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Adaptive capacity based water quality resilience transformation and policy implications in rapidly urbanizing landscapes

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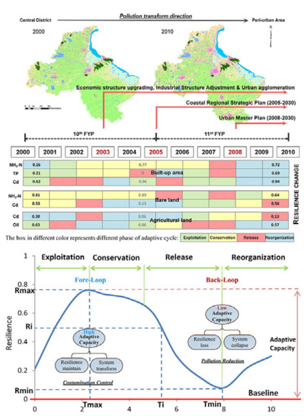
HIGHLIGHTS

- Integrated framework to analyze the resilience of urban land-water systems
- Addressed the changes of adaptive capacity based resilience and transitions
- Applied four transition phases of adaptive cycle to water quality management

GRAPHICAL ABSTRACT



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ABSTRACT

Resilience-based management focuses on specific attributes or drivers of complex social-ecological systems, in order to operationalize and promote guiding principles for water quality management in urban systems. We therefore propose a resilience lens drawing on the theory of adaptive capacity and adaptive cycle to evaluate the urban resilience between water quality and land use type. Our findings show that the resilience of water quality variables, which were calculated based on their adaptive capacities, showed adaptive and sustainable trends with dramatic fluctuation. NH_3-N, Cadmium and Total Phosphorus experienced the most vulnerable shifts in the built-up area, agricultural areas, and on bare land. Our framework provided a consistent and repeatable approach to address uncertainty inherent in the resilience of water quality in different landscapes, as well as an approach to monitor variables over time with respect to national water quality standards. Ultimately, we pointed to the political underpinnings for risk mitigation and managing resilient urban system in a particular coastal urban setting.

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1. Introduction

Urban resilience is a key concept in urban management and planning, appearing in urban development policy and guidelines as operationalizing and promoting a city's sustainability and flexibility and seeking to apply these principles for resilient cities (Colding, 2006; Resilience Alliance, 2007; Sellberg et al., 2015; West and Schultz, 2015). Intense human pressures characterize the rapidly urbanizing landscape, which makes urban resilience evaluation even more difficult than resilience in natural systems. On the other hand, there is a particular need for understanding urban sustainable management in order to manage the changes that come with urbanization. Urban resilience considers not just preventing disturbances in existing planning systems, but also concerns strengthening government abilities in terms of building structures of land distribution and functions in order to increase its adaptive capacity to disturbances (Ayda and Tuna, 2013).

Adaptive capacity refers to the ability of a system to deal with ecological and social disturbances in order to maintain resilience (Folke et al., 2002; Holling et al., 2002; Smit and Wandel, 2006). Systems with high adaptive capacity are able to re-organize and renew themselves against disturbances without significant structure changes. The loss of adaptive capacity is the loss of opportunity for resilience, and “gaining from the disturbances” becomes a new path of perceiving resilience. Recent studies identify and quantify adaptive capacity in social-ecological resilience at different scales based on the quantitative assessment of focal control variables within a certain safe space (Pelling and High, 2005; Rockström et al., 2014; Steffen et al., 2015). Specifically, in order to identify a safe operating space for humanity on Earth, different studies present a set of indicators of capacity to adapt to variability and resilience about climate change (Brooks et al., 2005; Engle and Lemos, 2010; Falloon and Betts, 2010; Hobson and Niemeyer, 2011; García-López and Allué, 2011), coastal communities (Maldonado and Moreno-Sánchez, 2014; Aguilera et al., 2015), and water resource system (Eakin et al., 2010; Rockström et al., 2014; Collet et al., 2015). The theory is well developed in terms of resilience thinking, however, the question of how to evaluate a system's adaptive capacity is still open.

Acknowledging that local actions on water management continue to trigger global-scale syndromes is a necessary first step toward effective governance (Vörösmarty et al., 2015). In the case of urban water quality, local governments play significant roles in urban planning, water/sanitation, and public policy, with a key function of setting up a legal environment that responds to and alleviates pressures. It not only emphasizes the adaptive capacity of urban-environmental systems, but also recognizes the role of human agency in fostering water quality change (Gunderson, 2000; Gaudreau and Cao, 2015). Together, the capacity among social-ecological agents to respond to disturbances leads to transitions within the adaptive cycle to more and less resilient states. The adaptive cycle is one relevant way to understand the transitions of self-organizing systems, but the cyclical pattern does not follow an absolute order (Resilience Alliance, 2007). The adaptive cycle also provides guiding lines for adaptive management, serving as a pathway for achieving the integration of key concepts into decision-making.

Landscape pattern change is one of the major anthropogenic impacts on the environment. Significant landscape pattern change occurs in the process of urbanization, industrialization and agricultural development. Land use change can modify watershed cover characteristics and can cause water quality deterioration (Bhat et al., 2006). Numerous studies analyze the relationships between land use and water quality using different methods (Tong and Chen, 2002; Su et al., 2011; Gilfedder et al., 2012; Dodder et al., 2014), though rarely adapting the perspective of resilience.

In our study, urban resilience refers to the ability of the urban system to establish and increase its adaptive capacity and provide particular guiding principles or sustainability strategies for policy makers and urban planners. Resilience issues between water quality and landscape change are the main concern for growth management in Lianyungang, China (Li et al., 2016). The way in which the adaptive capacity of an urban water system responds to land use change can be identified as a controller for redundancy and learning management, as well as a predictor for minimizing the risk causing irreversible degradation of urban land-water systems. Therefore, we quantified and visualized the temporal and spatial resilience of water quality variables in different land use types in Lianyungang, as well as the complex feedbacks and strategies for resilience changes of water quality. Our main objectives are to: (1) build a quantitative framework of resilience assessment based on the theory of adaptive capacity and adaptive cycle to explore the characteristics and resilience states of surface water quality variables; (2) apply the framework to evaluate resilience changes in both urban and peri-urban areas affected by rapid urbanization (2000 − 2010); and (3) highlight applications and suggestions for urban resilience management under urban agglomeration and city structure updating.

2. Methods

Based on our previous research, Lianyungang has undergone a complex period of multiple-policy implementations (Li et al., 2012; Li et al., 2016). Following resilience theory for urban planning, this section proposes a systematic methodology to investigate and quantify the resilience of water quality in conjunction with different land use types. This research addressed a rising topic that interprets the adaptive capacity of river basin system coping with external pollution. This is a very important topic in China and other rapid developing countries, which provided guidelines for water quality assessment and management.

2.1. Study area

Lianyungang (34° 36′ N, 119° 10′ E) is a prefecture-level city in the northeast of Jiangsu province in China and it covers an area of approximately 7500 km^2 (Fig. 1). As a port city, Lianyungang is located in the center of the Chinese coastline, linking eastern sea routes with western land routes. Its total GDP was 192 billion Chinese Yuan in 2014, an increase of 10.5% from 2013 compared to an average increase of 7.4% in China during the same period. The city's urbanization level has reached 57.13%, as compared to a total of 54.77% for all of China. However, there is increasing pressure placed on the city's water supply as a result of its rapid urbanization and economic growth. The annual available water in Lianyungang is only 1 billion m^3, but city's annual water consumption is 2.2 billion m^3, which means that the water supply and demand gap is greater than 50%. The average water availability per capita in Lianyungang is about 472 m^3. According to the Falkenmark Indicator (Falkenmark, 1989), when the annual water supply is below 500 m^3 per person, the population faces “Absolute Scarcity”.

Development policies reflect certain economic, demographic and spatial growth dynamics in cities, while also being shaped by them. In Lianyungang, urban planning during the 1990s was initially driven by a national and regional strategy to develop two core city-center areas, one serving the ports and the other serving special economic zones. However, this strategy led to a highly fractured urban landscape, and significant pressure on the environment. To address these issues, the Lianyungang government developed a new urban policy under the Coastal Regional Strategic Plan (2005–2030) and the Urban Master Plan (2008–2030, “Head to the east, embrace the ocean”). According to a report issued on the comprehensive improvement of the people of Lianyungang's wellbeing in 2011 (Lianyungang Bureau of Statistics), progress has been made over the last decade, including a more reasonable income distribution pattern in both urban and peri-urban areas, as well as a greatly improved situation related to pollution from transport and industry (waste water discharge, exhaust emission, etc.).

The new urban policy in Lianyungang has directly impacted the changes in social, economic and environment structures throughout the coastal area. In both city development guidelines, the focus of