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Spatial and Dynamic Analysis of Regional Sustainable Development Using Geographic Information System and Relative Carrying Capacity of Resources*

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ABSTRACT

Relative carrying capacity of resources is an index to measure sustainable development through carrying capacity. Case studies of eleven cities in Zhejiang (*Hangzhou, Ningbo, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Zhoushan, Taizhou and Lishui*) *illustrated regional sustainable development approach. In this study, to provide insight into spatial and dynamic analysis of region sustainable development, we calculated the relative carrying capacity of land resources and economical resources and synthetical carrying capacity of resources in different cities in Zhejiang, and geographic information system was carried out. The results showed that all cities but Hangzhou and Ningbo were ecologically sustainable, and relative carrying capacity of land resources in northern and eastern Zhejiang was larger than those in southern and western Zhejiang. The sampling years of Wenzhou, Hangzhou and Ningbo contribution rates of land resource to synthetic carrying capacity were grouped into three stages, and there were two milestones trends and changes in* 1996 *and* 2004, *respectively. This study demonstrated that geographic information system and relative carrying capacity of resources are effective for assessment of region sustainable development, and provide policy guidelines for decision-making.*

Keywords*: *Geographic Information System*, *Arcgis*, *Relative Carrying Capacity of Resources*, *Regional Sustainable Development*, *Contribution Rate

1. Introduction

Sustainable development has been widely recognized as an effective tool for harmonizing human society and nature. The main research and practice of sustainable development concept are focused on efficient use of the human and economical resources. Assessment of sustainable development for effective regional management is becoming concern, which included Relative Carrying Capacity of Resources (RCCR) [1], Ecological Footprint (EF) [2,3], Index of Sustainable Economic Welfare (ISEW) [4], Environmental Decision Support System (EDSS) [5], and Genuine Progress Indicator(GPI) [6].

Wang proposed that carrying capacity of natural resources was much lower than the carrying capacity of economy resources of Wenzhou and had been the state of overload from 1992 to 2004 [1]. Ivan and Anna explored the determinants of the ecological footprint of commuting municipal variability by using population density, accessibility, average household income, and job ratio. Nguyen and Yamamoto reported the estimated total ecological footprint of the world using the new method implied more serious problems associated with over consumption than using results from the original ecological footprint method.

Geographic information system (GIS) is a useful and effective tool for spatial features in various fields, particularly in environmental science. In recent years, it has been widely studied for geographical distribution and spatial analysis including particulate waste distribution

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[7], ecological connectivity [8], acute symptoms [9], paramphistomosis in sheep [10], verotoxin-producing Escherichia coli [11], etracapsuloides bryosalmonae infected fishes [12], international epidemiology of lung cancer [13] variance of intraseasonal variations [14], PBDEs in human breast milk [15], amino acid mutations [16], and Colletotrichum lindemuthianum [17].

Yokoi and Satomura revealed remarkable differences ill the geographical distribution, of variance between two types of intraseasonal variations in daily-mean radar reflectivity data ill the western part of the Indochina Peninsula [14]. Sudaryanto *et al.* proposed that concentrations of PBDEs were relatively uniform and the levels were in the same order as those in Japan and some European countries, but were one or two order lower than North America by using geographical distribution [15].

RCCR is essential for carrying capacity in order to assess regional sustainable development. At present, quantitative studies on the spatial analysis of regional sustainable development based on GIS and RCCR in a given region are still rare. With the rapid economic development, Zhejiang has faced with severe conflicts between limited natural resources and increasing resource requirements. Therefore, Zhejiang has become a great challenge for sustainable development over the last decades.

The present study based on [18] aimed to evaluate spatial and dynamic difference of regional sustainable development based on geographic information system and relative carrying capacity of resources in Zhejiang.

2. Studied Area

Zhejiang is located in the southern part of the Yangtze River Delta on the southeast coast of China. It covers a total land area of 101 800 square kilometers. Hills and mountains account for 70.4 percent of the total area in the province. The permanent population of the province reached 51.2 million by the end of 2008, an increase of 1.19% over the previous year. It reserves of stone coal, alunite, pyrophyllite, and tuff rank the first in China and the reserves of fluorite rank the second. In addition, rich deposits of oil and natural gas in the continental shelf are awaiting exploitation. There are 11 cities under the direct jurisdiction of Zhejiang provincial government, including Hangzhou, Ningbo, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Zhoushan, Taizhou and Lishui.

3. Methodology

3.1. Relative Carrying Capacity of Land Resources

Relative carrying capacity of land resources calculation equation is as follows:

$$C_{rl} = I_l Q_l . \quad (1)$$

where C_{rl} is relative carrying capacity of land resources, Q_l is the study area cultivated land, I_l is the study area nature resource carrying capacity index, $I_l = Q_{p0} / Q_{l0}$, and Q_{p0} is reference region population in the country, Q_{l0} is reference region cultivated land in the country.

3.2. Relative Carrying Capacity of Economy Resources

Relative carrying capacity of economy resources calculation equation is as follows:

$$C_{re} = I_e Q_e . \quad (2)$$

where C_{re} is relative carrying capacity of economy resources, Q_e is the study area economy, I_e is the study area economy carrying capacity index, $I_e = Q_{p0} / Q_{e0}$, and Q_{p0} is reference region population in the country, Q_{e0} is reference region economy in the country.

3.3. Synthetical Carrying Capacity of Resources

Synthetical carrying capacity of resources calculation equation is as follows:

$$C_s = W_1 C_{rl} + W_2 C_{re} . \quad (3)$$

where C_s is synthetical carrying capacity of resources, W_1 is the weight of C_{rl}, and W_2 is the weight of C_{re}. Here W_1 is 0.7 and W_2 is 0.3 according to actual nature resources conditions in Zhejiang[1].

3.4. Contribution Rate of Land Resource to Synthetic Carrying Capacity

Contribution rate of land resource to synthetic carrying capacity calculation equation is as follows:

$$\mathrm{Y}_l = \frac{C_{rl} \times 0.7}{C_s} \times 100\% . \quad (4)$$

where Y_l is contribution rate of land resource to synthetic carrying capacity.

3.5. Geographic Information System

A GIS can integrate hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information and can show features and feature relationships. The assessment and calculation data of relative carrying capacity of resources used in the analysis were drawn from Zhejiang statistical yearbooks in 2008. The spatial map analysis was performed by the ArcGIS 9.2 for Windows (Environmental al Systems Research Institute, Inc., USA) software packages.

Firstly, display Zhejiang province map features and

create selection layers. Secondly, add data such as calculated relative carrying capacity of land resources to Zhejiang province map. Thirdly, edit geographic data, and select geographic features. Fourthly, create a summary chart. Finally, lay out and print the maps of relative carrying capacity. The units of relative carrying capacity of resources are all ten thousand persons from **Figure 1** to **Figure 10** except **Figure 6**.

The flow chart of the GIS-based method for spatial analysis of regional sustainable development is shown in **Figure 1**.

4. Results and Discussion

Over load population relative to carrying capacity in Zhejiang is shown in **Figure 2**.

Number of over load population is positive, which means ecologically unsustainable. On the contrary, number of over load population is negative, which means ecologically sustainable. **Figure 2** showed that sustainable development level of Ningbo was the best, while that of Wenzhou was the worst because its over load population relative to carrying capacity is the largest and all cities but Hangzhou and Ningbo were ecologically sustainable. The sustainable development level order of over load population relative to carrying capacity in Zhejiang was as follows: Ningbo, Hangzhou, Jiaxing, Shaoxing, Huzhou, Zhoushan, Quzhou, Jinhua, Lishui, Taizhou and Wenzhou. Spatial sustainable development level in northern Zhejiang is better than those in southern Zhejiang.

Spatial map of relative carrying capacity of land resources in Zhejiang is shown in **Figure 3**.

Figure 3 showed that relative carrying capacity of land resources in northern and eastern Zhejiang was larger than those in southern and western Zhejiang, indicating resources quality in northern and eastern Zhejiang

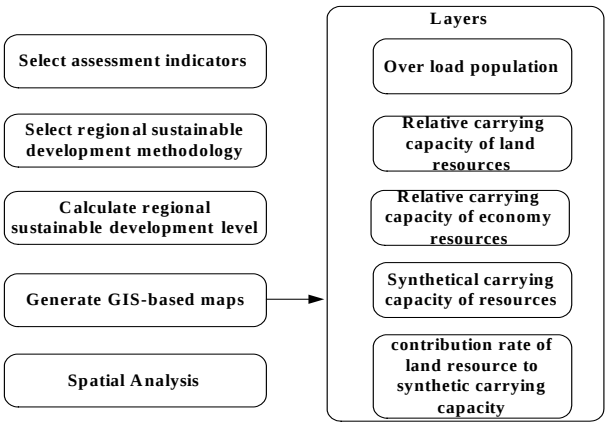

Figure 1. Flow chart of the GIS-based method for spatial analysis of regional sustainable development.

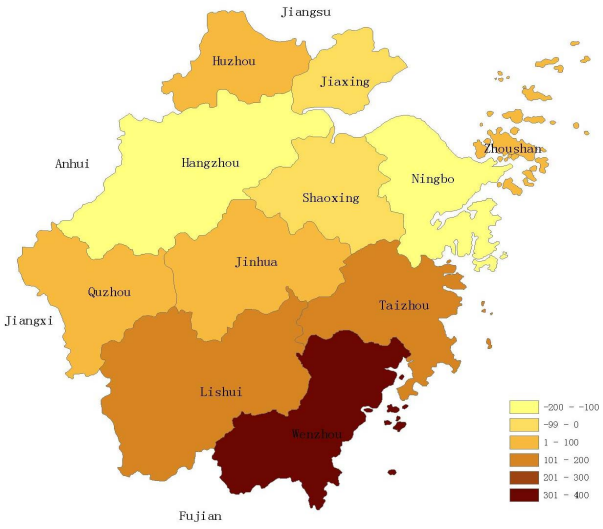

Figure 2. Spatial map of over load population relative to carrying capacity in Zhejiang.

better than those in southern and western Zhejiang. Spatial map of relative carrying capacity of economy resources is shown in **Figure 4**.

Figure 4 showed that relative carrying capacity of economy resources of Hangzhou, Ningbo and Wenzhou were larger than other those cities in Zhejiang, indicating economy development level in Hangzhou, Ningbo and Wenzhou better than those of other cities in Zhejiang.

Spatial map of synthetical carrying capacity of resources in Zhejiang is presented in **Figure 5**.

As can be seen in **Figure 5**, Zhoushan is located in the northeast of Zhejiang. It's an important gateway of inland place to the outside world and the juncture of water arteries linking south and north China with the Yangtse

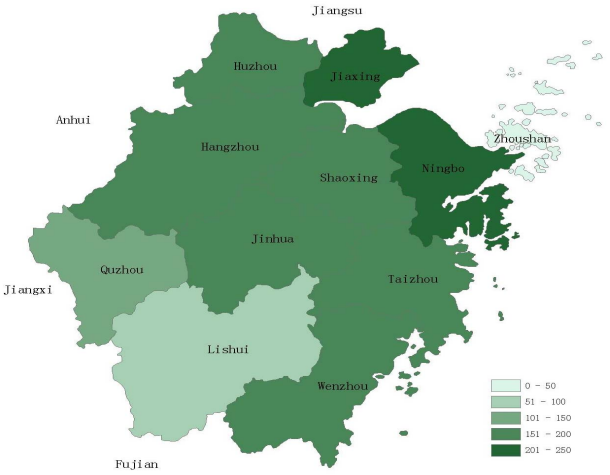

Figure 3. Spatial map of relative carrying capacity of land resources in Zhejiang.

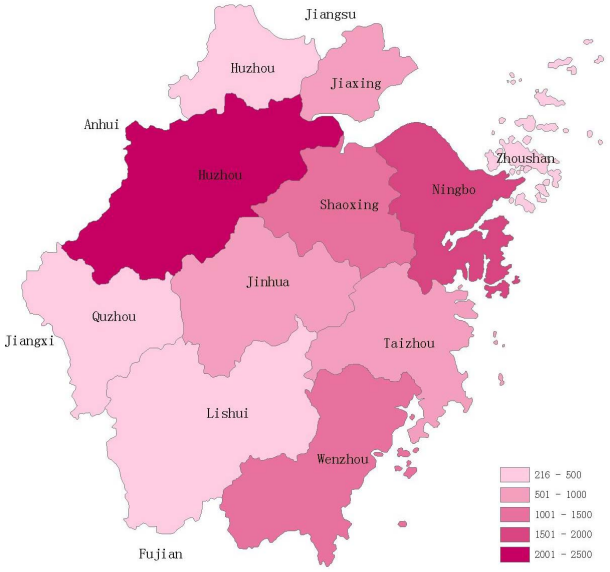

Figure 4. Spatial map of relative carrying capacity of economy resources in Zhejiang.

River. Quzhou is located in the west of Zhejiang, and is usually described as "the Artery of Four Provinces, the Western Gate of Zhejiang" which has rich mineral resources. Lishui is located in the combination of South Zhejiang and North Fujian mountainous regions. Lishui is very rich in resources and specialties with the total amount of five major natural resources ranking top among the province, *i.e.* forest, waterpower, agricultural and byproducts, mineral resources, wild animals and plants. **Figure 5** showed that Zhoushan, Quzhou and Lishui have the lower synthetical carrying capacity of resources in Zhejiang, whereas Hangzhou and Ningbo have the higher synthetical carrying capacity of resources in Zhejiang. The synthetical carrying capacity of resources in Zhejiang from the highest to the lowest was as follows: Hangzhou, Ningbo, Wenzhou, Shaoxing, Jiaxing, Taizhou, Jinhua, Huzhou, Quzhou, Lishui and Zhoushan. Although Wenzhou had relatively larger synthetical carrying capacity of resources, over load population was serious and sustainable development level of Wenzhou was the worst.

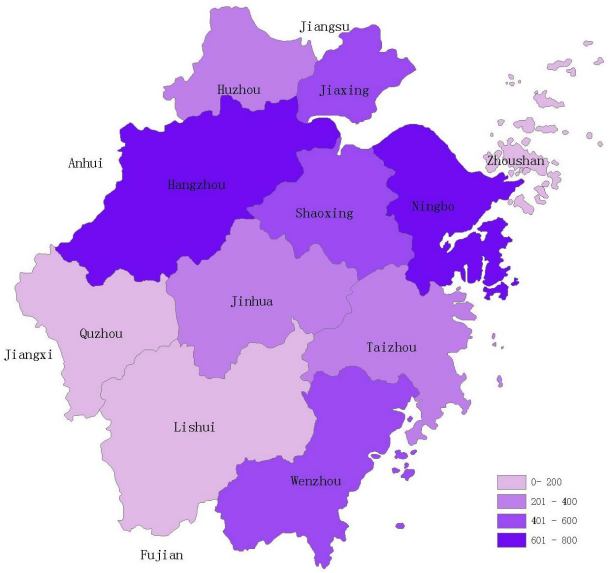

Figure 5. Spatial map of synthetical carrying capacity of resources in Zhejiang.

Spatial map of contribution rate of land resource to synthetic carrying capacity in Zhejiang is presented in **Figure 6**.

Figure 6 showed that contribution rates of land resource to synthetic carrying capacity in western Zhejiang were larger than those in eastern Zhejiang except Hangzhou. Slower economy, larger contribution rates of land resource to synthetic carrying capacity. Therefore policies of nature resource become a crucial factor for growth of sustainable development in Zhejiang.

Dynamic analysis of regional sustainable development using geographic information system and relative resource carrying capacity was developed for the cases of Hangzhou, Wenzhou and Ningbo. Dynamic plot of over load population relative to carrying capacity in Zhejiang is presented in **Figure 7**.

Figure 7 showed that the number of over load population declined rapidly from 1993 to 2004, and increased rapidly from 2004 to 2005, and keep calm 2005 to 2007

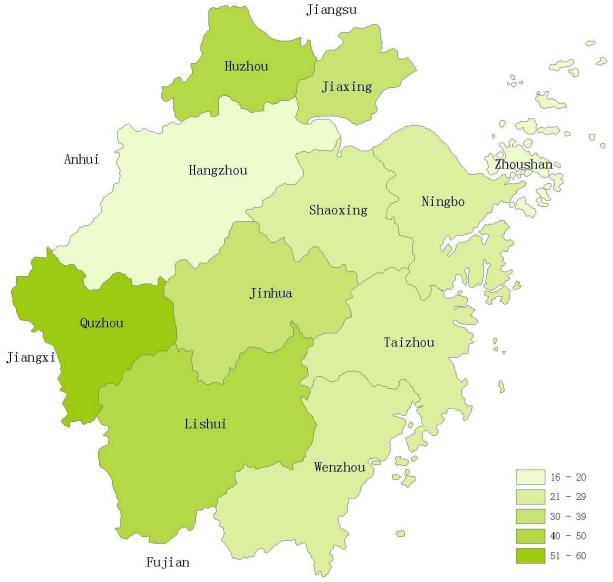

Figure 6. Spatial map of contribution rates of land resource to synthetic carrying capacity in Zhejiang.

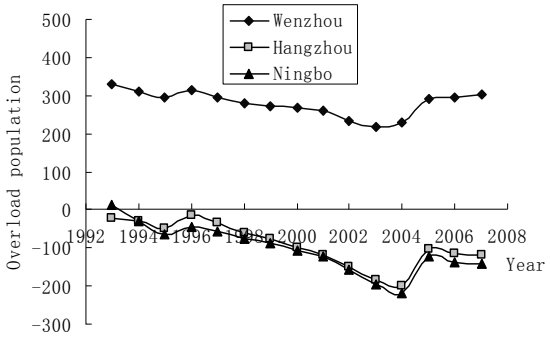

Figure 7. Dynamic plot of over load population relative to carrying capacity in Zhejiang.

in Zhejiang such as Hangzhou, Wenzhou and Ningbo. The three cities of Zhejiang province such as Wenzhou, Hangzhou and Ningbo have experienced significant structural changes due to the incessant growth in the number of urban population.

The over load population of Wenzhou varied from 2 196 thousand person to 3 291 thousand person during 1993 to 2007 with an average value of 2 793 thousand person. The over load population of Hangzhou and Ningbo varied from −127 and 138 thousand person to −2 012 and −2 189 thousand person during 1993 to 2007 with an average value of −912 and −1 033 thousand person, respectively, indicating Hangzhou and Ningbo non over load level of sustainable development from 1993 to 2007.

Dynamic plot of relative carrying capacity of land resources in Zhejiang is presented in **Figure 8**.

Figure 8 showed that relative carrying capacity of land resources in Zhejiang remained essentially constant from 1993 to 1995, while it increased with steady steps from 1996 to 2007. The order of relative carrying capacity of land resources from higher to lower as followed: Ningbo, Hangzhou and Wenzhou. The prevention and control land resource of Wenzhou was still severe.

Dynamic plot of relative carrying capacity of economy resources in Zhejiang is presented in **Figure 9**.

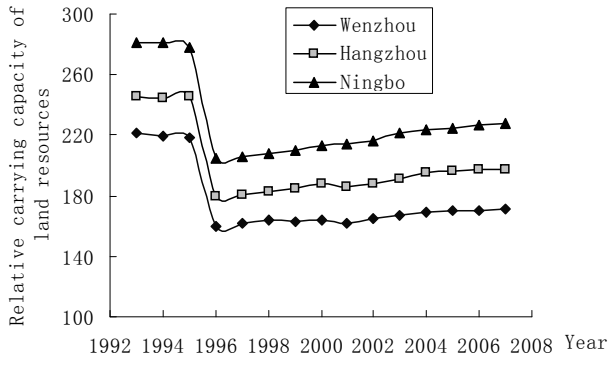

Figure 8. Dynamic plot of relative carrying capacity of land resources in Zhejiang.

Figure 9 showed that relative carrying capacity of economy resources increased steadily from 1993 to 2004, whereas it remained essentially constant from 2005 to 2007.

The order of relative carrying capacity of economy resources from higher to lower as followed: Hangzhou, Ningbo and Wenzhou.

Dynamic plot of synthetical carrying capacity of resources in Zhejiang is presented in **Figure 10**.

Figure 10 showed that synthetical carrying capacity of resources was increased steadily from 1993 to 2004, whereas remained essentially constant from 2005 to 2007.

The sampling years of Wenzhou, Hangzhou and Ningbo synthetical carrying capacity of resources were grouped into two stages. The order of synthetical carrying capacity of resources from higher to lower as followed: Hangzhou, Ningbo and Wenzhou.

Synthetical carrying capacity of resources in Zhejiang increased with increasing relative carrying capacity of economy resources in Zhejiang, and Synthetical carrying capacity of resources declined with declining relative carrying capacity of economy resources.

Dynamic plot of contribution rates of land resource to synthetic carrying capacity in Zhejiang is presented in **Figure 11**.

Figure 11 showed that sampling years of Wenzhou, Hangzhou and Ningbo contribution rates of land resource to synthetic carrying capacity were grouped into three stages, and there were two milestones in the contribution rates of land resource to synthetic carrying capacity temporal trends and changes, which year were 1996 and 2004. The contribution rates of land resource to synthetic carrying capacity increased suddenly from 1993 to 1996, and increased steadily from 1996 to 2004, whereas it remained essentially constant from 2005 to 2007.

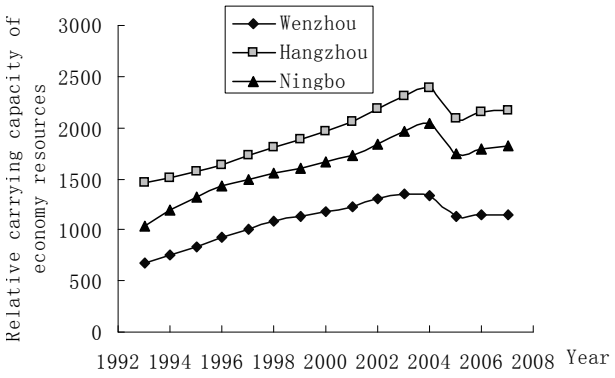

Figure 9. Dynamic plot of relative carrying capacity of economy resources in Zhejiang.

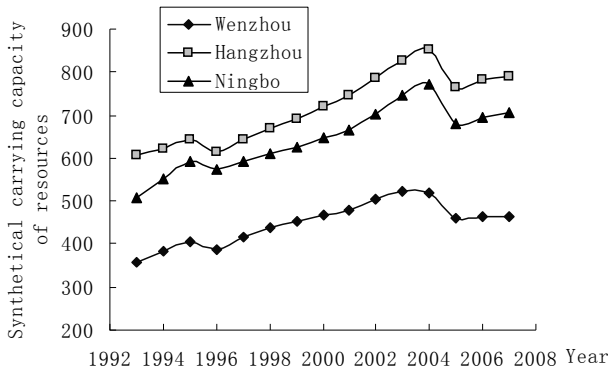

Figure 10. Dynamic plot of synthetical carrying capacity of resources in Zhejiang.

The order of synthetical carrying capacity of resources from higher to lower as followed: Wenzhou, Ningbo and Hangzhou.

In order to achieve "double-win" of economy and environment, the local government should take into considerations in developing circular economy including construction of eco industrial park (EIP).

Thus, the city's policies of sustainable development in the future should aim at emphasis on strengthening population and nature resources management, upgrading industrial structure, and raising the utilization efficiency of resources based on different regional situations.

5. Conclusions

Relative carrying capacity of land resources in northern and eastern Zhejiang was larger than those in southern and western Zhejiang. Zhoushan, Quzhou and Lishui have the lower synthetical carrying capacity of resources in Zhejiang, whereas Hangzhou and Ningbo have the higher synthetical carrying capacity of resources in Zhejiang. The contribution rates of land resource to synthetic carrying capacity in western Zhejiang were more than those in eastern Zhejiang except Hangzhou.

Hangzhou and Ningbo were not over load level of Sustainable development, whereas Wenzhou was seriously over load of that from 1993 to 2007. Synthetical carrying capacity of resources increased with increasing relative carrying capacity of economy resources in Zhejiang such as Wenzhou, Hangzhou and Ningbo and vice versa.

The geographic information system and regional relative carrying capacity of resources are useful tools to measure urban sustainable development and provide policy guidelines for decision-making.

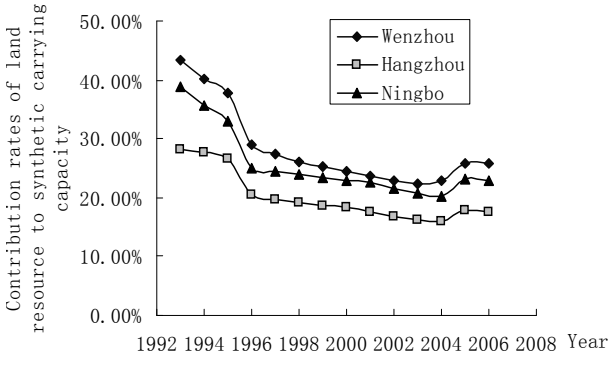

Figure 11. Dynamic plot of contribution rates of land resource to synthetic carrying capacity in Zhejiang.

6. Acknowledgements

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