Combining AHP with GIS for evaluating environmental carrying capacity in Shaanxi Province, China

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Abstract—**The analytic hierarchy process (AHP) has the special advantage in multi-indexes evaluation, and geographical information system (GIS) is good at spatial analysis. Combining AHP with GIS provides an effective means for studies of regional environmental carrying capacity (ECC) evaluation. Aiming at the regional features of ecosystem of Shaanxi Province, the synthetic evaluation index system is set up including eco-elastic force, resource carrying capacity and environment carrying capacity factors. Supported by GIS, taking the city as the evaluation unit, the information system database of ECC of Shaanxi Province is established. Based on the database and evaluation system, AHP, ECC evaluation index method and spatial analysis are integrated into the ECC evaluation in the study area. The results showed that only 23% of the total land area in Shaanxi Province maintains a good or better grade of the ECC. However, 50% of the total area is of a bad or worse grade of ECC. From the spatial distribution, the ECC gradually decreased from the south to the north with exception in a few areas, which presented the obvious characteristics of terrain. It is concluded that the current status of the integral ECC of Shaanxi Province is in the bad level, and highly intense human activities speeded up the degradation of regional ecosystem in recent years.**

Keywords- AHP; GIS; environmental carrying capacity; Shaanxi Province; China.

I. Introduction

ECC is defined that on certain economic, technical conditions and environmental standards, the largest population and social scale with the greatest standard of living can be carried by a region's resources and environment. ECC is crucial to the speed and scale of a regional economic and social development, and the continuous improvement of the ECC is a must for the sustainable development, as in [5]. On the condition of a certain social welfare and economic technological level, the extent of the regional population and economy is beyond the scope its ecosystem can carry, which may result in deterioration of the ecological environment and lack of resources, seriously may lead to abnormal development even recession of economic society.

The evaluation for ECC is helpful to find out the regional current status of sustainable development and puts forward the corresponding countermeasures to the protection of resources and environment. Consequently the evaluation of regional ECC is popularly applied at home and abroad. Developed by Satty (1980), the analytic hierarchy process (AHP) [11] is a decision analysis method that considers both qualitative and quantitative information and combines them by decomposing ill-structured problems into systematic hierarchies to rank alternatives based on a number of criteria, as in [7]. As a result, the AHP has the special advantage in multi-indexes evaluation. It is applied in many research fields, including nature, economy and society. AHP also becomes a common means of ECC evaluation at present, as in [3], [9], [10]. Geographic information system (GIS) is a modern information technique with powerful functions of storing, disposing, spatial analysis and visualizing. With the rapid development of GIS and computer technology, it is widely applied in research fields of natural resources, environment management and their evaluations. Therefore, combining AHP with GIS method, the research assesses the regional ECC, taking Shaanxi Province for example, as in [1], [2]. In the research, each weight of evaluation element is determined by AHP after establishing the selected evaluation indexes and units. Supported by GIS, the carrying capacity index and sub-index are calculated, and the grade maps are automatically created for synthesis evaluation of the ECC of Shaanxi Province. Moreover, the spatial distribution regulations are synthetically analyzed from the integrated ECC and three subsystems of eco-elastic force, resource carrying capacity and environment carrying capacity, respectively

II. Methodology

A. Establishment of the evaluation index system

The establishment of a proper evaluation index system is basic for the scientific analysis of ECC. The synthetic evaluation of ECC is affected by many factors, so chosen factors should be able to represent the features of the regional ecosystem. The main ecological problems should be taken into account when the researchers choose the factors. At the same time, access to the required data should also be considered when selecting factors. Based on the analysis of regional ecosystem characteristics, the ECC evaluation index system of Shaanxi Province is established as in the Table I.

TABLE I. EVALUATION INDEX SYSTEM OF ECC

1st grade	2nd grade	3rd grade.	4th grade.
al carryi ng capaci	Eco-elastic	Climate	Average temperature
			Sunshine hours
			Relative humidity

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	force		Rainfall
		Hydrologic	Number of Reservoir
			Reservoir capacity
			Effective irrigation area
		Environment pollution	Industrial waste water emissions
			Industrial waste gas emissions
			Industrial solid waste generation
		Disaster	Crop area affected
			Affected population
			Direct economic losses
	Resource carrying capacity	Water resources carrying capacity	Total water supply
			Per capita residential water consumption
		Land resources carrying capacity	Land area of administrative district
			Area of built-up area
			Arable land per capita
		Vegetation resources carrying capacity	Green area per capita
			Total sown area of crops
			Afforestation area
			Coverage area of gardening and greening
		Tourism resources carrying capacity	Proportion of tertiary industry in local GDP
			Passenger volume
		Energy resources carrying capacity	Annual electricity consumption
			Per capita residential electricity consumption
			Total supply of Liquefied Petroleum Gas
	Environment carrying capacity	Natural environmental carrying capacity	Investment in Anti-pollution Project
			Investment in urban environmental infrastructure
			Output value of comprehensive utilization of waste products
			Comprehensive utilization rate of industrial solid wastes
			Rate of industrial waste water reaching discharge standards
			Treatment rate of industrial sulfur dioxide
			Treatment rate of industrial soot
		Social-economic carrying capacity	GDP per capita
			Growth rate of GDP
			Level of urbanization
			Proportion of science expenditure in local fiscal expenditure
			Proportion of education expenditure in local fiscal expenditure
			Proportion of welfare expenditure in local fiscal expenditure

B. Dimensionless evaluation factors

Because the evaluation factors are of their own characteristics or extensity, and each data of factors had its own dimension and distribution, it is difficult to directly compare or operate. As a result, the original data should be dimensionless by range transformation. Furthermore, evaluation factors have negative and positive interrelation to ECC evaluation. Therefore, negative and positive interrelation factors should be dimensionless, with (1) for positive factors and (2) for negative interrelation factors.

All the factors are processed by these methods, as in [6].

$$x_i' = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \times 100 \qquad (1)$$

$$x_i' = \left(1 - \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)}\right) \times 100 \qquad (2)$$

where *i* is the evaluation unit, this paper chooses ten cities as the basic units for ECC evaluation, x_i is the original value of *i*, x_i' is the dimensionless value of *i*.

C. Weight of evaluation factors

The weight of each factor is determined with AHP. AHP is a systematic analyzing evaluation method to treat the complex and multi-index system quantitatively, which could decompose the complex problem to some layers and some factors, and could compare and calculate as the result of weight, as in [7]. Due to its ability of assigning proper weights to various factors of complex systems, the AHP method is applied to determine the weight of each factor in the research.

D. Calculation of synthetic index and sub-index of ECC

As a complex system with multi-subject and multi-level, the synthetic evaluation index of ECC is adopted to make levels more confident and accurate, which means that values of all index are overlaid in each evaluation unit and the synthetic value is used to determine the ECC. Based on regional information system database of ECC, we can get the synthetic evaluation value of each unit by using the equation.

$$ECC = \sum_{i=1}^{n} u_i w_i \qquad (i = 1, 2, \cdots, n) \qquad (3)$$

,where *EEC* is the synthetic index of ECC, *u* is the value of each index, *w* is the weight of each index, and *n* is the total number of indices.

E. Gradation of synthetic evaluation of ECC

The evaluation of ECC is not only aimed at the total situation of the ecosystem, but also at the natural and manual factors that resulted in the deterioration of ecosystem. In the research, the results of the synthetic evaluation index and each sub-index are graded as five levels according to the ECC distribution function: better, good, middle, bad, worse, respectively. Table Ⅱ showed the classified boundaries of the evaluation factors.

F. Creating grade maps

The thematic maps with CorelDraw are created based on the synthetic evaluation index, including grade maps of eco-elastic force, resource carrying capacity, environment carrying capacity and environmental carrying capacity.

TABLE II. CLASSIFIED BOUNDARIES OF SYNTHETIC EVALUATION OF ECC

Factor	**Grade and distribution range**				
	Worse	***Bad***	***Middle***	***Good***	***Better***

Eco-elastic force	10~16	16~22	22~28	28~34	34~40
Resource carrying capacity	8.0~10.4	10.4~12.8	12.8~15.2	15.2~17.6	17.6~20.0
Environment carrying capacity	1.0~2.6	2.6~4.2	4.2~5.8	5.8~7.4	7.4~9.0
Environmental carrying capacity	30~36	36~42	42~48	48~54	54~60

III. RESULTS AND ANALYSIS

As one of the extremely vulnerable regions in China [8], Shaanxi Province is shortage of water, serious soil erosion, lack of vegetation resources, serious disasters including ground subsidence, mud-rock flows and landslides, and threats to biological diversity. For these above reasons, it is essential for scientific synthetic evaluation of ECC of Shaanxi Province.

Based on the data excerpted from "Statistical Yearbook of Shaanxi (2007)" and "China City Statistical Yearbook (2007)", the study uses the methodology above to assess the ECC of Shaanxi Province.

A. *Analysis of eco-elastic force*

The evaluation results of eco-elastic force (Fig. 1) show that the sum of unit numbers with better, good and middle grades is 61% of the total area, which show good ecosystem stability of Shaanxi Province. Most of these areas are located at the south, where there are a plenty of rain and sunshine with continental monsoon climate.

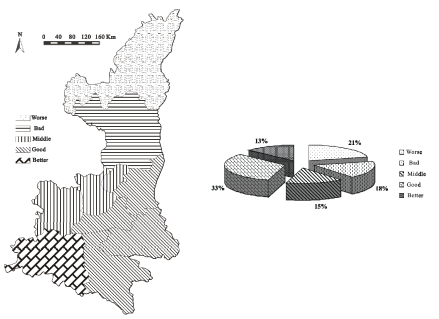

Figure 1. Grade map of eco-elastic force evaluation(Left) and Area proportion of units by eco-elastic force evaluation(Right).

From the spatial distribution of eco-elastic force (Fig. 1), it presents characteristics of terrain. The eco-elastic force in the north regions is worse than that in the south, and regions with bad or worse grade are focused in Yulin City and Yan'an City in northern Shaanxi, where there is Loess Plateau in the south and Maowusu Desert in the north leading to lack of water. The reason for better eco-elastic force in the south of Shaanxi Province is that the Qinling Mountains and Weihe River lead to better water and heat, better vegetation condition and better land quality. On the other hand, the GDP per capita in Yulin City and Yan'an City is relatively higher than the other cities of Shaanxi Province. Therefore, it reflects the regional social economy development has influences on the ecosystem stability to some extent.

B. *Analysis of resource carrying capacity*

According to the evaluation results of resource carrying capacity (Fig. 2), Areas with the bad and worse grades are 81% of the total areas in Shaanxi Province, which shows the low resource carrying capacity. The regions with middle, good and better grade are located in Xi'an City, Xianyang City and Baoji City, which are all the economically developed areas in Shaanxi Province.

This is because the water, land, vegetation, tourism, energy and other resources in Shaanxi Province are the state of scarcity or incomplete exploration, it is necessary to rely on the economic development to improve the resource carrying capacity (e.g. returning farmland to forests, improving the tourism environment and strengthening energy exploration, etc.). It proves that the regional social economy development also has influences on the resource carrying capacity.

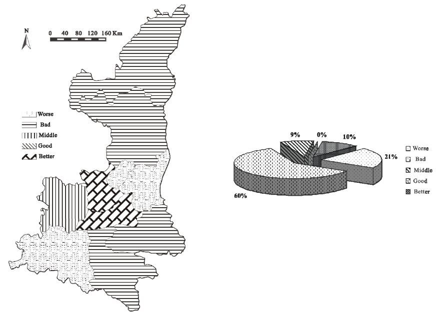

Figure 2. Grade map of resource carrying capacity evaluation(Left) and Area proportion of units by resource carrying capacity evaluation(Right).

C. *Analysis of environment carrying capacity*

The evaluation results of environment carrying capacity (Fig. 3) show that the regions with the middle, bad and worse grades are at an area proportion of 59%, which reflects the bad environment carrying capacity. From the grade map, the environment carrying capacity in the middle regions are better than that in the other regions of Shaanxi Province and better in the developed regions than in the developing regions. Although the developed economy, high industrialization and denseness of population in the middle resulted in some environmental problems, the serious environmental problems has been in existence for many years in Shaanxi Province, so we should rely on technology and funds brought by economic development to improve the environment, thereby enhancing the environment carrying capacity.

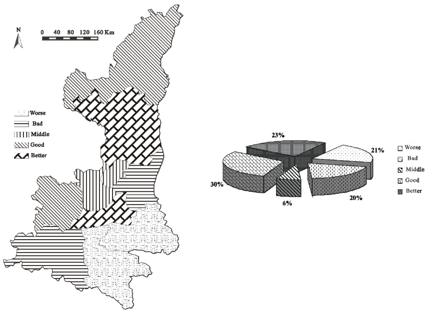

Figure 3. Grade map of environment carrying capacity evaluation(Left) and Area proportion of units by environment carrying capacity evaluation(Right).

D. *Analysis of ECC*

The results of ECC evaluation (Fig. 4) show that the regions in the status of middle, bad and worse are up to 77% of the total area of Shaanxi Province, which indicates a bad level of ECC. The best ECC is located in Xi'an City, for the city, as the political, economic and cultural center of Shaanxi Province, is relatively favorable in protection of environment and supply of resources. Its ecosystem stability is second to Ankang City and Hanzhong city, but it does not affect its best environmental carrying capacity. The worst region of ECC is Yulin City, mostly because of the bad ecosystem stability and backwards economical development.

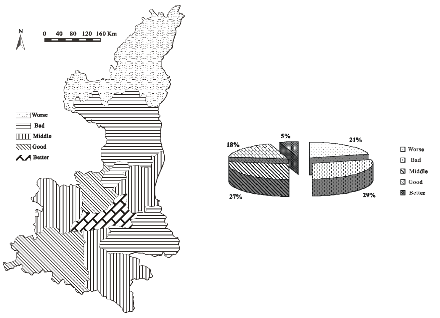

Figure 4. Grade map of environmental carrying capacity evaluation(Left) and Area proportion of units by environmental carrying capacity evaluation(Right).

IV. DISCUSSION AND SUMMARY

By combining AHP with GIS method, the study approaches the research on the current condition of ECC of Shaanxi Province, located in the northwest of China. The results show that:

(1) This methodology combining the AHP with GIS provides an improvement method for synthetic evaluation of ECC, which develops the GIS capability of spatial analysis and the AHP capability of multi-layers analysis. The evaluation results and the distribution pattern of regional ECC can be obtained with the method. Therefore, the method can be very interesting to policy makers involved in regional ECC evaluation, because it allows decision makers to clearly know current status of the integrated ECC of their regions, and to help them resolve some problems about the regional ecosystem.

(2) The synthetic evaluation of ECC for Shaanxi Province shows that region numbers of middle, bad and worse grade approximate to 4/5 of the total area, which basically accords with the actual situation of the ecosystem. From the spatial distribution, the ECC of Shaanxi Province gradually decreases from the south to the north with some differences in partial regions. Eco-elastic force is the main functional factor on the evaluation of ECC, while other factors such as resource carrying capacity and environment carrying capacity are secondary indices affecting the synthetic environmental carrying capacity of Shaanxi Province. As results, we should adjust measures to strengthen ecological construction for frail ecosystem regions, such as Yulin City.

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REFERENCES

[1] Krajnc, D., Glavic, P., "A model for integrated assessment of sustainable development", Resources, Conservation and Recycling, vol. 43, Jan. 2005, pp. 189-208.

[2] Aspinall, R., Pearson, D., "Integrated geographical assessment of environmental condition in water catchments: linking landscape ecology, environmental modelling and GIS", Journal of Environmental Management, vol. 59, Aug. 2000, pp. 299-319.

[3] Yuguang Chang, Chunqin Chang, Haipeng Niu,, "Tourism site ECC of Yuntai mountain based on Analytic Hierarchy Process", Journal of Henan Polytechnic University (Natural Science), vol. 27, Feb. 2008, pp. 188-192.

[4] Chuanfeng Han, Jianye Chen, Huimin Liu, "Construction model with enhancement of ecologically carrying capacity for Chongming Island", Journal of Natural Disasters, vol. 14, Apr. 2005, pp. 103-107.

[5] Kaiyun Wang, Chunjing Zou, Zhenghong Kong, Tianhou Wang, Xiaoyong Chen, "Environmental carrying capacity and Chongming Island's ecological construction", Chinese Journal of Applied Ecology, vol. 16, Dec. 2005, pp. 2447-2453.

[6] Ying Xiong, Guangming Zeng, Guiqiu Chen, Lin Tang, Kelin Wang, Daoyou Huang, "Combining AHP with GIS in synthetic evaluation of eco-environment quality—A case study of Hunan Province, China", Ecological Modeling, vol. 209, Dec. 2007, pp. 97-109.

[7] Jianhua Xu, "Mathematical methods in contemporary geography", China Higher Education Press, Beijing, 2002, pp. 224-230.

[8] Yujie Yan , Yi Hua, Ranxia Liu, "Achievements and problems of Shaanxi's ecological environment, nature resources and economic development", Journal of Shaanxi University of Science & Technology, vol. 23, Jan. 2005, pp. 108-112.

[9] Zhifeng Yang, Xin Sui, "Assessment of the environmental carrying capacity based on the ecosystem health", Acta Scientiae Circumstantiae, vol. 25, May. 2005, pp. 586-594.

[10] Xueyan Zhao, "Evaluation on the environmental carrying capacity in Gansu Province", Arid Zone Research, vol. 23, Mar. 2006, pp. 506-512.

[11] Saaty TL, The Analytic Hierarchy Process, McGraw Hill, New York, 1980.