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Spatio-temporal changes in precipitation over Beijing-Tianjin-Hebei region, China

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ABSTRACT

Changes in precipitation have a large effect on human society and are of primary importance for many scientific fields such as hydrology, agriculture and eco-environmental sciences. The present study intended to investigate the spatio-temporal characteristics of precipitation in Beijing-Tianjin-Hebei (BTH) region by using 316 meteorological stations during the period 1965–2014. Geographical Weighted Regression (GWR) method and High Accuracy Surface Modeling (HASM) method were applied to produce the precipitation patterns at different time scales. Mann-Kendall (MK) statistical test was applied to analyze the precipitation temporal variations. Results indicated that annual precipitation over the past 50 years appeared to be a non-periodic oscillation phenomenon; the number of wet years was approximately the same as that of dry years; significant positive trends were observed in spring during 1978–2014 and summer during 1996–2014; on the whole, precipitation in May, June, September, and December showed increasing trends at the 95% confidence level; and significant positive trends were also identified in July during 2000–2013 and August during 1997–2010, while slight decreasing trends were observed in February and November. Summer (June, July, and August) was the wettest season, accounting for 68.73% of annual totals in BTH. In general, northeastern BTH received the highest range of precipitation while northwestern area had the lowest. It was found that precipitation variation in this region had been closely linked to latitude, Digital Elevation Model (DEM), distance to the sea, and urbanization rate. In addition, land use played an important role in the decadal precipitation changes in BTH.

1. Introduction

Changes in climate have already affected agriculture, water resources, biodiversity and human life (Rana et al., 2011; Sayemuzzaman and Jha, 2014; Zhou et al., 2015; Higham et al., 2016; Chen et al., 2017). Improving knowledge on climate change is a major component in regional climatic and environmental change studies, and is important to environmental economic and policy makers (Solomon et al., 2007; Jhajharia et al., 2012). As one of the main elements for describing climate change, precipitation is a critical part of the eco-hydrology, agriculture, and urban planning (Houghton et al., 1995; Tobin and Bennett, 2010; Hou et al., 2014; Jabareen, 2015; Chatterjee et al., 2016). Therefore, it is significant important to investigate the changing patterns of precipitation to further understand climate change, and help policy makers set appropriate regulations for effective flood and drought control (Chatterjee et al., 2016; Wang et al., 2016).

Spatio-temporal precipitation patterns on a regional scale under the impacts of climate change have been extensively investigated in recent years (IPCC, 2014). Researchers showed that detecting long-term trends and variability of past climatic variables on regional and local scales is more useful for identifying climate change adaption options, particularly in urban planning and water resources management (Onof and Arnbjerg-Nielsen, 2009; Quirmbach et al., 2012; Irannezhad et al., 2014). Zhai et al. (2007) suggested that the precipitation trends during the recent 50 years across China were imperceptible but the regional and seasonal changes were significant. Sui et al. (2013) revealed that annual total precipitation increased in the northwest of China and in the middle to lower reaches of the Yangtze River basin. Liu et al. (2015) investigated the long term precipitation variability in the karst area of southwest China and found that annual precipitation showed a slightly decreasing trend, while autumn precipitation decreased significantly over the whole study area.

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Climate change has exacerbated the political and social stresses in China (Wang et al., 2015). This is particularly true for the Beijing-Tianjin-Hebei (BTH) region, which is one of the most important economic, political, cultural and transportation centers in China and is becoming more and more important in the world (Zhang et al., 2016). The coordinated development of BTH region has been included in the Chinese '12th Five Year Plan' as a national strategy in the past 5 years. Accurate understanding of precipitation in this area would be helpful for protecting urban residences and human life, and thus promoting coordinated development of the BTH urban agglomeration. It is reported that, people in the BTH region are observing more frequent extreme events, such as the severe drought in Tianjin during 1980–1982, the continuous high temperature event over Beijing in the early July 2010, and the extraordinary rainstorm disaster in Beijing in 2011 (Du and Huang, 2011; Su et al., 2015). These types of changes are likely to bring many challenges to the sustainable development of the region. The priority for the local policy makers and resource managers is to understand fully the current situation and trends of local climate in response to global warming to provide a scientific basis for developing appropriate mitigation and adaptation strategies. However, up to now, very few studies had been conducted to treat the quality controlled long time series under high density meteorological stations, and there has been no analysis about spatio-temporal changes in precipitation with high accuracy in BTH region.

The aim of this paper is to use a more accurate Geographical Weighted Regression (GWR) method together with a High Accuracy Surface Modeling (HASM) method to construct the precipitation distributions on different time scales and improve the trend analysis. The spatio-temporal precipitation variations and changes in BTH region during 1965–2014 are detected and analyzed, which are essential for planning water resources and urban food security. The paper proceeds as follows: Section 2 describes the study area and data; Section 3 gives the methodology and the results are shown in Section 4; the conclusions are given in Section 5.

2. Study area and data

2.1. Study area

The study area, BTH (36°03′N–42°40′N, 113°27′E–119°50′E), is approximately 215,864 km^2, including Beijing municipality, Tianjin municipality, and other 11 cities in Hebei province in China (Fig. 1). Beijing is the capital and the economic, political and cultural center of China. Tianjin is a heavy industrial city. As a core area of economic development in China, BTH has a long history of industrial and urban development, boasting the famous Jing-jin-tang (Beijing, Tianjin, and Tanshan cities) Industrial Belt (Tan et al., 2005). The eastern and southern BTH are adjacent to the Yellow River and Bohai Sea, corresponding to 46.17% of the whole study area. Taihang and Yan mountains are in western and northern BTH, which constitute 53.58% of the total area. The monsoon climate has obvious seasonal variations characterized by hot, rainy summers, and cold, dry winters. Meteorological disasters are frequent and have caused serious damages to human life, especially in recent years. Drought often strikes in the spring and flooding occurs in the summer (Feng et al., 2007). Precipitation in this region is complicated associated with the rapid urbanization and global climate change.

2.2. Data

A high-density network of monthly precipitation records at 329 meteorological stations in and outside BTH region has been used in this study, which was obtained from the National Climate Center of China for the period 1965–2014. The data include almost all national and provincial stations in this region, and represent the best dataset currently available that are first used for studying climate change in BTH. The introduction of the datasets in the outer of the area can improve the accuracy of the simulation results (Yue, 2011). The 329 sites were subject to strict quality control procedures by applying the software RHtests developed by Wang and Feng (http://etccdi.pacificclimate.org/software.shtml) to detect, and adjust for, multiple change points that could exist in the data series. Finally, data from 316 stations with consistent and missing data less than 1% remained for further analysis (Fig. 1). The Normalized Difference Vegetation Index (NDVI) at 1 km spatial resolution was obtained from http://www.spot-vegetation.com/ , which is a measure of vegetation activity and biomass. The Digital Elevation Model (DEM) with a spatial resolution of 90 m derived from http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp was resampled to 1 km by using AUNDEM software (Yang et al., 2007), which was further used as auxiliary data to develop the statistical transfer function for precipitation in the downscaling process. Furthermore, the urbanization rate was obtained from the statistical yearbook of China and represented the different urbanization development stages in BTH (Chen et al., 2011; National Bureau of Statistics of China, 2015).

3. Method

3.1. Simulation of spatial precipitation patterns

Obtaining accurate precipitation fields by using ground observations is not sufficient particularly if there are large climatic gradients. A way to improve the precipitation simulation is to describe precipitation as a function of topographical and geographical factors on the landscape. However, the relationship between precipitation and its influencing factors is usually not constant in space (Xu et al., 2015). GWR is popular due to its ability to explore the non-stationary and scale-dependent characteristics of the relationship between the dependent and explanatory variables. Most researchers found that the multiple regression with residual interpolation is better than direct observation interpolation due to the smoothing effect occurred in the regression process, which leads to system or random errors (Xu et al., 2015). The residual produced in the regression process can usually be modified further to generate improved precipitation fields (Perry, 2006; Ninyerola et al., 2007; Joly et al., 2011).

In this research, we first develop the relationships between precipitation and a range of topographic and geographic variables. Then, we modify the residual produced by the regression method using HASM. The combination of GWR and HASM has been successfully applied in precipitation simulation in recent years (Yue et al., 2013; Zhao et al., 2016). Precipitation in BTH region shows great spatial variations due to the complex topography, the large water body, and the rapid urbanization. Proximity to a large water body greatly affects the climate in a region (Domroes and Peng, 1988). Terrain features produce large precipitation gradients (Chen et al., 2014). And urbanization affects local precipitation by changing the heat flux (Marquinez et al., 2003; S.D. Zhao et al., 2014; Xu et al., 2015). A stepwise regression method was used to select the most influential factors from longitude, latitude, DEM, the sky view factor (Svf), the modified aspect (Asp), the distance to the sea (Dis), NDVI, and urbanization rate (CR). The definitions and formulae for CR, Svf and Asp can be expressed as (Scott, 2004; Yue, 2011; National Bureau of Statistics of China, 2015)

$$CR = {Purban}\Big/{ptotal} \times 100\% \tag{1}$$

$$Svf = \frac{1 + \cos(\pi \cdot (Slope/180^o))}{2} \tag{2}$$

$$Asp = \begin{cases} -\cos(\pi \cdot (Aspect/180^o)) & slope\ are \\ 0 & flat\ area \end{cases} \tag{3}$$

where P_urban stands for the number of urban populations; p_total is the urban-rural population number.