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On the relationship between landscape ecological patterns and water quality across gradient zones of rapid urbanization in coastal China

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ABSTRACT

In order to improve water quality and ecosystems health, the focus of river ecological restoration and water ecosystem-based management needs to reach beyond its usual policy domain by restricting the expansion of urban built-up land and reducing urbanization-related pollution. This study aims to assess the impacts of urbanization on water quality for three spatial urban development zones, i.e. center, inner peri-urban and outer peri-urban of the eastern coastal municipality of Lianyungang, China. We analyze the relationship between urban landscape ecological pattern and water quality in three landscape zones. The study explores this relationship and its policy implications. The results of our analysis are as follow: (1) In the center zone, the landscape pattern metrics, largest patch index (LPI) and total class area (CA) were strongly correlated with water quality parameters, such as COD_{Mn} and NH_3–N; (2) In the inner peri-urban zone, the number of significant relations of land use pattern metrics and water quality parameters in 2008 was greater than that in 2000 and 2004; (3) land use pattern metrics in the outer peri-urban were less correlated to water quality than in the other zones; (4) the degree of correlation in different spatial zones was in following order: center (2008 > 2000 > 2004), inner peri-urban (2008 > 2000 > 2004), outer peri-urban (2004 > 2000 = 2008). Thus, the relationships between landscape and water quality varies significantly over space due to varying watershed characteristics and pollution sources across space.
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1. Introduction

Urban areas are hot spots that generate ecological and environmental impacts at multiple scales (Qureshi et al., 2014), these are special ecosystems that present both the problems and solutions to challenges for sustainable development in a rapidly urbanizing world (Breuste and Qureshi, 2011; Grimm et al., 2008; Qureshi et al., 2010). Water quality degradation is caused by drastic land use, industrial pollution in catchments (Foley et al., 2005; Park et al., 2014). Numerous studies have especially looked at the relationship between land use change and water quality affected by human disturbances under the influence of rapid urbanization such as industrialization in urban and peri-urban areas and land conversions accommodating urban lifestyles (Carey et al., 2011; Hoanh et al., 2009; Tran et al., 2010; Haase et al., 2014). Water quality degradation in urbanized areas is related to abrupt population growth that causes large increases in nutrient and microbial loads (Maillard and Pinheiro Santos, 2008; Srinivasan et al., 2013) as well as in fecal indicator bacteria and heavy metals (Kang et al., 2010; Karim et al., 2014). Huang et al. (2009) investigated the spatial-temporal variability of water quality properties and the effects of land use changes on water quality.

Effective analytical tools are used to deal with spatial data and complex interactions in water quality management, such as geographical information systems (GIS), processing of high-resolution digital land-use data, and multivariate statistics (Maillard and Pinheiro Santos, 2008; Cai et al., 2010). One of the widely used software is FRAGSTATS (McGarigal et al., 2009; Leitão et al., 2006), and several metrics, like Patch Analyst in ArcView have been integrated into existing GIS software. Furthermore, remote sensing, GIS and related technologies are efficient methods to analyze spatial

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distribution information for watershed management (Maillard and Pinheiro Santos, 2008).

This study assesses the impacts of urban sprawl on water quality across different urban and peri-urban landscape ecological zones (center, inner and outer peri-urban) of Lianyungang, a fast developing coastal city. We compare two time periods, 2000 to 2004 and 2004 to 2008 to account for the huge regional development efforts and associated land use changes in the second period (Li et al., 2014). The relationship between selected urban landscapes and water quality parameters is investigated by satellite image processing (for land use data extraction), spatial analyses (using GIS techniques) and statistical data analysis. We also attempts to explore the relationship and its implications on the environmental management in three distinct urban development zones, which experienced a dramatic shift in urban living, and different land cover types in different areas.

2. Data and methods

2.1. Study area

Lianyungang Municipality is a less developed coastal area located at the shore of the Yellow Sea (Fig. 1), which has recently been experiencing rapid urbanization followed by environmental pressures and degradation (Li et al., 2010). Its total area is about 7500 square kilometers and includes three districts in the center area and four counties in the peri-urban area. Lianyungang. As one of the most rapidly developing areas in Jiangsu, has been experiencing rapid urbanization and economic development since 2000. For example, gross domestic product (GDP) increased from 293.13 billion RMB in 2000 to 825.83 billion in 2008, and further increased in 2011 to 1410.5 billion RMB, which was the third largest in Jiangsu province with an average annual increase of 13%. In the near future, as the only coastal port city in Jiangsu province, Lianyungang will become the largest economic agglomeration region in Jiangsu.

The Huaishu, Shuxin, and Qiangwei Rivers supply the majority of Lianyungang Municipality's drinking water and are crucial water sources for agriculture and industry. Lianyungang has implemented a series of watershed protection measures and the national standard of surface water in order to facilitate different water uses, including land acquisition, aimed at preserving water quality in the main watersheds. However, some of the rivers and reservoirs have been heavily polluted (water quality degraded to levels IV and V, in environmental quality standards for surface water GB 3838-2002), because of rapid urbanization and increasing share of impervious surfaces.

2.2. Land use classification derived from satellite image data

Remotely sensed data have been used in numerous studies for the past three decades to monitor and model urban change. We processed three sets of Landsat Thematic Mapper (TM) images from February 2000, December 2004, and February 2008 to investigate land cover change in the study area. The Landsat TM images were obtained from the Institute of Remote-Sensing Satellite Ground Station at the Chinese Academy of Sciences. The three images were classified by adopting a post-classification change detection method, which involved the use of spatial masking and supervised classification techniques (employing a maximum likelihood classifier with prior probabilities, Stefanov et al., 2001). Subsequently, all the land use maps were derived from three sets of Landsat TM images. Each image was corrected before interpretation using a geometric correction tool based on a 1:500,000-scale topographic map. A set of composite images was created for 2000, 2004, and 2008 by combining Landsat TM bands 3 (red), 4 (infrared), and 7 (mid-infrared)from the leaf-off and leaf-on imagery to create a six-band multi-date image. The accuracy assessment of Kappa statistics for the three sets of land use classifications was 0.84 (2000), 0.85 (2004), 0.83 (2008), respectively (Li et al., 2014). Different land use types were then categorized by using both unsupervised classification and supervised classification algorithms, and also based on the field trip data and resources. Land use classification system of land use survey was chosen and referred to form the classification system for this study. The final classification yielded seven classes for each image. The seven land use types were aggregated from 14 more detailed categories in the original data set by combining similar land use types into one broad category. The resulting categories are: (1) farmland and arable land; (2) built-upland defined as rural settlements, commercial lands, industrial parks, and developing areas; (3) wetland (saltern dominant); (4) forest; (5) sea; (6) water, including rivers and reservoirs; and (7) bare land resulting from human activities or natural disasters.

2.3. Spatial pattern metrics

Spatial pattern metrics were calculated using the open source software FRAGSTATS. FRAGSTATS reports a wide range of metrics including shape and complexity among other landscape aspects (cell size is 25, 25 meters). The software computes several simple statistics representing area and perimeter (or edge) at the patch, class, and landscape levels. This study primarily focuses on the class level metrics to target the medium scale processes and to suit relatively small areas (in terms of spatial extent). All the selected landscape metrics of size, distance, shape, isolation and diversity (Table 1) represent key components of landscape management. In addition, those metrics have been widely used in a number of studies that deal with the relationship of land use patterns and water quality (e.g., Uuemaa et al., 2005; Sivrikaya et al., 2007; Yang and Jin, 2010; Su et al., 2011; Huang et al., 2013). Landscape metrics have been considered to be effective tools for the identification of degraded ecological conditions (McGarigal et al., 2009). The landscape structure is important to explain the relationships between ecosystem processes and human activities and functions (King et al., 2005). The spatial pattern is also a useful landscape index for water quality, because of the diversification of length and width that could change their effectiveness as nutrient sinks (Carey et al., 2011).

2.4. Water quality data

Water quality data for the years 2000, 2004, and 2008 were obtained from the Lianyungang Environmental Quality Bulletin. The Lianyungang Environmental Quality Bulletin Web is an important and widely used public water quality database for research, education, and administration in Lianyungang. From the perspective of water quality, this paper used the spatial distribution of land use patterns.

Eighteen water quality sampling sites were selected from nine different rivers by carefully assuring the homogeneous distribution of the sample points (Fig. 1). The mean value of each water quality indicator at each sampling site was calculated separately in 2000, 2004 and 2008. The water quality indicators include pH, dissolved oxygen (DO), permanganate (COD_{Mn}), biochemical oxygen demand (BOD), ammonium (NH_3–N),oil (petroleum),volatile phenol (VP), phosphorus (P), fluoride (F), mercury (Hg), lead (Pb), arsenic (As), cadmium (Cd), hexavalent chrome (Gr^{6+}), and cyanide (CN). All these parameters were selected according to the requirements of water quality assessment (environmental quality standards for surface water (GB 3838-2002) based on the national standard of China). Additionally, for the availability and integrity of statistical data, some parameters were monitored before 2004. We included

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