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The relative impact of urbanization and precipitation on long-term water level variations in the Yangtze River Delta

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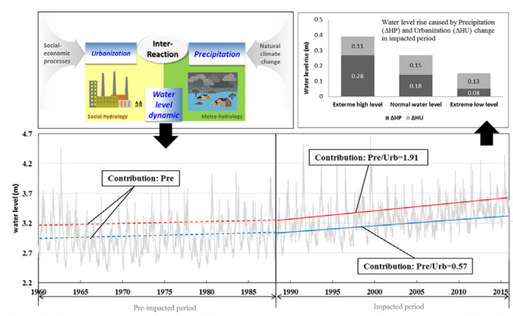
HIGHLIGHTS

- Pre-impact (1960–1988) and impacted period (1989–2015)
- Urbanization contributed in impacted period, precipitation contributed from Apr to Nov.
- Flood season: precipitation contributed two thirds of water level rise.
- Non-flood season: urbanization contributed two thirds of water level rise.
- Spatially, western basin dominated by precipitation, eastern basin controlled by urbanization.

GRAPHICAL ABSTRACT



The driving forces of water lever dynamic and their contribution rate on water level increment in Central Taihu Basin
Note: ------water level trend in flood season in pre-impacted period, ——water level trend in flood season in impacted period
------water level trend in non-flood season in pre-impacted period, ——water level trend in non-flood season in impacted period

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ABSTRACT

The combined and individual hydrological impacts of climate variation and urbanization have been extensively discussed over the past few decades, yet little is known about the relative impact of each. In this paper we took one of the most developed regions worldwide, Yangtze River Delta, as an example to analyse the long-term relative impacts of precipitation and urbanization change on water level alterations, based on precipitation, water level series, and annual impervious area data from 1960 to 2015. Abrupt changes detection in the water level series divided the data into the pre-impact period (1960–1988) and impacted period (1989–2015), and relative impacts of precipitation and urbanization on the water level increase from pre-impacted to impacted period, as well as their spatial and seasonal variations were estimated with the elasticity method. The results indicated that the urbanization change showed no distinct influence on the water level rise in the pre-impact period, while the precipitation played distinct roles only during summer months in the impacted period; the precipitation dominated two thirds of the water level rise in flood season, and in non-flood season the urbanization controlled the two thirds of the water level rise; spatially, the water level variations in old and new urban area were dominated by precipitation and urbanization process respectively; compared with precipitation amount, the water level correlated more strongly to the contribution ratio of precipitation. The results would provide a good reference for flood control and water resource management in the river basin, especially in the economically developed areas.

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1. Introduction

Climate change and human activity are two major factors driving hydrological cycle processes and alterations in the spatiotemporal distribution of water (Dey and Mishra, 2017; Lutz et al., 2014; Salvadore et al., 2015; Shuster et al., 2005; Watts et al., 2015). Climate variation can alter the spatial and temporal patterns of precipitation and ultimately the water cycle processes. The amount of analyses related to the impacts of climate change on hydrological systems has increased distinctly in the last several decades, especially in regard to studies of the precipitation response to climate change (Costa et al., 2011; Pyke et al., 2011; Teutschbein and Seibert, 2012; Tramblay et al., 2012; Xu et al., 2013). The influences of human activity, such as land use/cover change, reservoir operations, and direct water extraction, are however more complex because of its various modes and multi spatial/temporal scales, depending on the scientific and technologic level (Burns et al., 2012; Hibbs and Sharp, 2012; Niehoff et al., 2002a; Vanacker et al., 2005; Wang et al., 2013; Zhou et al., 2013). In particular, land use/cover change and river network change caused by widespread urbanization worth more research effort compared with the management measures, because it is more universal and can lead to intense modifications of the underlying surfaces, which consequently alter the local hydrological processes (Miller et al., 2014; Rose and Peters, 2001; Sheng and Wilson, 2008; Suriya and Mudgal, 2012). Precipitation variation and urbanization interact with each other in complex ways, and the combined effect of the two can profoundly change the rainfall and runoff mechanism in highly urban regions (Braud et al., 2013; Guo et al., 2008; Praskievicz and Chang, 2009). One such typical basin is Yangtze River Delta (YRD), which is one of the most developed and largest economy region in China. YRD encompasses Shanghai, Nanjing and Hangzhou city, covering an area of 0.2 million km^2, yielding a GDP of 1.9 trillion $ (2014), and supporting a total population of 150 million. These three measures account for about 2.2%, 18.5%, and 11% of the national summation respectively (Zm, 2017). Economically, the efficient development mode and the close linkage inside the urban agglomeration in this region, have formed demonstrative effect to other regions in China and even the world. Physically, YRD is characterised by broad flat geomorphology, barrier free lowland plain river networks, and abundant marine monsoon precipitation, which make this area particularly susceptible to threats from flood risk. Due to the combination of the economical and physical situation, the hydrological problem caused by the precipitation change and rapid urbanization in this region would be highly typical and representative.

Precipitation variation together with urbanization and their influence on hydrological processes are drawing more and more concern from the government, public, and academic circles (Defries and Eshleman, 2004; Dey and Mishra, 2017; Lioubimtseva et al., 2005; Niehoff et al., 2002b). However, because of the lack of detailed mechanistic understanding and the non-linear relationships between cause/consequence factors, most studies have focused on the combined effects of land use and climate change (Astaraie-Imani et al., 2012; Chung et al., 2011). Compared with the gradual precipitation variation caused by climate change, rapid urbanization processes occur over a relatively shorter period and at a higher intensity, and may thus cause more abrupt disturbances in hydrological processes. Consequently, the hydrological regime during the times with intensive human activities will differ from the original, natural sequence of variation. Identifying and quantifying to what extent the hydrological system responds to urbanization and precipitation individually represents an urgent research need, especially in lowland urbanised catchments. The temporal and spatial variation of the individual effect worth more research effort due to the spatio-temporal inconsistency of the precipitation and urbanization processes. Such research could provide supportive information for forecasting and strategic water resource management based on the dominating factors of hydrological change.

The Central Taihu Basin located in the middle of YDR is a typical plain river network area undergoing rapid urbanization and economic development in China, and the coupled hydrological consequences of urbanization and precipitation change have become the focus of headline news reports around the world, e.g., the cyanobacteria bloom event in 2007 and the flood event in 1999. Moreover, the deterioration of aquatic environments, degradation in ecosystem services, and decreases in flood regulation functions caused by complex environmental changes in this area have drawn a tremendous amount of attention because of its fragile hydrological system, despite the theoretical and methodological challenges (Deng and Xu, 2018; Wu et al., 2018; Xu et al., 2016). With the further promotion of urbanization and the significant increase of summer precipitation according to projections (Guo et al., 2011; Zhang et al., 2008), the flood risks in this area are expected to increase by approximately 4–15 times by 2050 under different climate change and socio-economic scenarios (Wang et al., 2013). An in-depth understanding of the influence and relative importance of each component on the regional hydrological processes and water resources will be essential to mitigating the increasing flood risks and carrying out strategic water management projects in the plain catchment.

In this research, we selected the Central Taihu Basin in the middle of the Yangtze River Delta as the study area to analyse the variation trends of urbanization, precipitation, and water levels from 1960 to 2015, and then, we estimated the relative impact of urbanization and precipitation on water level variations under different water level conditions; finally, the individual contribution rates of the two factors to the water level rise were evaluated, especially the extreme water level changes. These results would provide support for regional hydrological planning efforts as well as flood forecasting and prevention programs.

2. Materials and methods

2.1. Study area

The Central Taihu Basin is located in the middle region of the Yangtze River Delta, encompassing the cities of Suzhou, Wuxi, and Changzhou in the southeastern part of Jiangsu province in China (Fig. 1). The basin covers an area of 7929 km^2, and holds a population of 15.26 million. The study basin lies to the west of the Shanghai area, and it is bounded by the Yangtze River in the north and Taihu Lake in the west. Being dominated by a humid climate; the average annual precipitation of this area is approximately 1050 mm, and the average temperature is around 15.5 °C. The precipitation in the flood season (from May to July) accounts for 60.78% of the total annual amount. The seasonal and annual variation of precipitation is extremely high because of the impacts of tropical cyclones from the east Pacific and north Indian Ocean. The altitude of most areas varies from 2 to 5 m with slopes lower than 0.1%, except for a strip of remnants of ancient coastline with an elevation range from 5 to 8 m in the middle of the basin. Currently, this area has been suffering from increasing economic losses and confronted higher flood risk than history time, due to the combination of geographical location, economic background and climatic condition (Fig. 2).

2.2. Data acquisition and processing

The long-term daily averaged water elevation and precipitation data from 1960 to 2015 were collected from eight hydrology/precipitation stations located inside the study area (Table 1, Fig. 1). Because the precipitation stations were distributed evenly and densely in the plain area, the average daily precipitation was calculated to represent the overall conditions of the basin. The land use cover change was monitored with interpreted Landsat images of the study area from the 1970s, 1991, 2006, and 2015. The spatial resolution of the images from the 1970s was 60 m, while the remaining images had a resolution of 30 m. Land use maps and river network thematic maps were also referenced during the image processing. Due to the lack of remote sensing