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Invited paper

Threshold and resilience management of coupled urbanization and water environmental system in the rapidly changing coastal region

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ABSTRACT

The concept of thresholds shows important implications for environmental and resource management. Here we derived potential landscape thresholds which indicated abrupt changes in water quality or the dividing points between exceeding and failing to meet national surface water quality standards for a rapidly urbanizing city on the Eastern Coast in China. The analysis of landscape thresholds was based on regression models linking each of the seven water quality variables to each of the six landscape metrics for this coupled land-water system. We found substantial and accelerating urban sprawl at the suburban areas between 2000 and 2008, and detected significant nonlinear relations between water quality and landscape pattern. This research demonstrated that a simple modeling technique could provide insights on environmental thresholds to support more-informed decision making in land use, water environmental and resilience management.

1. Introduction

Urbanization due to rapid economic development leads to deterioration of ecosystems, such as depletion of water resources, degradation of water quality, and loss of habitats etc., and the problems are particular prevalent in developing countries (Seto et al., 2012; Bai et al., 2014; Fezzi et al., 2015). Water quality degradation is of major concern as it further leads to unsustainable arable land and farmland uses, especially in many parts of coastal areas in the world. However it is difficult to generalize the quantitative effects of urbanization on water quality due to complicated interactions of ecological processes involved, therefore it is challenging to inform land development policy how to achieve sustainable water resource management.

Threshold, also known as regime shift, tipping point, or breakpoint, is a well-developed concept and popular methodology to show great potential to deliver environmental and ecological knowledge to decision makers (Scheffer et al., 2001; Scheffer and Carpenter, 2003; Folke et al., 2004; Scheffer et al., 2009; Lenton, 2011). It is defined as abrupt changes in a response variable as a consequence of continuous change in an independent variable or the slope change (value or sign) for a function that shows ecological relations (Muradian, 2001; Kato and Ahern, 2011). Though the concept is subject to strong debate in its relevance for understanding ecosystem dynamics and implications for ecosystem management (Huggett, 2005), it is generally accepted that threshold analysis allows quantitative assessments whether there will be critical consequence on ecosystem status due to environmental changes and facilitate identification of ecosystem conservation or restoration goals (Groffman et al., 2006; Ficetola and Denoël, 2009) which is otherwise challenging to develop (King and Baker, 2010). The concept of environmental threshold is appealing in facilitating urban ecosystem-based management. However its analysis can be complicated as urban ecosystem is impacted by multiple environmental factors that may interact with each other.

A variety of statistical and mathematical approaches have been developed to detect thresholds, and development of these approaches continues to be an active area of research (Dodds et al., 2010; King and Baker, 2010; Sheppard and Cizek, 2009; Utz et al., 2009; Frair et al., 2008). Unfortunately, there is limited guidance about which model is most appropriate for environmental

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thresholds at a specific situation (Martin and Kirkman, 2009; Sofonia and Unsworth, 2010; Finlay et al., 2011). This lack of an established methodology is a major obstacle to the objectivity and the promulgation of studies on environmental thresholds (Betts et al., 2007; Ficetola and Denoël, 2009; Brenden et al., 2008). Traditional hysteresis models failed to account for human impacts, but we have seen a strong human component in most threshold analyses in the last decade (Liu et al., 2007). A developing framework, adopting threshold approaches to understand system dynamics and provide management guidance, has been proposed to show the utility of threshold models in system resilience or resistance to changes, decision making and management at relative short timescales in coupled natural and human systems (Kato and Ahern, 2011; Suding and Hobbs, 2009; Thrush et al., 2009).

Previous studies have shown the existence of landscape thresholds in water quality change for urban areas (Randhir and Ekness, 2009). It is important to understand how these landscape changes influence the resilience of a land-water system, and whether the temporal dynamics can cause water quality shifts. The objective of the research are: (1) to develop an operational approach for the identification of thresholds of landscape metrics for water quality shifts; (2) to explore how an improved understanding of thresholds can guide decision making to enhance resilience-oriented management for coupled land-water systems with rapid urbanization.

2. Materials and methods

We implemented nonlinear regression models to derive environmental thresholds quantitatively. The dependent variables in the regression models represent water quality, and the independent variables represent landscape patterns.

2.1. Study area

China is urbanizing at an unprecedented rate the nation's urban population increased from 17.9% to 52.6% between 1978 and 2012 (Bai et al., 2014). Most city development has been and will be in the eastern part of the country, particularly along the coast (Ma et al., 2014). Lianyungang is located on the East Coast of China, and forms the south wing of the Yangtze River Delta region which is the largest concentration of economic development in China (Fig. 1). Lianyungang has experienced rapid land use and land cover change characterized by extensive urbanization, typical in economically developed areas throughout the coastal cities in China. According to the local Statistical Yearbook, the population of Lianyungang reached 5.20 million in 2013, with the proportion of the urban population increasing from 19.46% in 2000 to 55.72% in 2013. Meanwhile, the amount of wastewater discharge of the city increased from 94.7 million tons in 2000 to 222.9 million tons in 2013 with an annual growth of 10%. The increased wastewater discharges, combined with wetland losses and habitat fragmentation, have resulted in the degradation of coastal water quality in Lianyungang (Sun et al., 2012). The surface water quality below national grade III (IV, V and under V) accounted for 40.5% of all the surface water bodies in the city in 2012, and it increased to 47.7% in 2013.

2.2. Data

2.2.1. Water quality data

Environmental Protection Agency monitored water quality at a total of 61 sites in the study area. According to our previous study (Li et al., 2015), the relationships between landscape and water quality varies significantly over space at different time, therefore we selected 18 sites which represent different spatial zones. The selected sites have high-quality data based on environmental reports, and they are widely spread out in geographical locations and watershed attributes to represent the whole study area (Fig. 1). We used annual means of 15 standard water quality variables (Lianyungang Environmental Quality Bulletin, Lianyungang Environmental Protection Agency), which were strongly correlated with different land use types according to our previous research (Li et al., 2015). The water quality variables include pH, dissolved oxygen (DO), COD_{Mn} (Permanganate), Biochemical Oxygen Demand (BOD), Ammonium nitrogen (NH_3–N), Oils (Petroleum), Volatile Phenol (VP), Total Phosphorus (P), Fluoride (F^-), Total Mercury (Hg), Lead (Pb), Arsenic (As), Cadmium (Cd), Hexavalent Chrome (Gr^{6+}), Cyanide (CN).

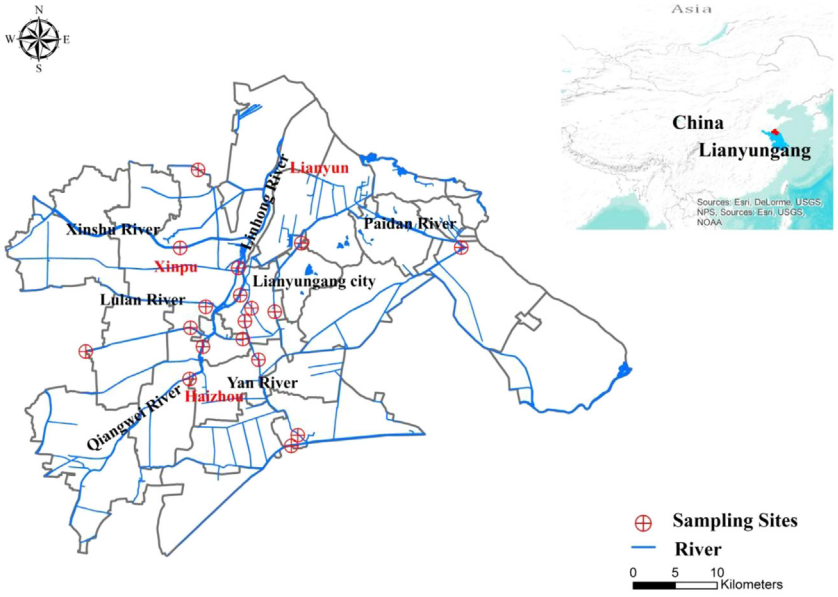

Fig. 1. Study area with sites for water quality data used in this study.