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Space-Time Changes in Interdependent Urban-Environmental Systems: A Policy Study on the Huai River Basin in China

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Abstract: Cities in the Huai River Basin are experiencing rapid urbanization, which has resulted in many challenges. Based on the concept of '*coupling*' – the interaction between the man-made urban environment and the ecological environment –, this paper presents a comprehensive index system and an interlinked coordination model which focuses on the nature of policy coordination between urbanization and the environment. This model was established using statistical data collected from 2003, 2006, and 2009 to assess the coupling relationship between urban and environmental subsystems. Furthermore, Exploratory Spatial Data Analysis (ESDA) is applied to examine dynamic spatial patterns of the impacts of both coupling and policy coordination. The results show that the degree of interdependency of the urbanization-environment system in the Huai River Basin has gradually increased over the years 2003-2006, reaching a maximum value in 2006, but decreasing thereafter. Both the degree of coupling and the degree of policy coordination appear to fluctuate over time. In the period 2003-2009, the urbanization-environment system showed always antagonistic and low coupling coordination features. The degree of both coupling and policy coordination of all cities show a positive spatial autocorrelation and similar characteristics of spatial agglomeration. This agglomeration trend is strengthening, as time goes on. In the period 2003-2009, cities of type Low-Low (LL) and type High-High (HH) occupied the dominant position in terms of number and area. Cities of type LL are mainly found in the southwest of the Huai River Basin, and cities of type HH mainly in the east and northeast. However, the difference between such cities and their neighbours is tending to decrease. In addition, there are a low number of cities of type high-low (HL) and type low-high (LH) in the Huai River Basin.

Keywords: Urbanization; environment; coupling coordination degree model; ESDA; Huai River Basin

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1. Introduction

Urbanization is a complex process of spatial morphological change and socio-economic development. It is the essential stage that most countries must experience to overcome poverty and achieve industrialization and modernization (Qiao et al., 2006; Xiao et al., 2010). With the continuous progress of urbanization, various contradictions and stresses between urbanization and the environment have become more serious. There is an objective dynamic coupling interaction between urbanization and the environment. On the one hand, the accelerated process of urbanization will inevitably cause changes in the environment. These changes may be characteristic of environmental deterioration in the early stage of urbanization, but of amelioration of the environment in a later development phase of urbanization. On the other hand, environmental changes may cause changes in the level of urbanization. As the quality of the environment improves, the level and acceleration of the urbanization process is promoted, and vice versa (Fang and Yang, 2006). Hence, there is an extremely complex interactive coupling relationship between urbanization and the environment. Since the mid-20th century, environmental problems caused by rapid urbanization have attracted considerable attention from both the general public and scientific researchers. The coupling relationship between urbanization and the environment has become a hot topic for research studies.

The Limits to Growth: A Report to The Club of Rome's Project on the Predicament of Mankind (Meadows et al., 1972) investigated environmental and resource restrictions caused by population growth and economic development at the global level for the first time. The coupling relationship between urbanization and the environment has been studied by scholars in various countries, while also fruitful research results have been obtained (Table 1). These studies mainly focus on two aspects:

- The coupling mechanism between urbanization and the environment, which involves the basic laws of the interactive coupling system of urbanization and the ecological environment (Huang and Fang, 2003; Fang, 2004). Norgaard (1990) put forward a new theory of coordinated development. He argues that a common development of the social and the ecological subsystem can take place by feedback loops. In this framework, the process of economic development is regarded as a process of constant adaptation to environmental change. In many studies, urbanization has always been regarded as a process related to the environment and safety (Brenan, 1999; Browder, 2002; Dae-Sik et al., 2003; Portnov and Safriel, 2004). Against this background, Fang and Yang (2006) have made a theoretical analysis of six basic laws governing the interactive coupling system of urbanization and the ecological environment.
- The nature and degree of coupling, including a prediction model of urbanization and the environment, which has two main research contents. The first is the environmental Kuznets curve (Grossman and Krueger, 1992; Soumyananda, 2004). Studies on the environmental Kuznets curve mainly focus on two aspects: one concerning the internal mechanism of the curve by theoretical analysis and formal testing (De Bruyn et al., 1998; Lindmark, 2002; Pasche, 2002); the other one concerning empirical analysis with respect to the factual existence of the environmental Kuznets curve. In addition, the threshold point of improved environmental quality accompanied by an increase of per capita income is simulated or predicted by a corresponding model (Vrishali, 1999; Andreoni and Levinson, 2001). The second research content of the degree of coupling involves constructing a coupling model of the urban and environmental system. The commonly used methods may contain systematic scientific methods

(Forrester, 1971; Vester and Hesler, 1980), a sensitivity model (Odum and Elisabeth, 2000), an energy flow model (Sukopp and Weiler, 1988), and an econometric model (Liu et al., 2007).

The Huai River Basin is a large, independent hydrographic unit with a self-organizing system. It is an important geographical unit which centres on resource system exploitation and the comprehensive utilization, organization and regional management of the economy (Chen, 2002). China's plan for the control and treatment of water pollution in a major river basin was first implemented in the Huai River. Since the 1980s, in the Huai River Basin, the economy has rapidly developed and the population has exploded. With the increasing rate of urbanization, the impacts of urbanization on the ecological environment, which is essential for human survival and development, are becoming increasingly significant (Qiao and Fang, 2005; Qiao et al., 2005). In the period of the 12th Five-Year Plan (2011-2015) for national economic and social development, under the conditions of "The eastern opening and the rise of central China", the speed of urbanization will exceed the national average in both the East of the Longhai area and the central plains economic region, both key zones for development at the national level in the Huai River Basin. Economic development and increasing population will certainly bring enormous pressure for the improvement of the ecological environment. Therefore, research on the coupling relationship between urbanization and the environment is essential, and is of great – theoretical and practical – significance for urban governance and environmental pollution control in the process of urbanization in China. This paper aims to examine the coupling relationship between urbanization and the environment in the Huai River Basin from both exploratory and analytical perspectives. The coupling coordination degree model is adopted to quantify the degree of coupling and the degree of policy coordination of the urbanization and environment system. More specifically, Exploratory Spatial Data Analysis (ESDA), which explores temporal and spatial changes in the degree of both coupling and policy coordination between urbanization and the environment in the Huai River Basin from an exploratory perspective, is applied here for the first time in order to visualize spatial patterns in the Huai River Basin.

Table 1 Research themes and contents of the coupling relationship between urbanization and the environment

	Theme	Content		Case study
Coupling relationship between urbanization and the environment	Coupling mechanism	Basic laws of the interactive coupling system, the coupling mechanism, and the relationship between urbanization and the environment		Norgaard, 1990; Brenan, 1999; Browder, 2002; Dae-Sik et al., 2003; Huang and Fang, 2003; Fang, 2004; Portnov and Safriel, 2004; Fang and Yang, 2006
	Degree of coupling and prediction model	Environmental Kuznets curve	Internal mechanism of the Kuznets curve by theoretical analysis and formula derivation	De Bruyn et al., 1998; Lindmark, 2002; Pasche, 2002
			Empirical analysis on the existence of the environmental Kuznets curve	Vrishali, 1999; Andreoni and Levinson, 2001
		Constructing coupling model		Forrester, 1971; Vester and Hesler, 1980; Sukopp and Weiler, 1988; Odum and Elisabeth, 2000; Liu et al., 2007

2. Materials and Method

2.1 Study area

The Huai River Basin is located in eastern China, between the Yellow River and the Yangtze River, the two largest rivers in China, at longitude 111°55'-121°25' East and latitude 30°55'-36°36' North. It is West of the Tongbai Mountains and the Funiu Mountains, bounded on the South by the Dabie Mountains, the Jianghuai Hills, the Tongyang Canal, the South bank of the Rutai Canal and the Yangtze, and in the North by the South bank of the Yellow River and the Tai Mountain (Figure 1). The Western, Southwest and Northeast areas of the Huai River Basin are mountainous and hilly. The rest consists of plains. Hilly areas and plains account, respectively, for about one-third and two-thirds of the total area. In addition, lakes and low-lying lands are scattered over the Basin. The Huai River is regarded as the geographical dividing line between the northern and southern parts of the Basin. The Huai River Basin lies in China's climate transition zone. It is characterized by an arid and semi-humid continental monsoon climate: its northern regions are in the warm temperate zone, and its southern regions are in the sub-tropical and semi-humid monsoon zone (Ni et al., 2011). The Huai River Basin has a temperate climate with an annual average temperature of 11-16℃. The Basin is divided into the Huai River and the Yishusi River by the ancient riverbed of the Yellow River. The mean annual precipitation in the Huai River Basin is about 875mm per annum. The total volume of water resources is about 794 billion m^3. The proportion of surface water resources and groundwater resources is 75 and 25 percent, respectively. Furthermore, 70 percent of the surface water resources accumulate in the flood season.

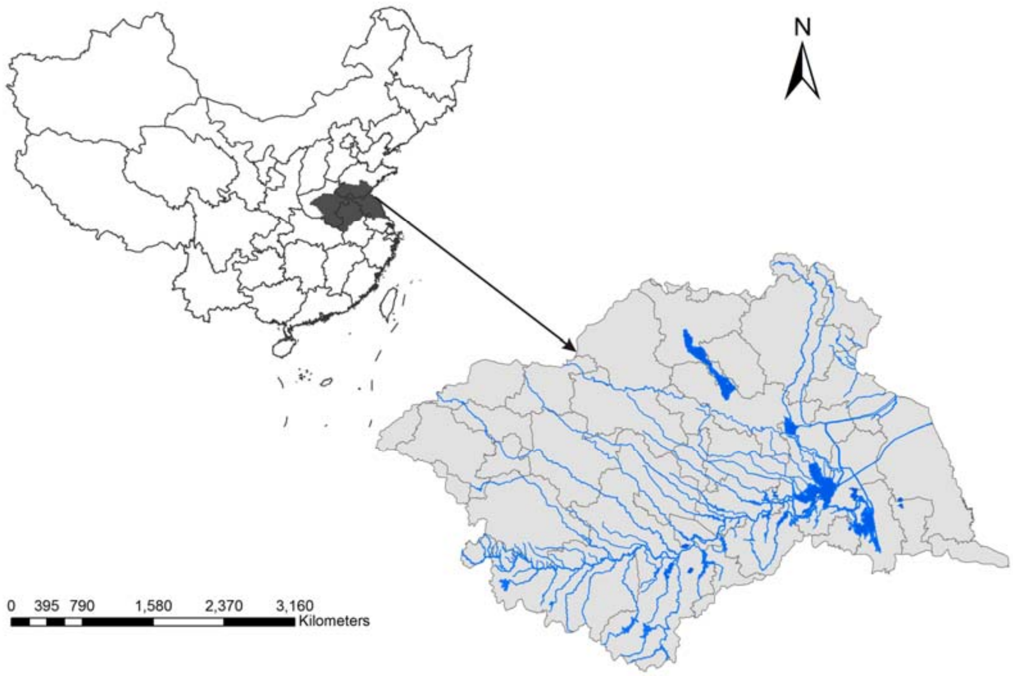

Figure 1 The location of the study area

The Huai River Basin flows through Henan, Anhui, Shandong, and Jiangsu Provinces and 35 prefecture-level cities with a drainage area of 269,600 km^2. In 2010, the Huai River Basin had a population of 171 million. It has the highest population density in China, with an urban population of over 61 million. The rate of urbanization is 35.9 percent. The total Gross Domestic Product (GDP) of the Huai River Basin is 3.45 trillion Yuan. And the GDP per capita is 20,000 Yuan which is below the national average. The proportions of primary, secondary and tertiary sectors in the economy are 16.4; 51.5; 32.1.

2.2 Data

The 35 prefecture-level cities of Henan, Anhui, Shandong, and Jiangsu Provinces in the Huai River Basin were selected as the study units. The raw data came from China's City Statistical Yearbook (2004, 2007, 2010). More disaggregated data came from the Henan, Anhui, Jiangsu and Shandong Statistical Yearbook from 2004, 2007, and 2010, respectively. Because of the divergence between the boundary of the river basin and the administrative units of the prefecture-level cities, the statistical data of the prefecture-level cities are extracted to accord with the basin boundary.

2.3 Research methods

2.3.1 Index system

Urbanization is a complex dynamic process influenced by many factors. The environment also changes with the characteristics of the process. Objectively, there are all sorts of contradictions between, and threats to, urbanization and environment. On the one hand, against the background of a resource shortage, urbanization will inevitably suffer from threats to resources and the environment, and these threats will destroy the surrounding environment to varying degrees during its development process. On the other hand, the fragile environment will restrict the development of cities, block the urbanization process, and may even ruin cities when the environmental subsystem would be destroyed (Liu et al., 2011). For the purpose of measuring the degree of both coupling and policy coordination between urbanization and the environment, index systems for urbanization and the environment were developed. On the basis of the previous studies (Liu, 2006; Qiao et al., 2006; Guan et al., 2011; Li et al., 2012), following the principles of scientific validity, comparability and data acquisition, and considering the actual situation of urbanization and the environment in the Huai River Basin, 16 statistical urbanization indicators on demographic urbanization, economic urbanization, social urbanization, and spatial urbanization, and 11 statistical environmental indicators of environmental endowment, environmental pressure, and environmental management were selected to establish a comprehensive index system of urbanization and environment coupling (Zhao and Chen, 2008) (see Table 2).

Table 2 Index system used for the evaluation of the relationship between urbanization and the environment

Sub-system	Functional group	Indicators	Direction of influence
Urbanization	Demographic urbanization	Percentage of urban population (%)	+
		Percentage of persons employed in tertiary industry (%)	+
		Percentage of persons employed in secondary industry (%)	+
	Economic urbanization	Per capita GDP (in yuan)	+
		Per capital value of secondary industry (in yuan)	+
		Proportion of investment in fixed assets to GDP (%)	+
		Proportion of value of tertiary industry to GDP (%)	+
		Average wage of staff and workers (%)	+
		GDP（in million yuan）	+
	Social urbanization	Number of books in public libraries per 10,000 people	+
		Number of hospital beds per 10,000 people	+
		Number of doctors per 10,000 people	+
		Number of public transport vehicles per 10,000 people	+
	Spatial urbanization	Percentage of construction land in the built-up areas (%)	+
		Per capita area of roads (m^2)	+
		Population density (persons/sq.km)	+
Environment	Environmental endowment	Per capita public green land areas (sq.m)	+
		Area of green land in built-up area (ha)	+
		Coverage rate of green land in built-up area (%)	+
	Environmental pressure	Per capita volume of household water use (tonnes)	-
		Per capita volume of residential electricity use (KWh)	-
		Per capita volume of industrial waste water discharge (tonnes)	-
		Per capita volume of industrial SO_2 emission (tonnes)	-
		Per capita volume of industrial dust emission (tonnes)	-
	Environmental management	Percentage of industrial solid waste utilized (%)	+
		Percentage of treated sewage (%)	+
		Output value of waste gas, waste water and industrial residue for multi-purpose use (in million yuan)	+

2.3.2 The coupling-coordination degree model

(1) Power function

In the study, the degree of coupling is introduced to qualitatively evaluate the degree of interaction between urbanization and the environment. Variable u_i (i= 1, 2, … , m) is the order parameter of the urbanization and environment system, while u_{ij} represents the indicator j of the order parameter i. Its value is X_{ij} (j= 1, 2, …, n). And α_{ij} and β_{ij} indicate the minimum and maximum value of indicator j. Therefore, the power coefficient u_{ij} of the urbanization and environment system can be expressed as (Liu and Song, 2005a):

$$u_{ij} = \begin{cases} (X_{ij} - \beta_{ij}) \big/ (\alpha_{ij} - \beta_{ij}), & \text{if } u_{ij} \text{ positive indicator} \\ (\alpha_{ij} - X_{ij}) \big/ (\alpha_{ij} - \beta_{ij}), & \text{if } u_{ij} \text{ negative indicator} \end{cases} \tag{1}$$

The value of u_{ij} ranges from 0 to 1.

Because urbanization and the environment are located in two different but interacting systems, their contribution to the order degree of the order parameters in each subsystem can be achieved by an integrated approach. A geometric method and a linear weighted model are here the common methods (Zeng, 2001). The subsystem's contribution of parameters to the total system u_i can be defined as:

$$u_i = \sum_{j=1}^{m} \lambda_{ij} u_{ij}, \quad \sum_{j=1}^{j=m} \lambda_{ij} = 1, \tag{2}$$

where λ_{ij} is the weight of each order parameter which can be determined by the entropy method.

(2) Entropy method

Methods to determine the weight of indexes are often used (see Cheng and Deng, 2010). Because of the arbitrariness of the subjectively assigned weight and the different degrees of the contribution of each index of the urbanization-environment system in different years, the weight of each indicator is calculated here by the entropy method. Based on the original information of the objective circumstances, the index weights are estimated by the entropy method in order to analyse the relevance and information content of the various indexes (Wu and Bai, 2011). The steps of the estimation are as follows (Wu and Zhang, 2008):

1) Proportion of the indicator j of sample i: $s_{ij} = x_{ij} \Big/ \sum_{i=1}^{n} x_{ij}$;

2) Information entropy of the indicator: $h_j = -\sum_{i=1}^{n} s_{ij} \ln s_{ij}$;

3) Standardization of entropy: $\alpha_j = \max(h_j) / h_j \, (j = 1, 2, \cdots, p)$;

4) Weight of the indicator x_j: $w_j = \alpha_j \Big/ \sum_{j=1}^{p} \alpha_j$,

where x_{ij} is the value of indicator j for sample i（i=1,2,…,n; j=1,2,…, p); n is the number of observations in the sample; and p is the number of indicators.

(3) Coupling-coordination degree model

Drawing on the concept of capacitive coupling and the capacitive coupling coefficient model in physics (Illingworth, 1996), the degree of coupling between multiple systems or elements can be defined as follows:

$$C_n = \left\{ (u_1 \times u_2 \times \cdots \times u_m) \big/ \left[\prod (u_i + u_j) \right] \right\}^{1/n}, \tag{3}$$

Based on the above formula, the degree of coupling between urbanization and environment is defined as:

$$C = \left\{ (u_1 \times u_2) \big/ \left[(u_1 + u_2)(u_1 + u_2) \right] \right\}^{1/2}, \tag{4}$$

where u_1 and u_2 represent the contribution of the urban subsystem and the environmental subsystem to the total system, respectively. C is the degree of coupling of the system, C□[0,1] (Liu et al., 2005a).

The degree of coupling C can be divided into four stages. $0<C\leq0.3$ is the low-level coupling stage. It is characterized by a low level of urban development and a high environmental carrying capacity. $0.3<C\leq0.5$ is the reverse stage, where the urbanization process is accelerated, whereas the environment carrying capacity is reduced. $0.5<C\leq0.8$ is the adjustment stage, where urbanization and the environment appear to be in a benign state of coupling. $0.8<C\leq1$ is the high-level coupling stage, where urbanization and environmental construction are mutually supportive (Gao et al., 2010). However, as a result of policies and accidental factors, the urban and environmental system may be downgraded to the previous coupling stage (Xu et al., 1997).

In some cases the degree of coupling on its own cannot satisfactorily reflect the integrated coherence and synergistic effect of urbanization and environmental development (Liu and Song, 2005b; Song et al., 2010). Therefore, the coupling-coordination degree model was developed to evaluate the degree of coupling and policy coordination between the urban and the environmental subsystems. It is defined as follows:

$$D = (C \times T)^{1/2},$$
$$T = (aU_1 \times bU_2)^{1/2}, \tag{5}$$

where D is the degree of policy coordination and C is the degree of coupling; T is the integrated and coordinated index of urbanization and the environment which reflects the whole synergistic effect; and a and b are undetermined coefficients. If the urban subsystem and the environment subsystems are equally important, then $a=b=0.5$. U_1 and U_2 are the integrated order parameters of urbanization and the environment, respectively. Like the degree of coupling, the degree of policy coordination can also be divided into four stages: $D\in(0,0.4]$ is low coupling coordination; $D\in(0.4,0.5]$ is medium coupling coordination; $D\in(0.5,0.8]$ is high coupling coordination; and $D\in(0.8,1)$ is very high coupling coordination.

2.3.3 Exploratory spatial data analysis

Exploratory Spatial Data Analysis (ESDA) is a method of analysing spatial autocorrelation which is used to measure the spatial effect of a phenomenon. This method can be applied globally and locally to explore spatial agglomeration and space anomalies, and reveals the spatial interaction mechanism which operates between various cities. We distinguish here:

(1) Global spatial autocorrelation—*Moran's I*

Moran's I is an important indicator for measuring the global spatial autocorrelation level. It is used to describe the spatial characteristics in the study area, and to test whether phenomena present spatial agglomeration. Moran's I is defined as:

$$Moran's\ I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{j=1}^{n}(x_i - \bar{x})^2 / n}, \tag{6}$$

where x_i and x_j are the observations from city *i* and city *j,* respectively, and w_{ij} is the element of the two-dimensional spatial weight matrix. The values of Moran's I range from -1 to 1. Under the condition of significance level $\alpha = 0.05$, similar observations tend toward spatial agglomeration, when Moran's I is significantly positive. Similar observations tend to be scattered, when Moran's I is negative. A Moran's I value of 0 indicates observations of independent random distribution.

(2) Local spatial autocorrelation

(a) The Moran scatter plot is a scatter plot that describes the correlation between a variable *z* and its spatial lag vector *Wz* (Anselin, 1996). The four quadrants of the Moran scatter plot are matched with four different types of cities with different degrees of coupling and policy coordination. The first quadrant portrays Type HH (high degrees of coupling and policy coordination in both the city and its neighbouring cities). Cities of Type HH are hotspot areas. The second quadrant shows Type LH (a low degree of coupling and policy coordination in the city and a high level in the neighbouring cities). The third quadrant indicates Type LL (low degrees of coupling and policy coordination in both the city and its neighboring cities). Cities of Type LL are blind spot areas. The fourth quadrant shows Type HL (a high degree of coupling and policy coordination in the city and a low degree in the neighbouring cities).

(b) Compared with the global indicator, the local indicator of spatial autocorrelation (LISA) considers spatial proximity for each city area. LISA's functions are as follows: it provides a means to assess the significance of "local" spatial patterns (Anselin, 1995). In combination with a classification into four types of association, this indicates significant local clusters (high–high [HH] or low–low [LL]) or local spatial outliers (high–low [HL] or low–high [LH]). Significance is typically based on a conditional permutation approach (Lu and Xu, 2007). The LISA model is expressed as:

$$I_i = z_i \sum_{j \neq i}^{n} w_{ij} z_j\ , \tag{7}$$

where z_i and z_j are standardized observed values of city *i* and city *j*, and w_{ij} is the spatial weight. A map showing locations with significant local Moran's I statistics, classified by type of spatial correlation, is referred to as a LISA Cluster map. It is an important tool in identifying "interesting" locations and assessing the extent to which the spatial distribution exhibits "spatial heterogeneity" (Jing and Cai, 2010). In this research, the Moran scatter plot is combined with a LISA significance map in order to establish a “Moran significance map”. Points in the different quadrants of the Moran scatter plot and in the LISA significance map can be identified in the “Moran significance map” (Wu and Wang, 2008).

3 Results and Discussion

3.1 Temporal changes in the degree of coupling and policy coordination

The coupling coordination degree model is important for the future development plans of the cities. As the Huai is one of the most polluted rivers in China, it is important to quantitatively evaluate and investigate the dynamic change in the degree of coupling and policy coordination between urbanization and the environment in the Huai River Basin.

After calculating the indexes of the coupled system, and the degree of both coupling and policy coordination of 35 cities in the Huai River Basin, the results indicate that the average degree of coupling of the 35 cities in the Huai River Basin in 2003, 2006, and 2009 was 0.458, 0.475, and 0.471, respectively. In terms of the numerical value of the degree of coupling, the degree of coupling of the whole urbanization-environment system in the Huai River Basin increased from 2003 to 2009, and reached a maximum in 2006. However, the system of the Huai River Basin was still in the antagonistic stage. In this stage, urbanization development passed its inflection point with a urbanization degree for population of 30 percent. Urbanization is now entering a rapid phase of development, and the impacts of such extensive development on the environment should not be neglected. A massive influx of funding and resources is needed for urban construction. But the environmental system cannot fully digest and absorb the impact of urbanization owning to the reduced environmental capacity (Liu et al., 2005b).

The average degree of policy coordination of 35 cities in the Huai River Basin in 2003, 2006, and 2009 appears to be 0.328, 0.317, and 0.326, respectively. The degree of policy coordination decreased from 2003 to 2006, but increased from 2006 to 2009. The whole urban-environmental system in the Huai River Basin was in a low coupling coordination stage during the whole study period. In 2006, significant changes took place in the degree of both coupling and policy coordination. Though the synchronicity of the urban subsystem and the environmental subsystem was higher in that year, which was reflected by the highest degree of coupling, the low degree of policy coordination was the manifestation of the low overall development level of the urbanization-environment system. This was plausible, because 2006 marked the first year of the overall implementation of the 11th Five-Year Plan (2006-2010) for national economic and social development. The macro-control measures had not yet began to take effect in the transition period. To date, the national economic development policies have not fully influenced the development of the whole urbanization-environment system. In general, the degree of both coupling and policy coordination fluctuates over time, which not only represents the closeness of the interactive coupling between urbanization and the environment, but also reflects the coupling intensity, focus, and level of policy coordination in the urban-environmental system, which all vary in different periods of urban development in the Huai River Basin.

In 2003, the degree of coupling was higher in the cities of Huainan and Zibo, with a value of 0.500, and lowest in Bozhou, with a value of 0.389. The degree of policy coordination was highest in the city of Hefei at 0.406, and lowest in the city of Nanyang at 0.254. In 2009, the highest degree of coupling remained at 0.500, occurring in the cities of Zibo and Luoyang, and the lowest degree of coupling was in the city of Fuyang with a value of 0.408 (Figure 2). The degree of policy coordination was highest in the city of Zhengzhou at 0.393, and the lowest in the city of Fuyang at 0.260. The results reveal that the gap between the highest and lowest degrees of coupling and policy coordination of urbanization-environment system in the Huai River Basin was shrinking during the process of urbanization.

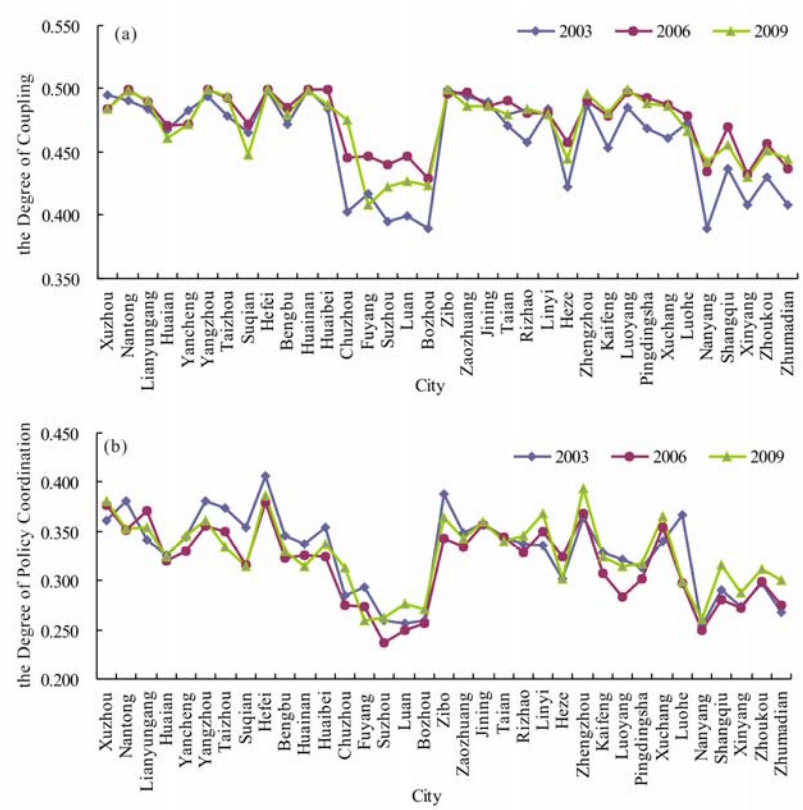

Figure 2 The degrees of coupling and policy coordination between urbanization and environment in the Huai River Basin

3.2 Changes in the spatial pattern change of the degree of coupling and policy coordination

The urbanization and environment systems of the 35 cities in the Huai River Basin appear to be all in an antagonistic stage. In 2003, apart from the city of Hefei, whose degree of policy coordination was 0.406, which is in the medium coupling coordination stage, the rest of the cities had a degree of policy coordination ranging from 0 to 0.4, indicating a low coupling coordination stage. To reveal the regional differences in the characteristics of the spatial evolution of all the cities' degrees of coupling and policy coordination in the study area, the Natural Breaks method was applied in order to classify the degree of coupling of the antagonistic stage into four subtypes: stronger, strong, medium and weak. Similarly, the degrees of policy coordination, except for Hefei's in 2003, were also classified into four subtypes (1 - 4) (see Figures 3 and 4).

Figure 3 shows that the number of cities in the stronger antagonistic stage gradually decreased in the period 2003-2009, but no obvious spatial distribution changes occurred in this period. Stronger antagonistic cities, such as Xinyang, Luan, Fuyang, Bozhou and Suzhou were mainly found in the southwest of Huai River Basin. Both the number and spatial distribution of the other three types of cities have significantly changed during the study period. The results reveal the following characteristics:

- In 2003-2006, the number of medium antagonistic cities decreased, while that of strong antagonistic and weak antagonistic cities increased. In 2003, strong antagonistic cities, such as Kaifeng, Zhoukou and Shangqiu, were mainly spread along the middle and upper reaches of the Huai River Basin. The medium antagonistic cities were mainly distributed along the Yihe River, the Shuhe River and in the North of Jiangsu Province. The weak antagonistic cities formed zones, which ran through the regional landscape from the upper and middle reaches of the Huai River Basin from Zhengzhou, Huainan, Hefei to Jining, Zaozhuang, and Xuzhou in the Nansihe Lake Basin. In 2006, strong antagonistic cities were in particular Zhoukou, Shangqiu, Heze, Suqian, Huaian and Yancheng. Most medium antagonistic cities were located in the area of the Yishusihe River Basin. And the spatial distribution of weak antagonistic cities, which were all distributed in the upper, middle and lower reaches of the Huai River Basin, tended to be scattered.
- In 2006-2009, the numbers of strong and medium antagonistic cities increased but, cities in the weak antagonistic stage decreased. In 2009, the strong antagonistic cities were in particular Nanyang, Zhoukou, Shangqiu and in the downstream areas of Lake Hongze. The areas with medium antagonistic cities in the middle and upper reaches of the Huai River Basin decreased. Such cities also covered a large area in the Yishusihe River Basin. Weak antagonistic regional areas decreased and their spatial distribution was more dispersed.

The number and spatial distribution of various types of cities with low degree of policy coordination had changed noticeably by 2006 (Figure 4) with the following characteristics:

- In 2003-2006, no significant changes occurred in the number and spatial distribution of low policy coordination cities of Type 1 and Type 2. Type 1 low policy coordination cities, such as Zhumadian, Xinyang, Luan and Nanyang, increased in both number and area, covering a vast region of the southwest Huai River Basin. Type 2 low policy coordination cities, such as Shangqiu, Zhoukou, Luoyang and Pingdingshan were mainly distributed in the northwest of the Huai River Basin. The number and spatial distribution of Type 3 and Type 4 low policy coordination cities changed significantly. There was a significant reduction in the number and area of Type 3 low policy coordination cities, such as Suqian, Huaian and Yancheng, which were more concentrated in the lower reaches of the Huai River Basin. The number and area of Type 4 low policy coordination cities, which were mainly in the Yishusihe River region, increased correspondingly.
- The number of Type 1, Type 3 and Type 4 low policy coordination cities decreased slightly in the period 2006-2009 and their spatial distribution hardly changed. In that same period, Type 2 low policy coordination cities, such as Shangqiu, Zhoukou, Luoyang and Pingdingshan in the middle and upper reaches of the Huai River Basin, increased in area, and this trend spread to Kaifeng, Heze, Zhumadian and other cities.

3.3 Analysis of the disparities in the degree of coupling and policy coordination on the basis of ESDA

In an open river basin system, the degree of coupling and policy coordination of a city depends not only on the intrinsic factors but also on the external conditions of its surrounding area (Wang et al., 2005). ESDA can identify the tendency of spatial differences to be enlarged or reduced. Furthermore, it can reveal the spatial interaction mechanism (Ying, 2000). Generally speaking, a city of Type HL or Type LH indicates that polarization occurs between a city and its surrounding cities with increasing spatial distance. On the other hand, a city of Type HH or Type LL indicates that a diffusion effect is occurring between a city and its surrounding cities with the reducing geographical spatial distance. Their spatial distance tends to reduce. The LISA cluster of the degree of coupling and policy coordination at the α level indicates that the polarization and diffusion effect between cities and their surrounding cities is really quite remarkable (Pu et al., 2005).

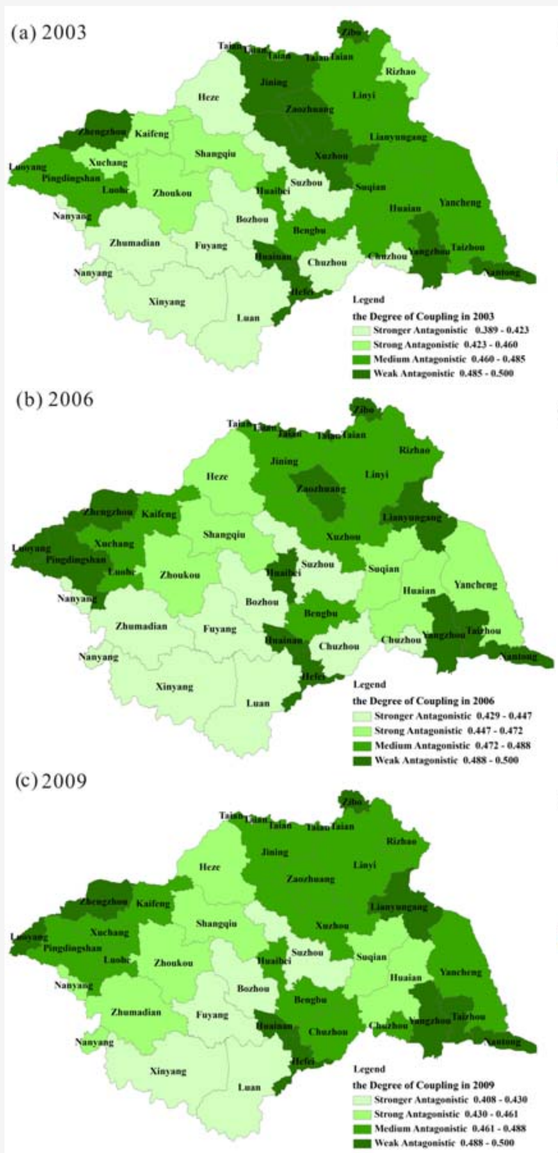

Figure 3 Change in the spatial pattern of the degree of coupling

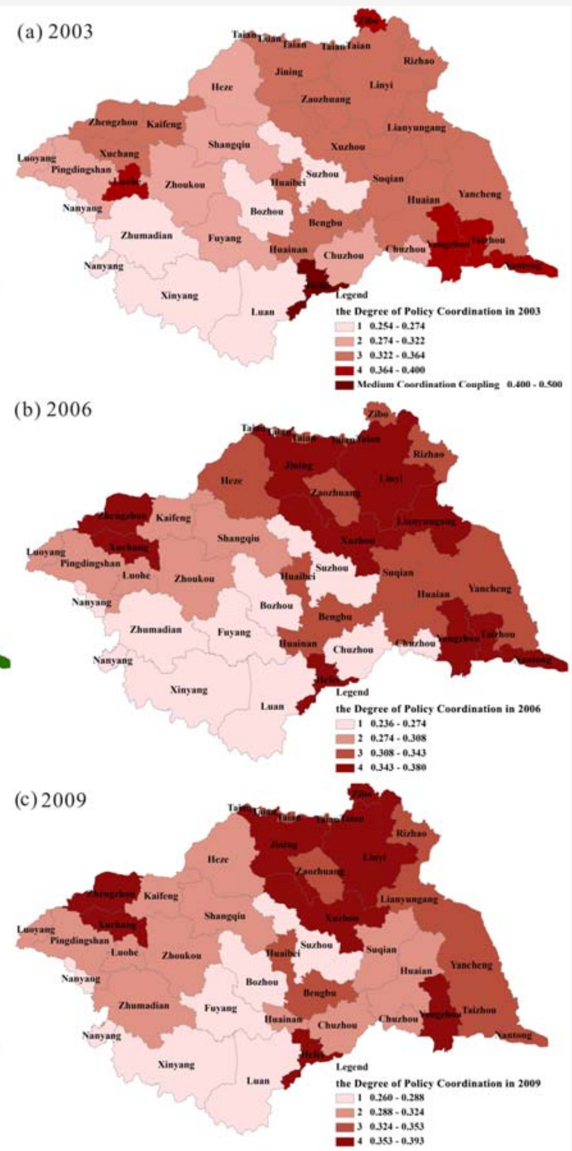

Figure 4 Change in the spatial pattern of the degree of policy coordination

The spatial relationship characteristics of the degree of coupling and the degree of policy coordination in the study area are found to be as follows (Figures 5 and 6): the Global Moran's I values of degree of coupling were 0.2427, 0.2288, and 0.3352 in 2003, 2006, and 2009, respectively, and the Global Moran's I values of the degree of policy coordination were 0.1980, 0.2759, and 0.3148, respectively. All positive values of the Global Moran's I demonstrate that the degree of both the coupling and policy coordination of all the cities shows positive spatial autocorrelation, which indicates that cities with similar levels of the degree of both coupling and policy coordination tend to cluster geographically. The spatial agglomeration trend tends to strengthen as time goes on. Although the Global Moran's I of the degree of coupling decreased slightly in the period 2003-2006, it then increased in the period 2006-2009. The concentration trend of cities with similar levels of the degree of policy coordination continually strengthens. It should be noted that this conclusion relates to a prefecture-level spatial scale.

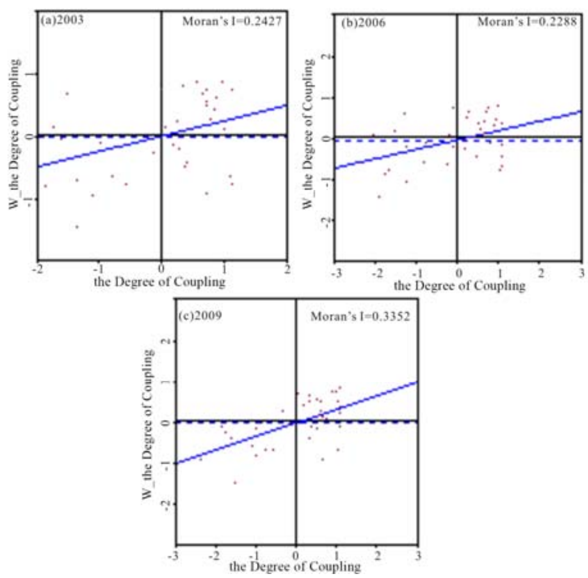

Figure 5 Moran scatter plot for degree of coupling

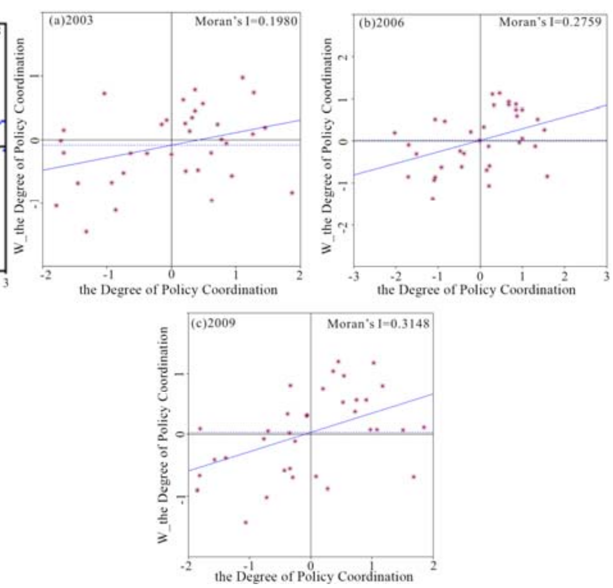

Figure 6 Moran scatter plot for degree of policy coordination

In order to clearly reveal the local geographic pattern changes of the degree of coupling and policy coordination in the Huai River Basin during the period 2003-2009, LISA and its significance (P=0.05) of both the degrees of the coupling and policy coordination in 2003, 2006, and 2009 were calculated and shown on the LISA cluster map (Figures 7 and 8). In the period 2003-2009, the degree of coupling in the Huai River Basin showed an obvious pattern of spatial heterogeneity at the 0.05 significance level (2-tailed). Compared with their surrounding area, cities of Type LL and Type HH occupied a dominant position in terms of number and area. At the 0.05 significance level, most cities were of Type LL, and these cities were mainly located in the middle and upper reaches of the Huai River Basin and formed a continuous distribution pattern, including Shangqiu, Zhoukou, Zhumadian, Fuyang and Xinyang. Cities of Type HL signified strong negative spatial correlation and marked heterogeneity and only included Huaibei and Fuyang in Anhui Province. Moreover, the spatial distribution of cities of Type LL and Type HL did not change in the course of the study period. In addition, cities of Type HH are hotspot areas. The degree of coupling of such cities is similar to that of their neighbouring cities. In 2003, cities of Type HH were found mainly in Shandong Province (Zaozhuang and Linyin) and Jiangsu Province (Yancheng), but, in 2006, only Linyi was categorized as this kind of city, but Yancheng in northern Jiangsu once again became Type HH in 2009. The results indicate that there was strong positive spatial correlation between these cities and their neighbouring cities. The Type LH city signified strong negative spatial correlation and marked heterogeneity. Only Chuzhou belonged to this category in 2003, and there were no cities of this type after 2003.

The spatial distribution of the degree of policy coordination shows a distribution pattern similar to that of the degree of coupling. During the period 2003-2006, cities of Type LL and Type HH occupied a dominant position in terms of number and area, particularly in 2006. At the 0.05 significance level, most cities were of Type LL. Rather than having a random distribution, they were concentrated in southwest of the Huai River Basin, and included Zhumadian, Xinyang, Shangqiu, and others. In 2006, influenced by its surrounding area, Zhoukou completely replaced Nanyang as a Type LL city. Since then the spatial distribution pattern of Type LL cities has remained unchanged. Type HH cities only included Linyi, Yancheng, and Taizhou in 2003. In 2006, the number of such cities reached its maximum with Yancheng city in Jiangsu Province as well as cities in most areas of Shandong Province. After 2006, the concentration effect of such cities was gradually weakened with their decreasing number. In 2009, Linyi and Zaozhuang were the only two cities of Type HH. In terms of their spatial evolution characteristics, this kind of cities had a very similar degree of policy coordination to that of cities of Type LH. In 2003, there was only one city of Type LH, Chuzhou, which was significant at the 0.05 level. Since then this type of city has ceased to exist. In 2003, the only city of Type HL was Huaibei. But in 2006, Bengbu, which is adjacent to Huaibei, also changed into a Type HL city. Thereafter, the spatial distribution pattern of Type HL remained unchanged.

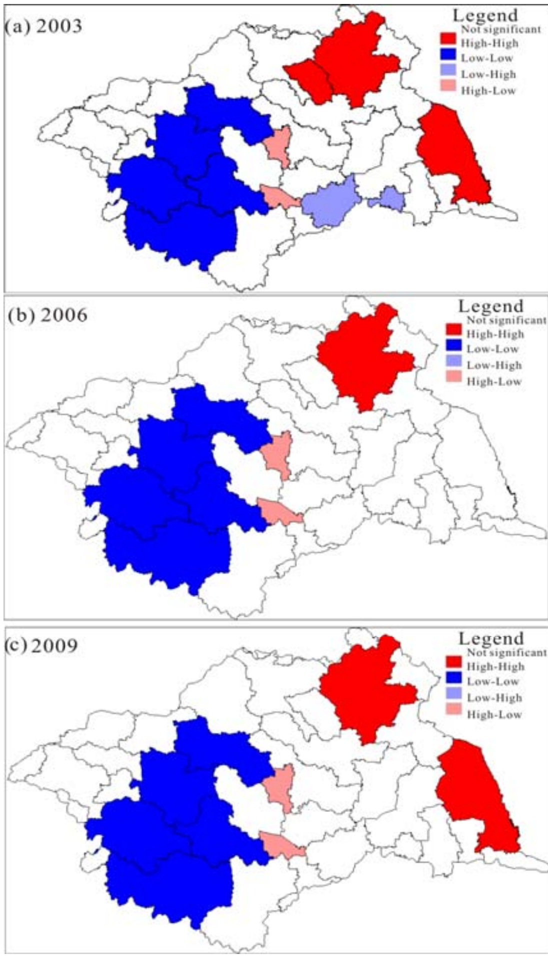

Figure 7 LISA cluster map of the degree of coupling

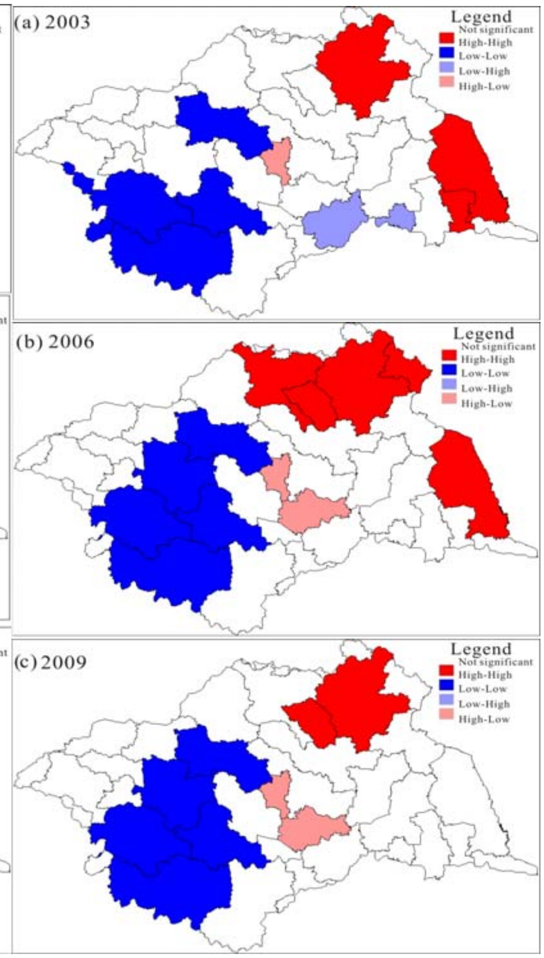

Figure 8 LISA cluster map of the degree of policy coordination

4. Conclusions

In this study, the degree of both the coupling and the policy coordination of the urbanization and environment system in the Huai River Basin in the period 2003-2009 was calculated by using a coupling coordination degree model. In addition, the spatial distribution characteristics of the degree of both coupling and policy coordination of prefecture-level cities were analysed with the use of ESDA to reveal their spatial relationships and dynamic evolution. The main conclusions can be summarized as follows:

- The degree of coupling of the urbanization-environment system in the Huai River Basin has gradually risen from 2003 to a maximum in 2006. The degree of policy coordination decreased in the period 2003-2006 but then increased in 2006-2009. In 2006, significant changes took place in the degree of both coupling and policy coordination. This was plausible because that year marked the first year for implementation of the 11th Five-Year Plan (2006-2010) for national economic and social development, and the macro-control measures had not yet begun to take effect. In the study period, the urbanization-environment system was always in the antagonistic and low coupling coordination stage. The degree of both coupling and policy coordination in the Huai River Basin fluctuate over time.

- The Global spatial autocorrelation indicates that the degree of both coupling and policy coordination in the Huai River Basin shows similar characteristics of spatial agglomeration since 2003, and this agglomeration trend is strengthening as time goes on. All kinds of cities classified in terms of their degree of both coupling and policy coordination show similar characteristics in their spatial distribution. In the period 2003-2009, cities of Type LL and Type HH occupied a dominant position in terms of number and area. Cities of Type LL were mainly found southwest of the Huai River Basin, while cities of Type HH were found mainly in the east and northeast. The difference between such cities and their neighbours has tended to decrease. And there were a low number of cities of Type HL and LH in the Huai River Basin.

Many factors influence the level of urbanization and environmental pressures. In view of the availability of data, indicators were selected as attributes of the urbanization and environment system in this study. However, the rationality of the selected indicators needs further empirical study. In addition, a different definition of neighbours could produce a different spatial weight matrix, which would influence the results of global and local spatial autocorrelation analysis. A comparative study on distance or other spatial weights definition criteria, which could examine the robustness of existing results, will be a topic for future research.

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