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Original Research Article

Future climate change impacts on the ecohydrology of Guishui River Basin, China

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ABSTRACT

Quantifying the impacts of future climate change on the ecosystem and hydrology is very important to ecohydrology research. In this paper, the vegetation model BIOME BioGeochemicalCycles (BIOME-BGC) and the Hydrological Simulation Program-FORTRAN (HSPF) are combined to investigate the potential impact of climate change on the hydrology and ecosystems of the Guishui River Basin in Beijing China, under two emission scenarios A2 and B2 of the future period 2010–2099. The projected daily maximum and minimum air temperatures, precipitation and evapotranspiration (*ET*) of HadCM3 are downscaled on to local meteorological stations using the SDSM (Statistical Downscaling Model). The model calibration and validation results are in accord with observed data of surface runoff and Net Primary Productivity (NPP). Average climate projections based on two emission scenarios were used in simulations to assess future ecohydrological responses in the Guishui River basin. Also, the uncertainties in climate change impacts are discussed in detail. The predicted daily maximum and minimum air temperatures and evapotranspiration show a reasonable upward trend, while daily precipitation and surface runoff generally show a downward trend in the next 90 years. The changing rates of daily maximum and minimum temperatures, precipitation, evapotranspiration and surface runoff are 0.46 °C, 0.45 °C, −3.68 mm/year, 15.83 mm/year and −0.05 m^3/s (0.26 °C, 0.26 °C, −4.99 mm/year, 9.36 mm/year and −0.04 m^3/s) per decade under A2(B2) scenarios, respectively. The results also show that global warming impacts would decrease annual discharge and increase annual NPP (at the rate of 10–30%). These results present a serious challenge for water and land management in the basin and will provide support for regional water management.

1. Introduction

The eco-hydrological cycle has been substantially influenced by climate change and human activities (Zalewski, 2002; Peng et al., 2013). It is therefore of utmost importance to analyze the impact of climate change on eco-hydrology, particularly in the capital city, Beijing, China which now faces both sustainability and water supply problems (Xia et al., 2011). Ecohydrologic changes from climate impacts alter runoff, evapotranspiration, surface storage, and soil moisture directly affect the region's biota and habitat. It is very important to understand numerous potential challenges including declining water resources, water-related disasters such as flood, environmental protections and ecological balance (Xu et al., 2013; Zhang et al., 2008).

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Future climate changes such as changes in temperature, precipitation and the frequency of extreme weather will influence ecohydrological processes. Quantifying the impacts of climate change on hydrology and ecosystems still represents a challenge in global change studies (Peng et al., 2013). However, until recently, evaluation of ecohydrological availability under climate change in Beijing is still limited.

In climate change impact studies, projections by global climate models (GCM) and regional climate models (RCM) have been widely used (Hwang et al., 2013). General Circulation Models (GCMs) can simulate large-scale annual or seasonal mean climate characteristics. It is a very reliable tool for analyzing large-scale aspects of estimated climate change. However, the models' coarse spatial resolution makes it difficult to be used for regional climate impact assessment, and as a result statistical downscaling is often used to compensate for this deficiency (Xu, 1999; Liu et al., 2012). The Statistical Downscaling Model (SDSM) is better able to predict climate change scenarios for the future of the region through the establishment of a statistical relationship between the GCMs and regional climate elements (Wilby and Dawson, 2013). Chu et al. (2008) found that SDSM is a proper tool for simulating temperature and precipitation in the Haihe River Basin.

Hydrological models can be used to simulate quantifiably the hydrological phenomena characteristics and the process of change. The Hydrological Simulation Program-Fortran (HSPF) model developed by the U.S. Environmental Protection Agency (EPA) has been used widely in watershed hydrology and water quality modeling (Bicknell et al., 2001). In recent years, the HSPF model is also applied in China. Zhang et al. (2012) combined HSPF with regression models to estimate the nonpoint source loading of Danshui catchment in the Dongjiang watershed in Guangdong Province. Xue et al. (2009) applied HSPF for runoff simulation in the Chaohe River tributary of the Dage River watershed. But the practice of utilizing the HSPF model to assess climate change impacts under future climate change scenarios is limited and requires further analysis.

Ecohydrological models can serve as useful tools for forecasting the impacts of climate change. Coupling ecosystem models with hydrological models is one of the research directions for future ecohydrological studies (Govind et al., 2009). Some researchers have made efforts to explore the integration process between ecological and hydrological models. Band et al. (1993) coupled FOREST-BGC with TOPMODEL to simulate forest ecosystem processes incorporating hillslope and hydrology in northwestern Montana. Yuan and Zhu (2007) coupled LPJ model (Lund-Potsdam-Jena Dynamic Global Vegetation) and Xinanjiang hydrological model to simulate the impact of interlinked climate and vegetation change on the hydrological cycle process in Hanjiang River, China. Peng et al. (2013) integrated BIOME-BGC and the distributed hydrological model, the Water and Energy Transfer Process in Large river basins (WEP-L), to quantify the impacts of climate change on the hydrology and ecosystem of the Loess Plateau, China.

In order to predict the ecohydrological impacts of future climate change in the Guishui River basin, Beijing, this paper presents an approach to couple a vegetation model BIOME BioGeochemicalCycles (BIOME-BGC; Running and Hunt, 1993) and hydrological model (HSPF; Bicknell et al., 2001) to demonstrate its use with climate change scenarios based on a general circulation model (HadCM3). The prediction results of the model were used to address three questions:

(a) How will the rates of daily maximum temperature, minimum temperature, precipitation evapotranspiration and surface runoff change under different future emissions scenarios (A2 and B2)?
(b) What will cause these changes?
(c) How will the variable changes in climate change impact on hydrology and ecosystems.

2. Site description

The study area (40°19′8″–40°38′40″ N, 115°48′52″–116°20′42″ E) lies in the Guishui River Basin in the suburbs of Beijing (Fig. 1). This piedmont plain is located in the northern portion of the North China Plain and includes Yanqing County. The terrain of the study area is mountainous and generally higher than the surrounding landscape. The terrain of the central section is lower and is part of the plain. The elevation ranges between 476 and 2150 m and total area is 860.67 km^2.

The cold and dry temperate zone continental monsoon climate of the study area is influenced by Mongolian high pressures systems in winter and has prevailing northerly winds. The area is controlled by continental depressions in summer and prevailing southerly winds, making the summers hot and humid. The average annual temperature is about 10 °C; average annual rainfall is about 390 mm and is concentrated in June, July and August. Forest and irrigated crops are the main vegetation cover in the basin. Forest is mainly distributed along the edge of the study area, with irrigated crops in the area's central region. The sources of the Guishui River flow are mainly precipitation and groundwater recharge. Due to drought coupled with a dramatic increase in population and domestic water use, the river flows declined sharply and the region is facing serious water shortages.

The Yanqing County study area is part of the Beijing metropolitan area and has experienced rapid urbanization in the past 20 years. The downstream portion of the Guishui River Basin includes a water conservation project, the Guanting Reservoir, which had already lost its function as a water source by 1997 but is expected to recover as a source of drinking water within the next 5 years by interwatershed water transfer. Also, with the acceleration of urbanization in recent years, the study area is still facing water problems related to being a constricted source of water and satisfying agricultural water needs.

3. Methodology

3.1. Data

In order to generate future climate change scenarios, three types of data were collected for the study: