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Driving force of the morphological change of the urban lake ecosystem: A case study of Wuhan, 1990–2013

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ABSTRACT

The conflict between rapid urban growth and the maintenance of water landscape is gaining momentum in China. The shapes of the urban lakes have been deeply affected by the rapid urbanization in recent decades. This study analyzed the temporal-spatial change of East Lake as the largest urban lake in China using remote sensing images during 1990–2013. Then the STIRPAT model is employed to assess the impact of human activities as driving force on lake changes. The results indicated that the surface area of East Lake showed a slight decrease trend in the first decade and a sharply reduce trend from 2000 to 2013. The accelerated decline trend of landscape shape indexes showed that the shapes complexity of East Lake's water body was decreasing and human intervention was intensifying in the study area. The increasing population and urbanization are found to be the principal driving forces of recession of East Lake ecosystem. And we conclude the driving mechanism of morphological change of urban lake to better understand the reasons of the urban lake change. The conservation of urban lake should be emphasized due to its fragility during rapid urban expansion.

1. Introduction

Urban lakes are important environments for maintaining urban ecosystem, which play significant roles not only in regulating climate, preserving biodiversity, adjusting and restoring flood, but also recreation, educational and other economic purposes (Irwin and Bockstael, 2007; Wang et al., 2008; Cuffney et al., 2010). Rapid urbanization makes the protection of urban lakes facing a lot of challenges (Grimmond, 2007; Grimm et al., 2008; Su et al., 2012), such as eutrophication or water pollution (Weber and Puissant, 2003; Liu et al., 2008a). The riparian environments have been significantly modified, such as decreased vegetation and diminished valuable biotopes (Sear and Newson, 2003; Yli-Pelkonen et al., 2006; Henny and Meutia, 2014). And a growing number of urban lakes are filled and encroached as a result of the desire of human beings for land (Du et al., 2010; Henny and Meutia, 2014), which destructed the lakefront landscape and decreased their ecological functions (Yang et al., 2009, 2011; Li et al., 2013).

The analysis of historical and recent multi-temporal and multi-spectral satellite data is useful to study and monitor the environmental change in long time-series. There have been recent efforts to study the morphological evolution of river system in urban area (Chen et al., 2013a; Xu et al., 2013). Some studies focused on the impact of urban expansion on wetland change in Wuhan (Wang et al., 2008; Du et al., 2010; Xu et al., 2010). But they did not analyze the driving force of the lakes changes. There are several models to estimate the ecological impact caused by human activities, such as Ordinary Least Squares regression model (OLS), Partial Least Square regression model (PLS), stochastic dynamic model, .etc. The IPAT and STIRPAT model were usually applied to analyze the relations between human activities and the environment (York et al., 2003; Lin et al., 2009; Chen et al., 2013b), such as ecological footprint (Jia et al., 2009), CO_2 emissions (Zhang and Yan, 2012; Yue et al., 2013), land use and land cover change (Veldkamp and Fresco, 1996; Liu et al., 2008b). Stochastic dynamic methodology and urban expansion scenario model coupled with cellular automata have been used to simulate the spatial and dynamic ecological patterns and urban evolution (Cabecinha et al., 2009; He et al., 2006).

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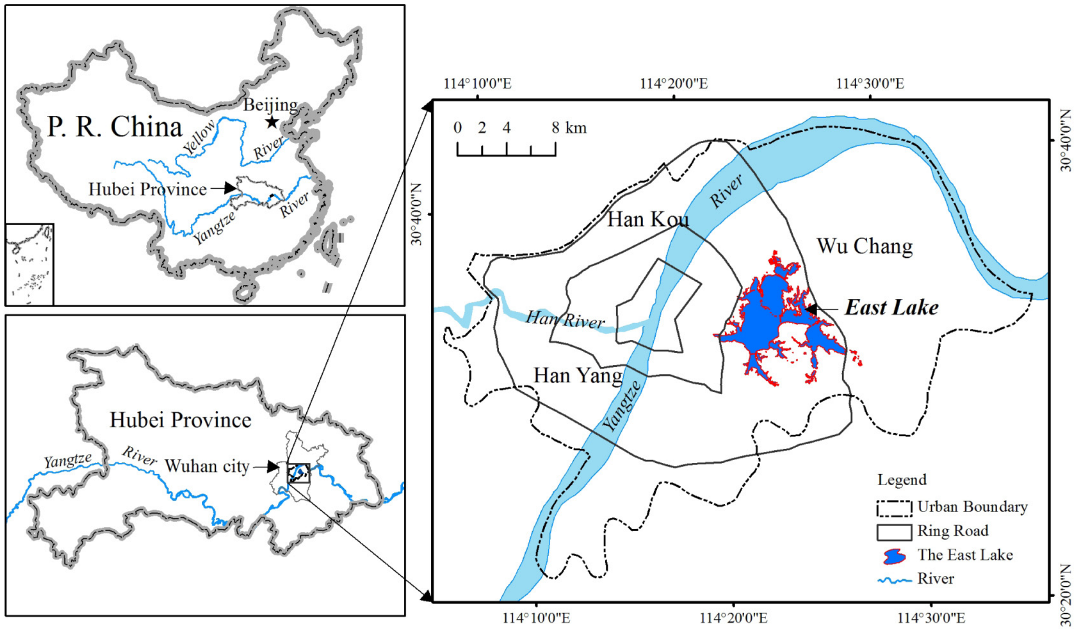

Fig. 1. Location of the East Lake in Wuhan.

However, few studies focused on the evolution of urban lake and their drivers. And relatively little knowledge has been generated to fully understand the mechanism of human activities on urban lake change. STIRPAT model can essentially be transformed into a random form of the OLS regression model, which allows for determining variables subjectively before selecting independent variables and has uncertainties that cannot totally exclude the impact of collinearity among the independent variables. The objective of this study was to detect spatial and temporal changes of urban Lake by using multi-temporal Landsat TM and ETM+ images and understand the driving forces of morphological changes of urban lake based on STIRPAT model. Therefore, the aims of this study are: (1) to calculate the surface area change of East lake during 1990–2013 and (2) to analyze the driving force of the change of the East Lake system.

2. Methodology

2.1. Study area

East Lake, the largest urban lake in China, is located in Wuhan City. Wuhan, which is divided to three towns of Wuchang, Hankou, and Hanyang by Yangtze river and Han river, is the capital of Hubei province (Fig. 1). It is famous for hundreds of lakes. Wuhan is a metropolitan city in the centre of China. With the economical development, Wuhan experienced the process of rapid urbanization after the reform and openness. As a result, urban lakes and wetlands have strikingly decreased in extent (Zeng and Lu, 2008; Xu et al., 2010) and water quality has deteriorated (Tang et al., 2009; Jiang et al., 2013). This region has a subtropical climate, with a mean annual temperature ranging from 15.8 to 17.5 °C, and an annual precipitation of 1205 mm. Much of the precipitation (~80%) falls in the rainy seasons of April to August.

2.2. Data collection

An important criterion in selecting satellite images for lake change analysis is that all the images should be free from cloud cover in the East Lake area. In this study, ten Landsat TM/ETM+ images meet the requirement acquired in 1990, 1993, 1995, 1997, 2000, 2003, 2005, 2007, 2010 and 2013 were selected to extract the surface area of East Lake. All the images are cloud-free on the East Lake region. The study area is entirely contained within path 123, row 39 for Landsat TM/ETM+. The images were downloaded from United States Geological Survey (http://glovis.usgs.gov/). The data used for reference include the following: (1) detailed topographic maps in 1990s, at scale of 1/10,000; (2) Panchromatic image with resolution of 15 m in 2000, 2003 and 2013; and (3) high resolution images in Google Earth in 2007, 2012.

Radiometric correction of the images had already been carried out by the NASA. Accurate geometric correction is essential for spatial analysis, since the potential exists for registration errors to be interpreted as lake area change, leading to an overestimation or underestimate of actual change. This geometric correction was used to perform image-to-image rectification for the images of selected years by using the Auto-sync model of ERDAS 9.3 with an RMSE of less than 1 pixel. The Landsat images were rectified to the Universal Transverse Mercator (UTM) projection system (spheroid WGS 84, datum WGS 84, zone 50).

The data on population, GDP and built-up area in selected years were obtained from the Wuhan statistical yearbook. The surface area of East Lake in sample years were used for the morphological change of urban lake. While the data extracted from all the ten years were applied to analyze the driving forces of the urban lake change.

2.3. Methods

2.3.1. Normalized difference water index (NDWI)

The use of NDWI for delineating the open water body was first introduced by McFeeters (1996). The green and near infrared (NIR) bands are most suitable for extracting the surface area of lakes by evaluating different NDWIs based on the different spectral bands of TM and ETM+ (Ouma and Tateishi, 2006). In this study, NDWI is calculated based on the green band 2 and NIR band 4 for Landsat TM/ETM+. For Landsat 8 NDWI is computed based on the green band 3 and NIR band 5.

$$\mathrm{NDWI} = \frac{B_G - B_{NIR}}{B_G + B_{NIR}} \tag{1}$$

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