supplies (Feng et al., 2008; Huang et al., 2009; Jiang, 2009; Liu et al., 2012). The UYR region was once rich in water resources due to abundant precipitation. However, increases in population and industries have introduced a greater water demand. In addition, uneven distribution of water resources has also caused frequent floods and droughts throughout history. Climate change affects the hydrological cycle and thus influences water availability issues. Unfortunately, climate change impacts lack comprehensive investigation (Arnell, 1999, 2004; Charlton and Arnell, 2011). Recently, it has been noticed that possible climate change will further affect variation of precipitation, surface water, evapotranspiration (ET) and groundwater recharge in the next few decades. Thus, knowledge of the quantity and spatiotemporal pattern of water resources is crucial to determine proper water allocation plans (Bhaduri et al., 2000; Holmes et al., 2005; Sharma and Shakya, 2006; Notter et al., 2007).

Global Climate Models (GCMs) have reported evident impacts of climate change on the hydrological cycle (IPCC, 2007). Climate change affects the function and operation of the existing water infrastructure. Negative trends pose challenges for reservoirs and electricity generation management. Increasing water demand has been threatened by the decline of river discharge. Reports warn of

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high discharge rates during the dry season under the pressure of climate change (Milly et al., 2005). The uneven distribution of water resources caused by climate change has not been investigated in depth. Climate change intensifies the spatial heterogeneity of water resources directly responsible for the frequency and severity of extreme hydrologic events (Prudhomme et al., 2003; Calanca, 2007; Jeroen and Wouter, 2011).

Several factors may affect surface hydrology and water availability, including rainfall, soil type, infiltration, topography, and vegetation, among which atmospheric forces are significant. The literature (Lin et al., 2010; Dash et al., 2012; Dawadi and Ahmad, 2012) suggests that it is a necessity to model and evaluate the impacts of climate change on water resource heterogeneity using distributed hydrological models (DHMs). Parish et al. (2012) conducted a simulation to integrate disparate climate and population data to estimate per capita water availability projections. García-Ruiz et al. (2011) illustrated the trend of stream flow decline in the Mediterranean area by modeling and analyzing river regime characteristics and reservoir inflow. Andersson et al. (2006) studied the impact of climate change and development scenarios on flow patterns using a Pitman hydrological model; watershed outlet discharges and regional scale evaporation are discussed. In addition to historical changes that may indicate future trends of water resource evolution based on a general or basin scale statistical analysis, possible changes of water resource spatiotemporal patterns have not been revealed in the UYR region.

This paper evaluates water resource spatiotemporal pattern changes in the UYR region. We model the water balance using the WetSpass model. GCM climate emission scenarios (IPCC A2 and B2) are used. Spatiotemporal estimations of historical water resources and hydrological cycle components, including precipitation, ET and groundwater recharge, are conducted. Historical observation is based on the time series of rainfall and runoff in the period of 1960–2000. GCM predictions are made for the years of 2001–2099. In particular, the results allow an assessment of the influences of climate change on the spatiotemporal patterns of surface water, ET and groundwater recharge, providing implications for water resource distribution in the next several decades.

2. Data and materials

2.1. Upstream Yangtze River

The UYR region is located in the west highland geographical region of China (Fig. 1). It is characterized as having abundant water quantity and land resource potential. The river originates from the Qinghai Tibet plateau. The drainage area covers approximately 983,000 km^2 (25.4–35.8°N, 90.5–111.6°E). Highlands comprise a major area, particularly in the northwest. Five major drainage basins include the Yanglong, Jinsha, Mintuo, Jialing, and Wu Rivers. Elevation ranges from 3000 to 5000 m. Climate varies across the region. The wet season ranges from April to September. Extreme basin-wide hydrological events occur frequently. Floods are caused by monsoonal variability, which brings approximately 80% of the precipitation in the wet season. Droughts are the major hydrological events during the dry season in the southwest area.

2.2. Climate change scenarios

In addition to historical changes indicating future trends of water resources at a basin scale, it is also important to investigate how climate change affects water resource spatiotemporal patterns. The IPCC has released emission scenarios SRES used for driving GCMs. It provides supporting data for climate evaluation and environmental consequences corresponding to future CO$_2$ emissions responsible for temperature rise. SRES contains a wide range of driving forces related to future development of demography, technology, and economy. Two major scenarios, A2 and B2, with opposite characteristics are selected. A2 describes a relatively immoderate and heterogeneous world with a low convergence of fertility patterns but continuously increasing global population. Economic development in A2 is primarily regionally oriented, but it is fragile and slow. B2 focuses on the sustainability of local solutions to economic, social, and environmental development. The population expansion rate is lower than A2. Abbaspour et al. (2009) produced climate scenarios for the 21st century (from 2010 to 2100) from the Canadian Global Coupled Model (CGCM 3.1). SDSM is adopted for regional atmospheric data downscaling in the UYR region (Wilby and Dawson, 2007). Stochastic weather generators are used for downscaling. Local observed daily precipitation is used to generate precipitation time series and determine the statistical parameters correlated to the GCM grid. The future precipitation time series are then created using the climate change scenarios and parameters calculated above.

2.3. Land cover and soil texture

Land cover (National County Land Coverage Vector Data, resolution: 1 × 1 km) data are provided by Chinese Academy of Sciences (CAS). A statistical summary shows that land use in the UYR region can be classified into 23 categories (Fig. 2a). The region is dominated by grassland (50.8%), open forest (9.95%), forest land (13.7%) and rural area (3.52%). In the highland area, the landscape is covered by low-density grass, gobi, and exposed land. In the lower area, high-density grass, forests and shrubs dominate. The area percentage of each land cover type shows no significant changes (Sig>0.05) for the different investigation periods. Thus, land cover of year 2000 is adopted in this study. Soil data are obtained from the Soil Database supported by CAS (Nanjing Institute of Soil Science). A soil map is created from digital soil maps deriving soil particulate size at a scale size of 1:1,000,000 (Shi et al., 2004). The main soil texture (Fig. 2b) is loam (37.1%), silt (32.3%) and silty clay-loam (11.3%). The soil texture is characterized as silt in the upstream area but as a mixture in the downstream area. The topography of the region is derived from the DEM database HYDRO1K, a USGS 30 arc-second global digital elevation model.

2.4. Meteorological and hydrological data

UYR is sub-delineated into 52 geo-hydrological catchments. The upstream to downstream topological relationship is illustrated in Fig. 3a. Meteorological data are collected from 15 weather stations (Fig. 3b) within the UYR, including daily precipitation, air temperature, humidity, wind speed, and sunshine hours provided by the China Meteorological Administration (CMA). Precipitation and meteorological data are spatially interpolated using the inverse distance method (IDM) from 1960 to 2000. Measured discharges of 51 hydrological stations (Fig. 3c) are collected from China's Ministry of Water Resources.

2.5. Distributed hydrological model

In this study, the WetSpass model (Wang et al., 1997; Batelaan and De Smedt, 2001) is used to assess monthly water resource distributions and river discharges. The WetSpass model was built as a physically based modeling tool for estimation of long-term average spatial patterns of surface runoff, ET and groundwater recharge, which needs long-term seasonal average precipitation input. The WetSpass model is capable of modeling long-term variations of surface water generation, ET and groundwater recharge

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