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Green space water use and its impact on water resources in the capital region of China

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ABSTRACT

Green space plays important roles in the environment as an integral part of the urban ecosystem. It may have various impacts on urban water resources depending on its location and type. Beijing is a major city that is severely deficient in water resources and the conflicts of water demand between different users such as industry, farm, residence, orchard, etc., becoming increasingly evident. Thus rational water utilization within the green space is critical to regional water security. Based on remote sensing, field investigation, and statistical data, this study focuses on the water use and the impacts of three types of green space (i.e., mountainous vegetation, suburban farmland, and green gardens) on water resources in the capital region of China from 2002 to 2013. The results show that the mean annual evapotranspiration (ET) was around 600 mm for the mountainous vegetation, which is almost equal to precipitation (P) in normal years. However, in the years with elevated rainfall, the mountainous vegetation distributing in catchment region contributed water to the reservoirs. In contrast, suburban farmland and green gardens were both dependent on groundwater for irrigation, with the rainfall utilization rate being low, which caused negative effects on water resources. The inefficient irrigation of suburban farmland was up to 115 mm and the suburban farmland area with higher water consumption was 230 km^2 in 2005 (out of the total 50% suburban farmland). ET of the green gardens was relatively low (400 mm) compared to the mountainous vegetation. P (525 mm) could meet the demand of ET, and consequently, irrigation (as high as 581.95 mm/m^2) was actually superfluous. Our results suggest that an integrated water management scheme is needed for the green space, this includes improving irrigation efficiency and increasing infiltration rate of rainfall in urban land surface.

1. Introduction

Urban green space is a network system, which consists of green gardens, urban forests, suburban farmland and water (Xu et al., 2011; Diane et al., 2011; Lee and Maheswaran, 2011; Wolch et al., 2014). The green space has the functions of e.g., air purification, carbon sequestration, and recreation (Kong et al., 2010; Xu et al., 2011; Colding and Barthel, 2013; Zhang et al., 2012a,b; Yang et al., 2015), while also having great impacts on water resources by regulating the distribution of evapotranspiration (ET) and consequently water yield (WY) (Bosch and Hewlett, 1982; Farley et al., 2005; Lu et al., 2011). The impacts of urban green space on water resources have been concerned broadly because the different types of green space may play different roles in water resource dynamics under various environmental conditions (Xia et al., 2007; Coutts et al., 2012; Yang et al., 2015).

Many cities in the world have constructed specific water management systems for urban green space according to climate, terrain and green space development plans. For example, in order

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to decrease urban flood risk and reduce irrigation water, Boston and Minneapolis (USA) have explored the water management of urban green space since 1900s (Welch, 1993). They established an urban park system along rivers in the cities, which strengthened regulation of surface runoff and decreased the dependence on ground water for green space (Brown et al., 2013; Dobbie et al., 2014). In contrast in London and Tees Valley of Britain (UK), the scattered distribution of green space caused lower irrigation efficiency and high water waste. The theory of Green Infrastructure (GI) is building a unified management mechanism through the construction of green space network, which can connect the sporadic small green gardens and farmland by the greenways effectively (Tzoulas et al., 2007; Gill and Handley, 2007). In Melbourne and Sydney (Australia), the theory of Water Sensitive Urban Design (WSUD) has been put forward that a complete rain water recovery and reuse system should be established which increased rainfall utilization and reduced groundwater consumption (Wong, 2007; Coutts et al., 2012).

Water resources management of green space have been focused in China during the past twenty years (Xia et al., 2007; Byomkesh et al., 2012; Barthel and Isendahl, 2013). Despite many policies about water management for urban green space being implemented, problems of water shortage and water waste are still not solved because they only focused on single issue. For example, the ability of water supplement to the reservoirs has gradually declined with the changes of land use type (e.g., the unreasonable expand of forests and grassland), which caused substantial decrease of available water (Huang et al., 2012; Li et al., 2015). Insufficient utilization of rainwater and extensive irrigation still exists in farmland and green gardens causing water use deficiencies.

Beijing, as the capital of China, is a region with serious water shortage. The water resources per capita of Beijing are less than 100 m^3, which was far below the average level of China and well below the internationally recognized limit of 1000 m^3 (Huang et al., 2012; Wang et al., 2013; Fan et al., 2015). The demand for green space is increasing with the urban development and environment deterioration. At the end of 2014, the green space area was 10359.1 km^2 was about 63.12% of total area of Beijing. According to the requirements of urban green space developing in "the Urban Master Plan for Beijing (2004–2020)", green space in Beijing will grow at a faster rate in coming years. However, the water stress may be intensified with the contradictions between water scarcity and urban green space development (Xu et al., 2011). Therefore, it is critical to quantify the water use of the green space and identify the potential issues.

Good understanding of the interactions between climate, landform, type, and spatial distribution of the green space is the basis for making an appropriate water management scheme. Therefore, the objective of this study is to assess the impacts of green space on the water resources of the Beijing region, focusing on three types of green space including mountainous vegetation, suburban farmland, and green gardens. Specifically, we aim to 1) examine the spatial and temporal variation of ET and WY from 2002 to 2013 as well as the hydrological consequences of the three types of green space; and 2) evaluate the irrigation efficiency for farmland and green gardens. We also expect to provide useful management advice to local government on green space water management.

2. Material and methods

2.1. Study area

Beijing (39°26′ - 41°03′ N, 115°25′ - 117°30′ E) is located at the border of the North China Plain and Inner Mongolia (Fig. 1a), and the total area is 16411 km^2 (Xie et al., 2017). The Taihang mountain chain is located in the west and the Yanshan mountain chain located in the north, while the elevation is below 100 m above sea

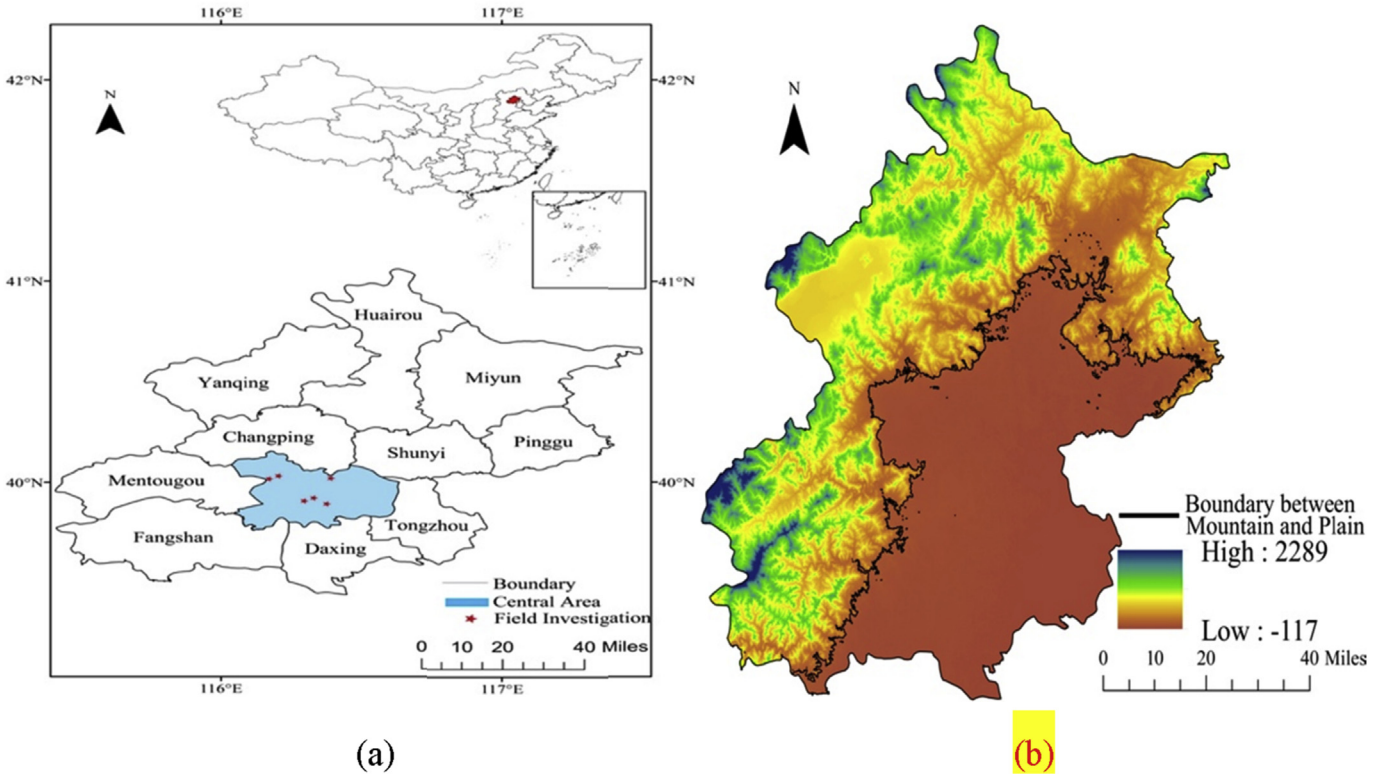

Fig. 1. Location of the study area (a); The DEM of Beijing (b).

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