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An empirical study on the spatial distribution of the population, economy and water resources in Northeast China

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ABSTRACT

The relationship among the population, economy and water resources is complex, and the contradictions and conflicts will appear and aggravate with the rapid development of economy and society in Northeast China. Based on the statistical analysis of the available data, this paper depicted the static distribution characteristics of the population, economy and water resources of Northeast China in 2011. It was found that the spatial distribution of the population, economy and water resources was unbalanced in Northeast China. The water resources mismatched with the population and economy. The population and economy were relatively dense and developed in the southwestern part of Northeast China respectively, while the water resources was relatively scarce. However, the situations in the northern part of Northeast China were opposite to those in the southwestern part. The population-economy inconsistence indexes of the cities in northern part of Northeast China showed a significant trend of spatial aggregation and heterogeneity. The cities with lower (<1.5) and higher (>1) inconsistence indexes all faced the problem of water resources shortage. Applying geometric gravity center method and grey correlation model, the result indicated that there was relatively high spatial relevance and the relative deviation among the spatial dynamic distributions of the population, economy and water resources was large. The gravity centers of economy and per capita average annual total water resources moved westward, while the gravity center of population gravity center moved eastward in the period of 1997–2011 in Northeast China. It must be noted that, the migration trend of the economy gravity center was more significant than those of the population and water resources.

1. Introduction

It is a contradictory unity of population, economy and water resources. There are both distinctions and relations among these three elements (Liu and Wang, 2003; The Research Group of Sustainable Development Strategy, CAS, 2007; Chen, 2002). Water is not only essential for the existence of human beings, but also for the development of social and economy. Many scholars studied the relationship between the water resources carrying capacity and economy or population. Ruan benqing thought water resources carrying capacity should be measured by the regional economic development scale and the population quantity (Ruan and Shen, 1998). Li lingyue considered water resources carrying capacity was the maximum capacity of the population growth and economic development (Li and Gan, 2000). Xia jun deemed water resources carrying capacity should be depicted by the indices of population and economic development scales (Xia and Zhu, 2002). Wang yu believed the measure standards of water resources carrying capacity were the population quantity and economic development level (Wang et al., 2002). Therefore, it is very important to make clear the relationship among population, economy and water resources. However, there is no report about quantitative research on these three elements so far. Related researches mainly focused on analyzing the relationship between two elements (Zhao, 2008; Meybeck et al., 2001; Fischer and Heilig, 1997; Luo et al., 2009; Wan et al., 2007; Wang et al., 2005; Lu et al., 2006; Crenshaw et al., 1997).

In this paper, Northeast China includes Heilongjiang, Jilin, Liaoning provinces and five cities of Inner Mongolia Autonomous Region (HulunBuir City, Xing'an League, Xilingol League, Tongliao City and Chifeng City). Northeast China has large population, abundant resources and developed economy, which occupies an important place in China. The average annual total water resources of Northeast China accounts for about 7.18% of China (The Ministry

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of Water Resources of the People's Republic of China, 2012; Shi and Dai, 2007). In 2011, the total land area, population and GDP of Northeast China accounted for 15.11%, 8.82% and 10.64% of China respectively (National Bureau of Statistics of the People's Republic of China, 2013; Mei et al., 2012). Being located in the center of Northeast Asia, the position of Northeast China is of strategic significant. Besides developed secondary industry, this area has the largest forested region, the best grassland and the largest marketable grain base in China. It has important strategic position and function in the overall economic layout of China. At the same time, the harmonious and stable development of Northeast China is related to the economic development and social stability of the whole country (Qian et al., 2007; Sun and Ding, 2011, 2012). The natural conditions, geographical location, economic system, social environment and historical context of different regions in Northeast China are almost similar, so they can be compared with each other. It provides a new case to do research on revealing the regional internal relation and difference and evolution process and mechanism. It also provides a new perspective to research the regional sustainable development. Therefore, it is obvious that, the development of Northeast China plays an important role in China. Studying the development of Northeast China through the perspective of population, economy and water resources is also crucial.

2. Methodology

2.1. The static analysis method for spatial distribution of the elements

2.1.1. The spatial distribution characteristics of the elements

Referring the existing research results (Yang, 1999; Yang et al., 2002), this paper takes density, proportion and geographic concentration as the evaluation indexes of the spatial distribution characteristics. At the same time, the relative proportion of population and economy geographic concentrations is defined as "the spatial distribution inconsistent index of population and economy" (hereinafter referred as inconsistent index). This index embodies the relationship of the geographic concentration between these two elements.

2.1.2. The spatial statistical analysis of the element distribution characteristics

The spatial statistical analysis provides the solution for the static relationship among different elements, the core of which is revealing the dependence, correlation and autocorrelation characteristics of the data which is related with geographical positions. The exploratory spatial data analysis is one of the core contents of the spatial statistical analysis, and can be divided into global spatial autocorrelation, cluster and outlier analyses.

2.1.2.1. Analysis of the global spatial autocorrelation. The global spatial autocorrelation index (Moran's I) uses location and value to calculate spatial autocorrelation. This tool can judge whether the given data is clustering, discrete or random mode. We can also use Moran's I index, Z score and p value to evaluate the significance of the global spatial autocorrelation index (Griffith, 2003).

The spatial autocorrelation statistic can be expressed as:

$$I = \frac{n}{S_0}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{i,j}z_i z_j}{\sum_{i=1}^{n}z_i^2} \quad (2.1)$$

where x_i is the attribute of element i; $\overline{X}$ is the average of element i; z_i is the deviation between the attribute of element i and its average value, z_i equals to $(x_i - \overline{X})$; $\omega_{i,j}$ is the spatial weights of element i and j; n equals to the total of all elements; S_0 is the sum of all spatial weights.

2.1.2.2. Analyses of the cluster and outlier. The tool of cluster and outlier analyses (Anselin Local Moran's I) can identify the spatial cluster of the elements which have similar attributes. This tool can also identify the spatial outliers (Anselin, 1995).

The local correlation statistics of the spatial correlation can be expressed as:

$$I_i = \frac{x_i - \overline{X}}{S_i^2}\sum_{j=1, j\neq i}^{n}\omega_{i,j}(x_j - \overline{X}) \quad (2.2)$$

where

$$S_i^2 = \frac{\sum_{j=1,j\neq i}^{n}(x_j - \overline{X})}{n-1} - \overline{X}^2 \quad (2.3)$$

2.2. The dynamic analysis method for spatial distribution of the elements

2.2.1. The gravity center of elements

Referring to the mechanics, with the data of longitudes and latitudes of the gravity centers, this paper uses the geometric gravity center method to calculate the gravity centers of population, economy and water resources in Northeast China (Xu and Yu, 1993).

2.2.2. The correlation characteristics analysis method for the movements of the gravity centers

A system containing both known and unknown information is called "gray system" (Zhang and Zhang, 1996; Deng, 2002). The gray correlation analysis model belongs to one of multi-element statistical analysis methods. Based on the sample data, this model descripts the relevance size between different elements through gray correlation. The water demand of the population is affected by economic scale, industrial structure, population growth rate, development and utilization of water resources and so on. So the relationship between population and water resources is gray. In the production function, the output is decided by technical level, labor input and capital input. Labor input related to population quantity, age structure and wage level and so on. Water consumption is only one part of water resources, and water resources is also one part of capital in the production function. So the relationship of population-economy and water resources-economy are both gray. Obviously, the relationships between population and economy, water resources and economy and population and average annual total water resources are gray. This paper uses the gray correlation analysis model to evaluate the relevance of the movements of the gravity centers of these three elements.

$X_i(t)$ and $X_j(t)$ are the coordinates of the gravity centers of element i and j respectively. So $\Delta_{i,j}(t) = |X_i(t) - X_j(t)|$ (t = 1997, 1998 ... 2011) represents the absolute value of the difference between these two coordinates. If $\Delta(\max)$ and $\Delta(\min)$ are the maximum and minimum values of these differences, then $0 \leqslant \frac{\Delta(\min)}{\Delta(\max)} \leqslant \frac{\Delta_{ij}(t)}{\Delta(\max)} \leqslant 1$. Obviously, with the increment of $\frac{\Delta_{ij}(t)}{\Delta(\max)}$, the consistency of change between (X_i) and (X_j) becomes weaker. In order to limit the standardized data between 0 and 1, the value can be taken as $\frac{\Delta(\min)/\Delta(\max)}{\Delta_{ij}(t)/\Delta(\max)}$.

In order to avoid the situation of $\Delta(\min) = 0(\Delta_{ij}(t) = 0)$, the upper formula can be modified as $\frac{\Delta(\min)/\Delta(\max)+\rho}{\Delta_{ij}(t)/\Delta(\max)+\rho} = \varepsilon_{ij}(t)$ $\rho \in [0, 1]$ Where $\varepsilon_{ij}(t)$ is the correlation index between x_i and x_j in t year. The significance of difference between the correlation indexes can be improved with smaller ρ, which is called as resolution coefficient.

$\Delta(average)$ is the average value of all absolute values of the differences. Defining $E_\Delta = \frac{\Delta(average)}{\Delta(\max)}$, if $\Delta(\max) > 3\Delta(average)E_\Delta \leqslant \rho \leqslant 1.5E_\Delta$; if $\Delta(\max) \leqslant 3\Delta(average)1.5E_\Delta \leqslant \rho \leqslant 2E_\Delta$. Via

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