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Exposure of population to droughts in the Haihe River Basin under global warming of 1.5 and 2.0 °C scenarios

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A B S T R A C T

Based on outputs from regional climate model COSMO-CLM (CCLM), climate conditions in the Haihe River Basin (HRB) under the 1.5 and 2.0 °C global warming scenarios were projected. Drought characteristics were analyzed by the Standardized Precipitation Evapotranspiration Index (SPEI), and population exposure to regional droughts in the warming world were then assessed by a combination of the population in 2010. It was revealed that both annual precipitation and potential evapotranspiration will increase in the 1.5 °C warming level relative to the reference period of 1986–2005 in the HRB. But annual precipitation was projected to decrease in the 2.0 °C warming level, although potential evapotranspiration was projected to increase. The temperature in the HRB was projected to rise faster than the global mean, and the timing of the regional 2.0 °C warming level will come earlier. Under the global warming of 1.5 °C, intensity and coverage of droughts in the HRB exhibit no significant trends relative to 1986–2005, while the drought frequency might decrease to a certain degree. Under the global warming of 2.0 °C, intensity and coverage of droughts will increase notably. In particular, drought coverage in the 2.0 °C level will be 1.9 times larger than that of the 1.5 °C scenario. Drought frequency under the 2.0 °C warming scenario will increase relative to the 1.5 °C warming scenario but still be less than that of the reference period. As a result, population exposure to droughts in the 1.5 °C warming level could be reduced by 30.4% relative to the 1986–2005 period, but increase by 74.8% in the 2.0 °C warming level. Seasonally, an increasing trend of exposure to severe droughts in summer, autumn and winter was projected in the 1.5 °C global warming level, while that to extreme droughts in summer and winter will decrease. Under 2.0 °C global warming scenario, increasing trend of severe and extreme droughts was projected in spring, autumn and winter. And the exposure to extreme droughts in autumn and winter might be doubled relative to the reference period. Similar spatial distribution patterns were found for population exposure in 1.5 °C and 2 °C global warming levels with high values projected in south and central basin but low in north and west. But the difference is, less population will be exposed to droughts in most area of HRB under 1.5 °C warming scenario, while population exposure will be larger under 2.0 °C global warming scenario relative to 1986–2005. The additional 0.5 °C from 1.5 °C to 2.0 °C will obviously increase the drought risks, especially in the southern and central HRB. Considering the projections that more drought risks might exist under the 2.0 °C warming scenario than in the 1.5 °C level, a perspective to keep the increase in global mean temperature below 2.0 °C and limit it to 1.5 °C, has far-reaching implications to socioeconomic development in the HRB.

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1. Introduction

As one of the most frequent natural disasters in China, droughts affect agricultural production and regional economy greatly, drought losses account for 19.4% of the total meteorological disaster induced losses in China for 1985–2014 (CMA, 2015). Located in the drying band in China, the Haihe River Basin (HRB) is sensitive to climate change (Zhai et al., 2010). Numerous studies show that the intensity, frequency and coverage of droughts in the HRB have increased from 1951 to 2010, and the drought stricken area of 14,900 km^2 for 1986–2010 was 1.6 times greater than that of 1961–1985 (Yan et al., 2013; He et al., 2015; Yang et al., 2016). Projections show that both temperature and precipitation in North China will increase (Li and Ding, 2012; Wang and Chen, 2014), but a drying trend will remain in some regions of northern China in the 21st century (Hu et al., 2015; Chen et al., 2016a). Therefore, future meteorological disasters attributable to global warm in the HRB are worth of attention.

Drought indices are more intuitive and comparable than original climatic or hydrological data to describe drought event with different processes. The most commonly used drought index is the Standardized Precipitation Index (SPI), which is based on precipitation distribution. The SPI can indicate the intensity and duration of droughts and reflect droughts at diverse temporal and spatial scales. However, the SPI does not consider the influences of temperature and evapotranspiration on drought conditions and thus is insufficient to study droughts under changing climate. The standardized precipitation evapotranspiration index (SPEI) (Vicente-serrano et al., 2010), which was developed based on the SPI and takes the impact of water balance into account, is sensitive to temperature and thus suitable for drought impact assessments in the context of global warming (Chen and Sun, 2015; Huang et al., 2017).

The Paris Agreement proposed in December 2015 highlighted " holding the increase in the global average temperature to well below 2.0 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" and recognized that this would prominently weaken the risks and impacts of climate change (UNFCCC, 2015; Knutti et al., 2016). Previous studies on extreme events in a changing climate have indicated that droughts are increasing globally as a whole including China, although droughts over some Asian regions will occur less frequent with weaker intensity in the 21st century (Sheffield and Wood, 2008; Kim and Byun, 2009; Dai, 2013; Leng et al., 2015). Now with a clear intention to keep global warming below 1.5 °C or 2.0 °C, climate conditions and their impacts on the social economy at extra increasing of 0.5 °C from 1.5 °C to 2.0 °C need to be further studied.

Climate models project the climate change, and help societies prepare against the possible meteorological disasters in the future. The Coupled Model Intercomparison Project (CMIP) has provided multi-model simulations at global scales. Unfortunately, extreme regional events are hardly captured by projection from global climate models (GCMs) (Nasrollahi et al., 2015). Regional climate models (RCMs), which are dynamically downscaled from GCMs, can provide more accurate information on climate extremes and their potential impacts (Liang et al., 2008). The regional climate model Cosom-CLM (CCLM) used in this paper has already demonstrated substantial capability to capture the climate conditions in China (Cao et al., 2013; Fischer et al., 2013; Tao et al., 2013; Huang et al., 2015, 2016, 2017).

This study projects climate conditions and droughts under the 1.5 °C and 2.0 °C global warming scenarios in the HRB, one of the rapidly developing areas sensitive to climate change in China, based on the CCLM outputs. Combined with the demographic data in 2010, population exposure to droughts in the HRB in the warming world will be assessed. The main target of this paper is to project the influence and characteristic of droughts in the 1.5 °C and 2.0 °C global warming levels to provide regional evidence of the impacts from an extra increase of 0.5 °C so as to support policymakers in the development of climate change mitigation strategies.

2. Regional setting, materials and methods

2.1. Regional setting

Located at 112°-120°E, 35°-43°N, west of the Bo-Hai Sea and north of the Yellow River, the HRB covers an area of 0.32 million km^2, which accounts for 3.3% of China's land (Fig. 1). The HRB belongs to semi-arid and semi-humid climatic regions, with an annual mean temperature of approximately 10 °C. Annual precipitation in the basin ranges between 400 and 800 mm, lower in the west and higher in the south and east. The HRB is a major grain production area in China, and more than 160 million people (12.1% of China's population) live there. Water resources in the HRB have decreased by 26% in the past 30 years, and per capita water resources in the HRB were less than 300 m^3 (Chu et al., 2010; He et al., 2015).

2.2. Materials

Observed monthly meteorological data from 36 ground stations in the HRB for 1986–2005 were provided and quality controlled by National Meteorological Information Center of China Meteorological Administration. The dataset includes 8 primary meteorological factors such as monthly maximum, minimum and mean temperature and precipitation.

Daily simulated data from the COSMO-CLM (CCLM) model were obtained from the Potsdam Institute for Climate Impact Research in Germany. CCLM was developed from the weather prediction model Local Model (LM) of the German Weather Service and joined in the Coordinated Regional Climate Downscaling Experiment (Rockel et al., 2008; Fischer et al., 2013). With spatial resolution of 0.44°. CCLM was transferred to a regular 0.5°resolution by the bilinear interpolated method in this paper (Huang et al., 2015), and a total of 165 grids were included within the HRB. Change of droughts in the basin under global warming scenarios of 1.5 °C and 2.0 °C (relative to pre-industrial levels) were analyzed by comparing them with the reference period of 1986–2005.

Population data used in this paper were obtained from the Demographic Yearbook 2011, which was compiled according to the 6th national population census in 2010. For analytical purposes, we interpolated population data to the 0.5°grids, consistent with those of the 165 CCLM grids in the HRB.

2.3. Methods

2.3.1. Standardized precipitation evapotranspiration index (SPEI)

Drought is a natural disaster raised from water deficit and affects surface and ground water resources (Zargar et al., 2011). The SPEI-12 used in this paper can reflect the long-term water loss process and indicate the inter-annual change of droughts. Classification of SPEI drought levels was shown in Table 1. For deducing the SPEI, differences between precipitation and potential evapotranspiration (ETo), which reflects the water surplus or deficit in a region, were initially fitted by a three-parameter Log-logistic distribution function, and its cumulative density function was then standardized to reflect the intensity of droughts.

The Thornthwaite equation for ETo recommended by Vicente-Serrano inexplicably overestimated ETo values with increasing