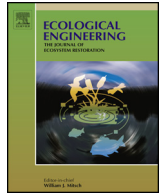




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## Effects of human activities on the eco-environment in the middle Heihe River Basin based on an extended environmental Kuznets curve model

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### ABSTRACT

With rapid socio-economic development over the past three decades in China, adverse effects of human activities on the natural ecosystem are particularly serious in arid regions where landscape ecology is fragile due to limited water resources and considerable interannual climate variability. Data on land use, surface and ground water, climate, gross domestic product (GDP) per capita from the middle Heihe River Basin were used to (i) examine changes in water consumption, land use composition, and vegetation cover; (ii) evaluate the effectiveness of short-term management strategies for environmental protection and improvement, and (iii) apply and extend the environmental Kuznets curve (EKC) framework to describe the relationship between economic development and environmental quality in terms of the normalized difference vegetation index (NDVI). The results showed that with rapid development of agriculture and economy, land use change for the period 1986–2000 was characterized by the expansion of constructed oases, considerable contraction of oasis-desert transitional zone and natural oases. This has led to a decrease in ecosystem stability. Since 2001, effective basin management has brought about improved environment conditions, with a more optimal hierarchical structure of vegetation cover. The original EKC model could not explain most of the observed variation in NDVI ( $R^2 = 0.37$ ). Including additional climate variables, the extended EKC model to explain the observed NDVI was much improved ( $R^2 = 0.78$ ), suggesting that inclusion of biophysical factors is a necessary additional dimension in the relationship between economic development and environmental quality for arid regions with great climate variability. The relationship between GDP per capita and NDVI, with the effect of precipitation and temperature taken into consideration, was adequately described by an N-shaped curve, suggesting that the relationship between society and the environment followed a process of promotion, contradiction, and coordination.

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### 1. Introduction

The human activities and climate change have interacted synergistically to impact the relationship between social and ecological systems in the late twentieth century (Steffen et al., 2005). The complex interactions between social and ecological systems have fundamentally changed in China during the past several decades. The impacts of human activities on natural ecosystem are especially serious in arid areas where landscape ecology is very fragile due to limited water resources (Luo and Zhang, 2006). The Heihe

River Basin is one of the largest arid inland river basins in north-west China, where oases evolve as a result of opposite processes of oasisification and desertification (Zhang et al., 2003; Su et al., 2007). The landscape composition, the spatial pattern or distribution of oases, desert and oasis-desert transitional zone are known as the ‘eco-circle level structure’, and this notion of a structure of ecological relevance at a large scale can be used as an indicator of ecosystem stability to identify the processes of oasisification and desertification based on the relative abundance of oases, desert and oasis-desert transitional zone at the basin or regional scales (Zhang, 2009, 2010). During the period from the 1970s to the 1990s, the ecosystem changed greatly in the Heihe River Basin because of over-exploitation of water and land resources for agricultural and economic development, leading to changes in the eco-circle level

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structure, with decreased ecosystem stability (Chen et al., 2004), and serious eco-environmental problems (Wang and Cheng, 1999). In 2001, short-term management programs were implemented to cease any new land reclamation for agricultural use, improve agricultural water use efficiency, and convert some farmland back to forest and grassland. This integrated water resources management and regulation system has so far brought about positive environmental outcomes for the region (Wu and Tang, 2007). Therefore, it is very important to recognize the impacts of human activities on the eco-circle level structure at a basin scale and the environmental quality at a local scale in different periods, to identify and explain factors and processes that drive the environmental change in the Heihe River Basin, and to provide support for decision making in terms of long-term strategies for environmental protection.

Much research has been undertaken to investigate the eco-circle level structure, land use/cover and environmental change, and the impacts of natural factors and human activities in arid regions based on remote sensing and GIS technology (e.g. Shoshany, 2000; Ayad, 2005), especially since the Implementation Strategy of the Land-Use and Land-Cover Change (LUCC) project was published in 1995 (Nunes and Auge, 1999). In China, research has been concentrated in the inland arid area of northwest China (e.g. Lu et al., 2003; Zhao et al., 2011). Using a model for inland eco-circle level structure with water as the critical input, Chen et al. (2004) analyzed mechanism for and characteristics of changes in ecosystems in arid regions, indicating that use of water and land resources would significantly impact the ecosystem stability. The significant positive correlation between NDVI (normalized difference vegetation index) and precipitation demonstrated that climate variability and change could play an important role in the environment variability in arid and semi-arid regions (Li et al., 2003). However, Kong et al. (2010) investigated vegetation change and environmental drivers in the Tarim River Basin, and the results indicated that environmental factors only contributed to a small proportion of vegetation-related land cover change and the influences of expanding agricultural activities were the main causes of land cover change in arid regions. Dai et al. (2010) also showed that the natural vegetation change was influenced not only by climate change, but also human activities which significantly changed the planted vegetation based on correlation analysis of NDVI and driving factors over northwest China.

All the research has contributed to ecological system study in arid regions of northwest China. However, there were few comprehensive studies in the Heihe River Basin, especially in the middle Heihe River Basin, where advanced irrigation agriculture and intensive human activities have resulted in an over-exploitation of water and land resources, leading to serious eco-environmental problems in the Middle and Lower Basin. To improve the environmental quality, short-term management programs were first implemented in the middle Heihe River Basin. Thus, the middle Heihe River is one of the ideal regions in the inland arid area to demonstrate the relationship between society and the environment. The impacts of human activities on the ecosystem in the middle Heihe River Basin are still largely unclear and there is a lack of quantitative analysis of the interactions between socioeconomic and biophysical processes at the basin scale. Acceleration of urbanization process has led to serious deterioration of the ecosystem in the Heihe River Basin in the late twentieth century (Meng et al., 2005) and the eco-environment has been greatly improved with implementation of short-term management programs since 2001 (Ding et al., 2011). Therefore, it is important to quantify the effectiveness of management strategies to ameliorate the adverse effects of human activities on the ecosystem in the middle Heihe River Basin.

The environmental Kuznets curve (EKC) presents a hypothetical relationship between economic development and environmental

outcome (Grossman and Kreuger, 1991, 1995; Chowdhury and Moran, 2012). While the economic development is commonly measured in terms of the income per capita, a multiple of indicators of environmental degradation such as the level of air or water pollution have been used as a measure of the environment outcome from economic development (Shafik and Bandhopadhyay, 1992; Grossman and Kreuger, 1995). The relationship between economic growth and environmental quality can be very complicated, and has been a source of great controversy (Shafik, 1994). Moreover, the EKC model may represent an N-shaped, an inverse N-shaped, a U-shaped, an inverse U-shaped or even a linear relationship (Canas et al., 2003), showing multiple relationships at different stages of economic development and at different spatial scales (Chowdhury and Moran, 2012). There is broad empirical support for the existence of EKC for various pollution indicators or vegetation cover to explain the development–environment relationship (Foster and Rosenzweig, 2003; Shen, 2006; Jalil and Mahmud, 2009). Li et al. (2013) tested the relationship between population growth and vegetation cover in 21 cities in Guangdong Province, China, the results show that there is a long-term inverted N-shaped relationship between population growth and vegetation cover, indicating that population increase with urbanization may have a negative or positive impact on the vegetation cover at different stages of development because of the intensive human activities. However, the current EKC model has not considered natural factors in determining vegetation change as a measure of environmental quality. As the human activities have multiple effects on the environment in the middle Heihe River Basin in different stages of economic development, and climate variability and change are strongly correlated with vegetation variability in the arid region (Zhao et al., 2011), we propose an extended EKC model to include anthropogenic and natural factors for a general explanation of the dynamic relationship between regional development and environmental quality for the middle Heihe River Basin.

Our research had three objectives. The first objective was to analyze the changes in the ecosystem under the influence of intense human activities based on changes of land use and the eco-circle level structure between 1986 and 2000 in the middle Heihe River Basin; the second objective was to assess the effects of short-term management strategies in terms of the spatiotemporal variations of vegetation cover in the Zhangye–Linze–Gaotai basin as an example; and the third objective was to develop an extended EKC model to explore the driving mechanism of the environmental changes for possible future projections, taking into consideration both natural and social-economic factors.

## 2. Materials and methods

### 2.1. Study area

The middle Heihe River Basin, between the Yingluo Gorge and Zhengyi Gorge stream gauging stations, is located in the central part of the Hexi Corridor, between 98°20′–102°12′E and 37°57′–40°03′N (Fig. 1), with a total area of  $2.61 \times 10^4$  km<sup>2</sup>. The middle Heihe River Basin has a number of administrative districts, including Ganzhou District, Gaotai County, Linze County, Shandan County, Minle County, a part of Sunan County of Zhangye City, Jiayuguan City, and Suzhou District of Jiuquan City. The study area has a temperate continental arid climate with adequate sunlight and infrequent occurrence of precipitation. The mean annual precipitation is only 140 mm and more than half of it occurs in summer months (May–September). The mean potential evapotranspiration in the region is about 1000–2000 mm yr<sup>-1</sup> (Wang et al., 2007). The area has an unbroken irrigation agricultural history since the

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