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Combining AHP with GIS in synthetic evaluation of eco-environment quality—A case study of Hunan 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 eco-environmental evaluation. Aiming at the regional features of eco-environment and main environmental problems of Hunan Province, the synthetic evaluation index system was set up including natural environment, disaster, environment pollution and social economy factors. Supported by GIS, taking the county as the evaluation unit, the regional eco-environmental information system database and evaluated the eco-environmental quality of Hunan Province were established. Based on the database and evaluation system, AHP, eco-environmental evaluation index method and spatial analysis were integrated into the eco-environmental quality evaluation in the study area. The results showed that 35.2% of the total land area in Hunan Province (approximately 68 462.45 km^2) maintains a good or better grade of the eco-environmental equality. However, 22.8% of the total area (approximately 44 345.00 km^2) was of a bad or worse grade of eco-environment quality. From the spatial distribution, the eco-environmental quality gradually decreased from the east to the west with exception in a few areas, which presented the obvious speciality of terrain. It was concluded that the current status of the integral eco-environment quality of Hunan Province was in the middle level, and highly intense human activities speeded up the degradation of regional eco-environments in recent years.

1. Introduction

Ecological environment is a basic element for human subsistence and connects the regional economy with social sustainable development. The evaluation for eco-environment quality is helpful to find out the regional current status of sustainable development and puts forward the corresponding countermeasures to the protection of eco-environment (Su et al., 2007; Zhu et al., 2004; Jibson et al., 2000; Luzi et al., 2000; Huang and Sun, 2006; Wang and Li, 2006). Consequently the evaluation of regional eco-environment quality is popularly applied at home and abroad. Developed by Satty (1977), The analytic hierarchy process (AHP) is a decision analysis method that considers both qualitative and quantitative information

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and combines them by decomposing ill-structured problems into systematic hierarchies to rank alternatives based on a number of criteria (Chen et al., 2008). As a result, the AHP has the special advantage in multi-indexes evaluation. It was applied in many research fields, including nature, economy and society (Ramanathan and Ganesh, 1995; Ibrahim and Khaled, 2005; Lai et al., 2002; Omasa et al., 2004; Krajnc and Glavic, 2005; Jie et al., 2004). AHP also becomes a common means of eco-environment quality evaluation at present, for ecological environment is a large and multi-layer system (Klungboonkrong and Taylor, 1998; Yedla and Shrestha, 2003; He et al., 2004; Hill et al., 2005; Kang, 2002; Solnes, 2003; Kurttila et al., 2000). Geographic information system(GIS) is a modern information technique with powerful functions of storing, disposing, spatial analysis and visualizing (Gregory et al., 2003; Charnpratheep et al., 1997; Wu et al., 2002; Li et al., 2006; Thirumalaivasan et al., 2003). With the rapid development of GIS and computer technology, it was widely applied in research fields of natural resources, environment management and their evaluations (Lan et al., 2004; Valavanis et al., 2004; Davide, 2004; McNeil et al., 2006; Zhang et al., 2005; Aspinall and Pearson, 2000; McKinney and Cai, 2002). Therefore, combining GIS with AHP method, the research assessed the regional eco-environment quality.

In fact, the assessment of eco-environment quality was a rapidly developing research field. Due to the systemic complexity, most of previous evaluation studies of eco-environment were emphasized on some particular and unilateral research fields (Li, 2007; Andrew et al., 2000; Zeng et al., 2007; He et al., 2006; Qin et al., 2006). Multi-factor synthesis analysis and unitary assessment (including resource, environment and social economy, etc.) were rarely found (Liu et al., 2003), especially the application of quantitative analysis method on the whole region. Some of assessment researches were still unilateral aiming at regional uppermost ecological problems (Chao and Olle, 1998; Thomas et al., 2002; Xu et al., 2001). The GIS model was used in environmental quality assessment and environmental modeling. Paul (1998) developed a general framework and specific procedures by a screening level ecological risk assessment for urban watersheds, and applied it to the case of the Brunette River watershed in Canada. Schotten et al. (2001) applied a land use model to simulation for the residential construction and land use for the Netherlands by using GIS. Li et al. (2004) developed the land use adjustment using a modified soil loss evaluation method supported by GIS. Matejicek et al. (2003) integrated the remote sensing (RS) and GIS as an ecological model to obtain an NDVI index and simulate N pollution. Gregory and John (2003) predicted landslide hazard using multiple logistic regression and GIS in the hilly terrain along the Kansas and Missouri rivers in northeastern Kansas, USA. However, this approach using some GIS modules was only a tool to display the results, which did not integrate the eco-environmental model to GIS.

This paper aimed at improving the synthetical eco-environmental quality evaluation by combining GIS with AHP, which apply their functions to establish integrated evaluation systems from the aspects of natural background, environmental pollution, eco-environment disaster and human social economy activities, with a case study of Hunan Province. In the research, each weight of evaluation element was determined by AHP after establishing the selected evaluation indexes and units. Supported by GIS, the quality index and sub-index were calculated, and the grade diagrams were automatically created for synthesis evaluation of the eco-environment quality of Hunan Province. Moreover, the spatial distribution regulations were synthetically analyzed from the integrated eco-environment quality and four subsystems of natural situation, environmental pollution, eco-environment disaster and social economy, respectively (Fig. 1).

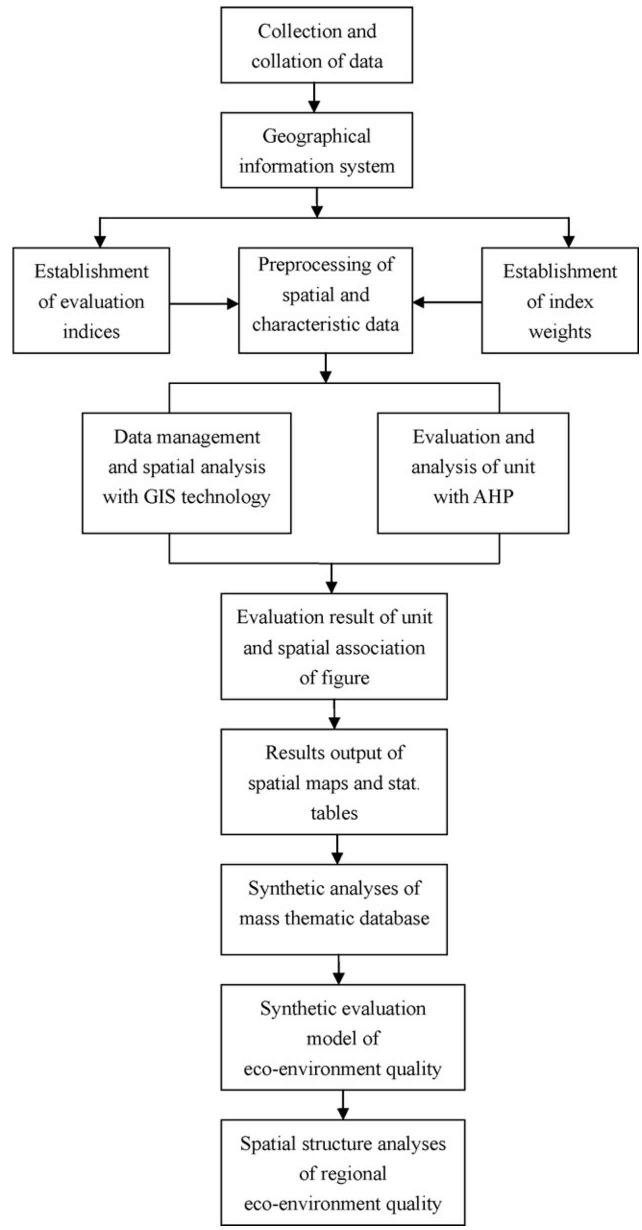

Fig. 1 – Flow-chart of eco-environment quality evaluation of Hunan Province.

The integrated analysis of the regional eco-environment in Hunan Province would prompt the protection of ecological environment and the regional sustainable development, as well as the improvement of human habitats. The objectives of this study were also to disclose the current situation, the main affecting factors and spatial pattern of eco-environment qual-

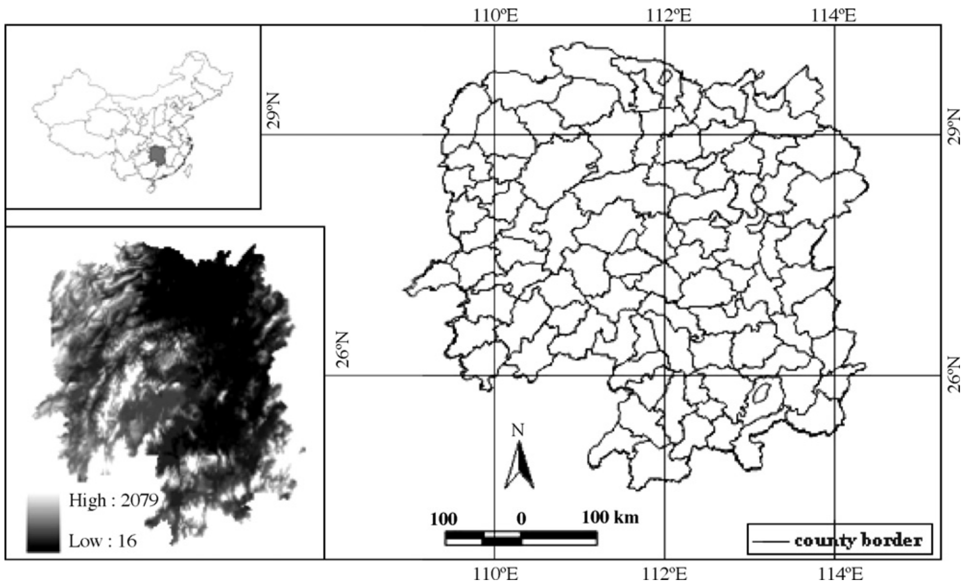

Fig. 2 – Location of Hunan Province.

ity in this region, and to provide a good approach to evaluate the synthetic eco-environment quality for provincial administrative divisions.

2. Study area

The study site was Hunan Province (Fig. 2), which is located in the middle of China at 108°47′∼114°13′ E, 24°39′∼30°08′ N. It is composed of 13 cities and 1 municipality, with a total area of 211 800 km^2, 2.21% of total land area of China. The population was 67 321 000 in the end of 2005. Hunan Province is a mountainous region with the elevation descending from south to north, varying from 16 to 2079 m. Mountains and hills account for 51.2% of the total area of Hunan. The annual rainfall is from 1300 to 1600 mm from April to July, which is one of the plentiful rain areas in China. According to the natural situation, Hunan province ranks the 9th in the evaluation of the countrywide survival resources enrichment by its abundant sunshine and rain (Chinese Academy Science, 1999). It is one of the main agricultural provinces in China and an important base of agricultural products. It held the balance of national agriculture for the image of "a land flowing with milk and honey."

Because Hunan Province is located in the middle reach of the Yangtze River, its ecological status is very important to keep an ecological balance of the water system, and to promote a healthy development of society and economy in the middle and lower reaches of the Yangtze River. While in the middle part of "three easily disaster-affected zones" of China, Hunan Province became one of the most severe disaster regions for its natural calamities (Li, 2000). The special geographical location of Hunan Province leads to the sensitivity and fragility of its ecological environment. It is one of the most seriously natural disaster affected provinces in the southern Yangtze River especially for flood and drought. Unreasonable exploitation and utilization of natural resources speeded up the degradation of eco-environment and the loss of combined advantage of nature resources. For these above reasons, it is essential for scientific synthetic evaluation of eco-environment in Hunan Province.

3. Methodology

3.1. *Establishment of the evaluation index system*

The establishment of a proper evaluation index system was basic for the scientific analysis of eco-environment. The synthetic evaluation of eco-environmental quality was affected by many factors, including natural features and man-made features with multi-subject and at multi-level. It was a homeostasis system of energy cycling and matter exchanging between natural environment and liberal environment. So chosen factors should be able to represent the features of the regional eco-environmental system. The main eco-environmental problems should be taken into account when the researchers chose the indicator groups. At the same time, access to the required data should also be considered when selecting factors. Based on the analysis of regional eco-environment characteristics, the eco-environmental quality evaluation index system of Hunan Province was established by four big groups including natural situation, environmental pollution, disasters and social economy, and 15 small groups, total of 28 factors after consulting some experts for advice of eco-environment and the assessing standard of ecological demonstration area of Hunan Province, the present statistical investigation system of China (Table 1).

3.2. *Selection of evaluation unit*

The evaluation units were composed of a series of many factors that affected the eco-environment quality, to reflect some definite space and entity to a certain extent. The county administrative division was also the grass root for the pro-

Table 1 – Index system of eco-environment synthetic evaluation in Hunan Province

First grade (A)	Second grade (B)	No.	Third grade (C)	No.	Fourth grade (D)	No.
Eco-environment quality	Natural environment	B1	Climate	C1	Annual temperature	D1
					≥10 °C accumulated temperature	D2
					Mean annual rainfall	D3
					Rainfall variation rate	D4
			Hydrology	C2	Surface runoff depth	D5
					Water area proportion	D6
			Land	C3	Cultivated area proportion	D7
					Effective irrigated land proportion	D8
			Biology	C4	Forest cover rate	D9
	Disaster	B2	Meteorological disaster	C5	Drought area proportion	D10
					Flood-waterlogging area proportion	D11
			Trend disaster	C6	Soil erosion area proportion	D12
	Environment pollution	B3	Water pollution	C7	Intension of poisonous effluent	D13
			Air pollution	C8	Intension of poisonous waste gas emission	D14
			Solid waste pollution	C9	Intension of poisonous waste residue producing	D15
			Agriculture pollution	C10	Intension of chemical fertilizer application	D16
					Intension of pesticide application	D17
					Intension of agricultural film application	D18
	Social economy	B4	Population	C11	Population density	D19
					Natural population growth rate	D20
			Economy	C12	Gross domestic production	D21
					Local fiscal revenue	D22
					Per capita income	D23
			Science and technology	C13	Quantity of scientific and technological research funds	D24
					Scientific research people proportion	D25
			Education	C14	Quantity of Education funds	D26
					Full-time teacher proportion	D27
			Social welfare	C15	Health technical staff proportion	D28

Note: Intension of poisonous effluent = (total amount of wastewater-criteria quantity of poisonous effluent)/runoff depth; intension of poisonous waste gas emission = (total amount of waste gas-treatment quantity of waste gas)/regional land area; intension of poisonous waste residue producing = (total amount of waste residue-treatment quantity of waste residue)/regional land area; intension of chemical fertilizer application = amount of applied fertilizer/regional cultivated area; intension of pesticides application = amount of applied fertilizer pesticide/regional cultivated area; intension of agricultural film application = amount of applied agricultural film/regional cultivated area.

tection and remediation of the eco-environment. Data of this paper were based on the county administrative division—the basic statistic unit. Eighty-eight county administrative divisions were chosen as the basic units for eco-environment quality evaluation.

3.3. *Collection and disposition of data*

For the synthetic evaluation of eco-environment quality, many general data and figures should be collected from natural, economic and social aspects for considering the interrelationship of population, resources, ecology and social economy development. The correct data collection was the key to the success of modeling. There were two kinds of data for the evaluation of eco-environment. One was characteristics, including natural environment, social economy, environmental pollution and disaster index. The other was extensity, including remote sensing figures and some thematic maps, such as forest floor maps, distribution maps of waterlogged and dry area and runoff depth maps.

The data of land utilization came from the digital maps of land resources and present land use on the scale of 1:250 000 provided by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The climate and weather data came from the database of "Building of background laid temperature and humidity of eco-environment" in the project of "Establishment of dynamic information service system of national basic resources and environment remote sensing" by the Institute of National Resources and Regional Planning, Chinese Academy of Agricultural Sciences. This database included average annual temperature, average rainfall and accumulated temperature over 0 and 10 °C, humidity index and so on. The soil erosion data came from the database of "national soil erosion remote sensing investigation" based on the Landsat. TM Blip database on the scale of 1:100 000 established by China National Environmental Monitoring Center. The other data, including social economy, environmental pollution, some disaster data and some written materials (such as investigation report of forest resources, monitoring report of agricultural environment, planning and construction of demonstration plots) were provided by Hunan Statistic Bureau, Hunan Environmental Protection Agency, Hunan Station of Agro-Environmental Monitoring and Administration. All these data were recorded in year of 2000.

Because of different scales of the various maps, they were scanned and digitized into computer. By using *ArcGIS8.1*, maps were reprojected into the standard projection system. All the data were converted into the basic evaluation unit (88 counties) to form the regional eco-environmental information system database.

3.4. *Dimensionless evaluation factors*

Because the evaluation factors were of their own characteristics or extensity, and each data of factors had its own dimension and distribution, it was difficult to directly compare or operate. As results, the original data of evaluation factors should be dimensionless by range transformation. Furthermore, evaluation factors had negative and positive interrelation to eco-environmental quality evaluation. Positive interrelation for those factors was highly advantageous to eco-environmental quality. The higher the evaluation values of those factors were, the better the eco-environmental quality was. Negative interrelation for those factors was disadvantageous to eco-environmental quality. The higher the evaluation values of factors were, the worse the eco-environmental quality was. So negative and positive interrelation factors should be dimensionless, with Formula1 for positive factors and Formula2 for negative interrelation factors. The dimensionless unit made all of the factors consistency, while higher values of factors were more important to the contribution of eco-environmental quality. In this research, positive factors were D1, D2, D3, D4, D5, D6, D7, D8, D9, D21, D22, D23, D24, D25, D26, D27 and D28, while negative factors were D10, D11, D12, D13, D14, D15, D16, D17, D18, D19 and D20.

All the factors were processed by these methods (Liu et al., 2003).

$$x_i' = \frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}} \times 100 \tag{1}$$

$$x_i' = \left(1 - \frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}}\right) \times 100 \tag{2}$$

where *i* is the evaluation unit, X_i is the original value of *i*, $X_{i\,max}$ and $X_{i\,min}$ are the maximum and the minimum value of *i*. For convenient of processing, all transformed data were magnified 100 times.

In addition, the extensity data should be evaluated from the thematic maps. Different types and grades were graded and marked to make each spot have its special value in each single picture layer. The function of Overlay with *Arcinfo* was applied to analyze the spatial nappe of each single layer and each basic evaluation unit layer. The value of each evaluation unit was determined by the area ratio of different marking range in each evaluation unit. The area of each grade and type in the evaluation units was measured and statistic by using *Arcinfo*.

3.5. *Weight of evaluation factors*

The weight of each factor was determined with AHP according to the expert advice. AHP was 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 (Xu, 2002). Due to its ability of assigning proper weights to various factors of complex systems, eco-environment system was suitable to employ AHP (Li et al., 2007). In the research, based on the Delphi expert advice system, the AHP method was applied to determine the weight of each factor (Dorey, 2000). The detailed analytic process was as follows.

3.5.1. *Establishment of the hierarchic structure*

Based on the expert advice, the evaluation system was divided into four levels—A, B, C, and D, denoting Objective Layer, System Layer, Factor Layer and Index Layer, respectively (Table 1). Each layer in this hierarchic structure was compared in pairwise comparisons related to each of the elements at the level directly above. The level structure was established by analyzing the relationship of each index.

3.5.2. *Establishment of comparison matrix*

Layer A was broken down into Layers B, C, and D to establish the pair-wise comparison matrix. The matrix was expressed with $A = (aij)_{n\times n}$.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdot & & & & \\ \cdot & & & & \\ \cdot & & & & \\ a_{n1} & a_{n1} & \cdots & \cdots & a_{nn} \end{bmatrix}$$

Relative importance of B1, B2, B3 and B4 were analyzed by *Delphi* method, also called *Expert Judgment System*. In this research, we invited experts with eco-environmental backgrounds to give the relative importance of each factor, respectively, then analyzed all the opinions, and finally, gained the rank of relative importance for each factor (Chen and Liu, 2004; Xiong et al., 2003). Conclusions were:

1. Natural environment was crucial to ecological-environmental quality, and it was the base for regional eco-environment, in which climate was an important indicator for natural environment. Therefore, weight of B2 was the highest.
2. The serious impact to the eco-environment was induced by human beings. The situation of social economy development and high population density were the reflection of human beings activities degree. Therefore, B4 had relatively high weight.
3. Comparing with B1 and B4, B2, and B3 were less important. But it could not be ignored, for the disaster and environmental pollution were directly related to eco-environmental quality, ecological issues and regional sustainable development.

Based on these conclusions, the pair-wise comparison matrix was established for Layers A and B (Table 2).

In order to gain the weights of the B1, B2, B3, and B4:

(1) The product of *mi* of every element was calculated to get the product of every row *Mi*:

$$m_i = \prod_{i=1}^{4} a_{ij}, \quad (i = 1, 2, 3, 4)$$

(2) Get the quartic root of *Mi*:

$$\overline{w_i} = \sqrt[4]{m_i}$$

Table 2 – A–B judgment matrix

A	B1	B2	B3	B4
B1	1	2	3	1
B2	1/2	1	3	1/2
B3	1/3	1/3	1	1/2
B4	1	2	2	1

(3) So the weights of B1, B2, B3, and B4 could be obtained by the following formula:

$$\overline{w} = (\overline{w_1}, \overline{w_2}, \ldots \overline{w_n})^T$$

$$w_i = \frac{\overline{w_i}}{\sum_{i=1}^{n} \overline{w_i}}, \quad (i = 1, 2, 3, 4)$$

Using the above method, the weights of B1, B2, B3 and B4 were 0.3561, 0.2117, 0.1105 and 0.3218, respectively.

3.5.3. *Single ranking*

Based on the corresponding pair-wise comparison matrix of A-B level, elements in a level of the hierarchy were compared related to single element at the level directly above and ranked by eigenvector of the matrix (Zhang et al., 2003). Calculate the eigenvalue of λ_{max} as:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)i}{w_i}$$

$$AW = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdot & & & & \\ \cdot & & & & \\ \cdot & & & & \\ a_{n1} & a_{n1} & \cdots & \cdots & a_{nn} \end{bmatrix} \times \begin{vmatrix} w_1 \\ w_2 \\ \bullet \\ \bullet \\ \bullet \\ w_j \end{vmatrix}$$

where W is the corresponding eigenvector of λ_{max} and Wi ($i = 1, 2, \ldots, n$) is the weight value for ranking. In our research, $\lambda_{max} = 4.1171$.

To keep the consistency of the judgment matrix, its consistency should be tested. Defining CI as:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where CI is the consistency index; λ_{max} is the largest or principal eigenvalue of the matrix and could be easily calculated from the matrix; n is the order of the matrix.

When the matrix had a complete consistency, CI = 0. The bigger CI was, the worse consistency the matrix had (Xu, 2002). In this research, CI = 0.0391.

Then, the consistency ratio (CR) was calculated as follows:

$$CR = \frac{CI}{RI}$$

where RI is the average of the resulting consistency index depending on the order of the matrix (Satty, 1977; Xu, 2002). When CR was less than 0.10, the matrix had a reasonable consistency. Otherwise the matrix should be changed. The calculated results of weight would be accepted when the consistency ratio was satisfactory (Liu and Xie, 2003). In this research, RI = 0.90, CR = 0.0434 ≤ 0.10.

3.5.4. *Total ranking*

Because of the pair-wise comparison, matrixes of Layers B and C, C and D were with the same method as that of Layers A and B. Based on the results of a series of simple rankings, the weights of all elements in a level of the hierarchy relative to a whole level directly above can be obtained, which was

Table 3 – Weight of each evaluation index of eco-environment

First grade	Second grade no.	Weight	Third grade no.	Weight	Fourth grade no.	Weight
A	B1	0.3561	C1	0.1507	D1	0.0565
					D2	0.0188
					D3	0.0565
					D4	0.0188
			C2	0.0435	D5	0.0145
					D6	0.0290
			C3	0.0810	D7	0.0270
					D8	0.0540
			C4	0.0810	D9	0.0810
	B2	0.2117	C5	0.1765	D10	0.0588
					D11	0.117
			C6	0.0353	D12	0.0353
	B3	0.1105	C7	0.0271	D13	0.0271
			C8	0.0271	D14	0.0271
			C9	0.0107	D15	0.0175
			C10	0.0456	D16	0.0107
					D17	0.0176
					D18	0.0104
	B4	0.3218	C11	0.0948	D19	0.0474
					D20	0.0474
			C12	0.0948	D21	0.0511
					D22	0.0155
					D23	0.0282
			C13	0.0627	D24	0.0367
					D25	0.0260
			C14	0.0437	D26	0.0256
					D27	0.0181
			C15	0.0260	D28	0.0260

totally ranked, and was carried from the upper layer to the lower layer. After the above analytic process, weight of each evaluation factor was determined for integrated evaluation of eco-environmental quality of Hunan Province (Table 3).

3.6. *Calculation of synthetic index and sub-index of eco-environmental quality*

As a complex system with multi-subject and multi-level of eco-environmental quality, the synthetic evaluation index of environmental quality was adopted to make levels more confident and accurate (Li et al., 2006; Liu et al., 2002; Wang, 2001), which means that values of all index were overlaid in each evaluation unit and the synthetic value was used to determine the environmental quality. Based on regional eco-environmental information system database, the *ArcGIS* software was used in the calculation of the index, gradation and creation of grade map in synthetic evaluation of eco-environment quality. The process of calculation was as follows.

Firstly, a characteristic database of each evaluation unit was established. Secondly, the eco-environment quality synthetic index of each evaluation unit was automatically calculated with the software of *ArcGIS* based on the weight of each factor. Then, the needed spatial data were chosen from the eco-environment thematic database. Series of data processing was done through the overlay of spatial data and characteristic data. The vector was grated to supply the need of evaluation model. Finally, the quantification evaluation of regional eco-environment quality was carried out with the method of multi-level weighted sum after standardization and quantization of the thematic data. The output represented the synthetic index of environment evaluation.

The synthetic evaluation value of each unit was the sum of the corresponding weight values of all related factors by using the equation.

$$\mathrm{EEQ} = \sum_{i=1}^{n} u_i w_i$$

where *EEQ* is the synthetic index of eco-environment quality, u is the value of each index, w is the weight of each index, and n is the total number of indices, $i = 1, 2, 3, \ldots, n$.

3.7. *Gradation of eco-environment quality*

The evaluation of eco-environment was not only aimed at the total situation of the eco-environment quality, but also at the natural and manual factors that resulted in the deterioration of ecology quality, which was helpful for the problems discovering and for the resolution settling to different ecological regions.

In the research, the synthetic index of eco-environment evaluation was graded with the Spatial Analysis Module of *ArcGIS* (Xie et al., 2002; Zhang et al., 2003). According to the equality distribution function, the results of the synthetic evaluation index and each sub-index were graded as five levels. Each level presented the spatial distribution speciality and the regional differences of eco-environment quality. The num-

Table 4 – Classified boundaries of eco-environmental evaluation

Factor	Grade and distribution range				
	5 Worse/more serious	4 Bad/serious	3 Middle	2 Good/slight	1 Better/slighter
Natural environment	33.7–38.2	38.3–42.8	42.9–50.4	50.5–55.0	55.1–60.5
Social economy	15.9–22.9	23.0–30.0	30.1–37.1	37.2–44.2	44.3–51.3
Disaster situation	42.2–52.2	52.3–62.3	62.4–72.4	72.5–82.5	82.6–92.6
Environmental pollution	45.9–54.8	54.9–63.8	63.9–72.8	72.9–81.8	81.9–90.8
Eco-environment quality (integrated index)	47.1–52.6	52.7–58.2	58.3–63.8	63.9–69.4	69.5–74.5

bers ranging from 1 to 5 were assigned to better, good, middle, bad, worse or slighter, slight, middle, serious, more serious, respectively. Table 4 showed the classified boundaries of the evaluation factors.

3.8. *Creating grade maps*

Each ID number was associated with characteristic database to make correspondence of the polygon of evaluation units and their characteristics. The thematic maps with *ArcGIS* were created based on the evaluation index of each factor, including grade maps of natural environment situation, disaster situation, environmental pollution, social economy and eco-environment synthetic quality (Fig. 5, Fig. 7, Fig. 9, Fig. 12, Fig. 16).

4. Results and analysis

4.1. *Analysis of natural environment sub-index*

The evaluation results (Fig. 3) showed that the sum of unit numbers with better, good and middle grades was 60 and 70.6% of the total area, which showed good natural environment situation of Hunan Province. Most of these areas were located at the east, the north and the south, where there were plenty of rain and sunshine with continental monsoon climate transiting from middle subtropics to northern subtropics. These regions were the prime agricultural band with high biotransformation ratio, which had 2313500 hm^2, 72% of the total cultivated land in Hunan Province (Fig. 4).

From the spatial distribution of natural environment (Fig. 5), it presented clear speciality of terrain. The east regions of natural environment situation was better than those in the west, and regions with bad or worse grade were focused on Wuling mountain and Xuefeng mountain in western Hunan, where there were mainly mountains leading to the lack of light and heat. The reason for better natural environment situation in southeast, middle and northern of Hunan Province was that the relatively low hypsography leaded to better water and heat, better vegetation condition, better land quality. The worst grade regions were mainly distributed in northwest regions of Xiangxi Municipality, Zhangjiajie City and Huaihua City, which were the economically backward areas of Hunan Province. Therefore, it reflected the disadvantageous of bad natural conditions had influences on the regional social economy development to some extent.

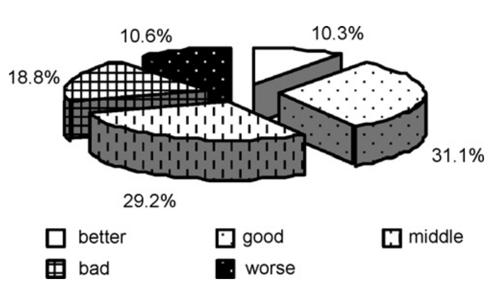

Fig. 3 – Area proportion of units by natural environment evaluation.

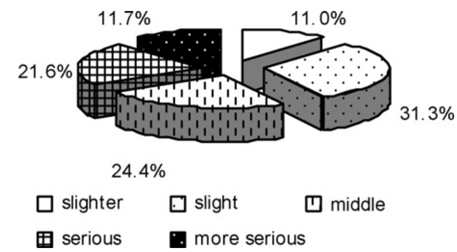

Fig. 4 – Proportion of cultivated land at different natural grades.

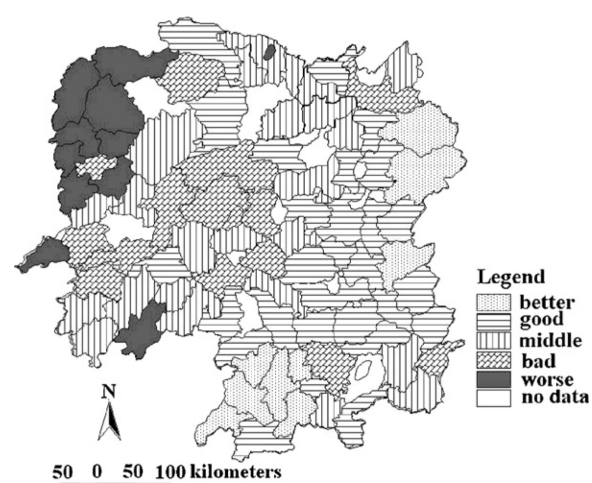

Fig. 5 – Grade map of natural environment evaluation.

4.2. *Analysis of disaster sub-index*

Areas with the serious and more serious grades were 33.3% of the total areas in Hunan Province (Fig. 6), which showed the serious effect by disaster. The regions with slighter grade were located in western, southwest of Hunan Province from the disaster evaluation of eco-environment (Fig. 7). Dongting

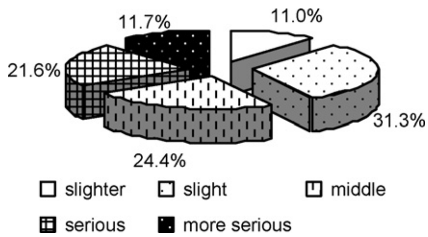

Fig. 6 – Area proportion of units by disaster evaluation.

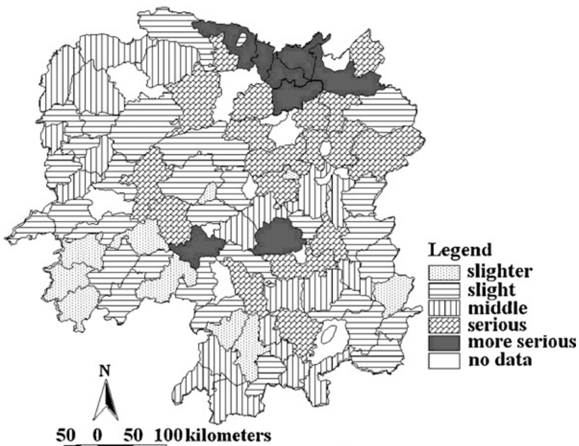

Fig. 7 – Grade map of disaster evaluation.

Lake area in the north was the most seriously disaster affected region. Because the lake hypsography was low and flat, the floods from Xiang, Zi, Yuan, Li River in Hunan Province were flowing into the Dongting Lake from April to June, and the flood of Yangtze River intruded back to Dongting Lake from July to August, which led to the frequent flood. From the data from 1950 to 1995, the flooded area was 26 34 700 hm^2, and the flood frequency was higher and higher in 1990s (Mao et al., 2000).

Another serious region was in the middle of Hunan Province, which was influenced by drought. These regions were surrounded by mountains from the east, the south and the west. The warm and wet current from the south could not follow in, and the cold high pressure from the north could not push out. Moreover, there was few damming engineering measure, which led to the weak ability of water management in these regions. The drought frequency was once every 1.5∼1.6a. The serious drought often happened in summer and autumn, which led to a great loss of agriculture production. After 1980s the serious drought was clearly moving toward the south, for example: three continual droughts from 1989 to 1991 in the south of Hunan Province, which resulted in 520 000 000 kg grain loss in Lingling City and Chenzhou City (Zuo and Qiu, 2000).

4.3. *Analysis of environmental pollution sub-index*

The evaluation results of environmental pollution (Fig. 8) showed that the regions with the middle, serious and more serious grades were 56 unit numbers at an area proportion of 59%, which reflected the wide distribution of environmental pollution. From the grade map of environmental pollution

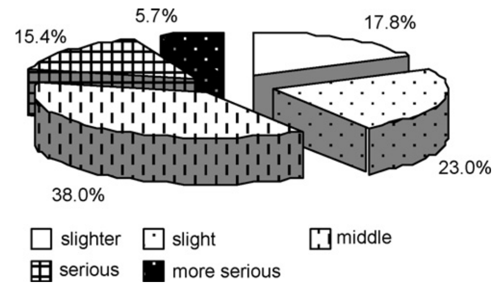

Fig. 8 – Area proportion of units by environmental pollution evaluation.

(Fig. 9), the east was polluted more serious than the west, and more severely in the developed regions than in the developing regions. The developed economy, high industrialization and denseness of population in the east resulted in the pollution of industry and habitation. Furthermore, the Dongting Lake area in the northern and the southern hilly parts of Hunan Province were at the more serious grade, where the reason was the abuse of chemical fertilizer, pesticide and agricultural film in these agriculture centers. Another reason was the concentration of mining factories with low treatment efficiency of waste gas, water and waste also made the pollution more serious. Generally, the development of economy was affected not so seriously by human activities in the west as that in the east of Hunan Province. For these types of areas with worse grade, some environmental protection measures should be intensified, such as tree planting, pollution source management.

The discharge of wastewater, waste gas and waste residue at each pollution grade was different (Fig. 10). At serious grade and more serious grade, pollution contribution by the wastewater was larger than by the waste gas.

4.4. *Analysis of social economy sub-index*

The total area proportion at better, good and middle grades of the social economy was 66.1%, which showed better economy situation of Hunan Province (Fig. 11). From the grade map of social economy evaluation, it showed that there was a significant difference on social economy development between

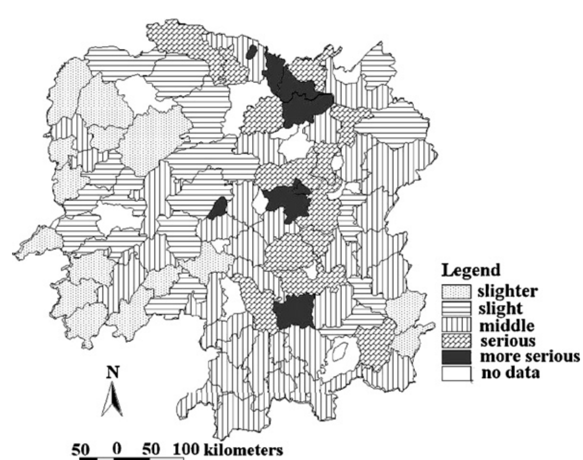

Fig. 9 – Grade map of environment pollution evaluation.

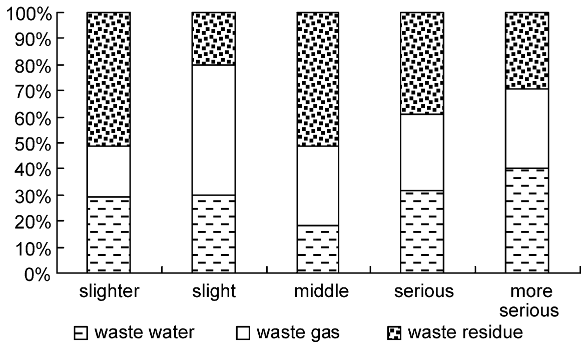

Fig. 10 – Discharge ratio of waste gas, water and residue.

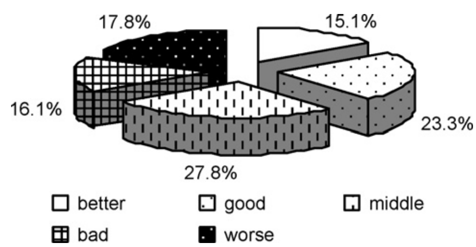

Fig. 11 – Area proportion of units by social economy evaluation.

the east and the west (Fig. 12). The regions with better development, which had better location superiority and mainly focused on the band along the railway of Beijing to Guangzhou, were located in the east, south and the Dongting Lake area, such as Changsha City, Zhuzhou City, Changde City and so on. The lag regions with bad and worse grades, which were the minority and outlying regions with the obstruction traffic and fragile eco-environment, were located in the west and the southwest, such as Xiangxi Municipality, Zhangjiajie City and Huaihua City. Bad economic foundation and slow development made these regions prior in the development policy planning. At the present time, there were 17 poverty counties in these regions, which was 60% of the total poverty county in Hunan Province.

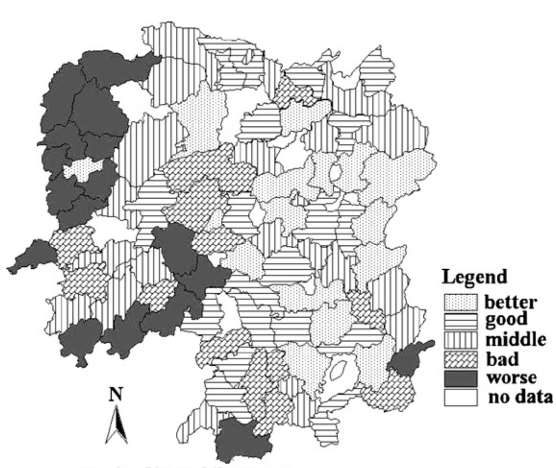

Fig. 12 – Grade map of social economy evaluation.

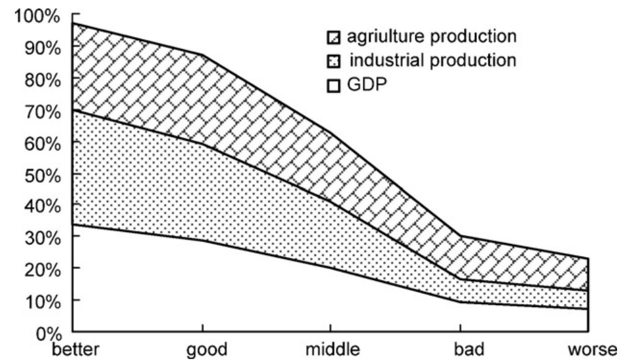

Fig. 13 – Indicator proportion of social economy grades.

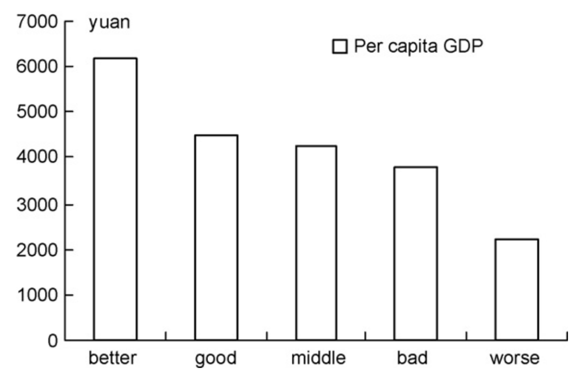

Fig. 14 – Per capita GDP of social economy grades.

The social economy indicators at each grade showed that agricultural production, industrial production, and GDP were descended in turns, which reflected the changing order of economic indicators (Fig. 13). The bigger the value of each index, the more important its status was in the social development of Hunan Province. The land ratio of better grade was 15.1% with more than 1/3 of socioeconomic indicators. The ratio of per capita GDP at a better grade was 3 times of that at a worse grade (Fig. 14). As results, some measures including favorable policies, funds aid and educative cultivating for the backward areas should be strengthened to improve regional economy development.

4.5. *Analysis of synthetic eco-environment quality*

The results of eco-environment quality evaluation (Fig. 15) showed that the regions at middle, bad and worse status were added up to 64.8% of the total area of Hunan Province, which

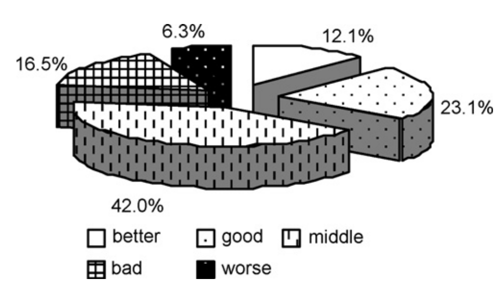

Fig. 15 – Area proportion of units by eco-environment quality evaluation.

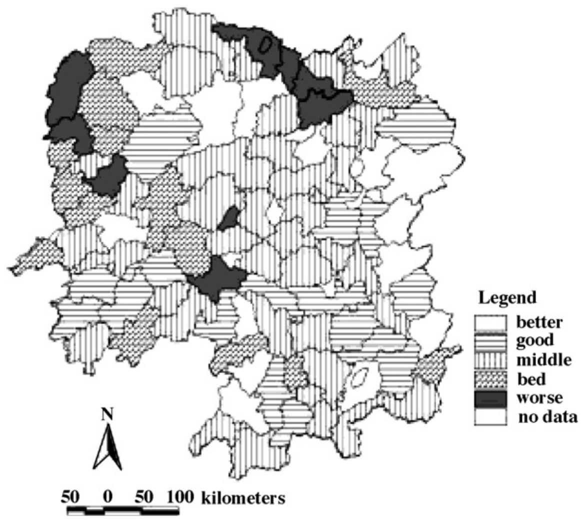

Fig. 16 – Grade map of synthetic evaluation.

indicated a middle level of integral eco-environment quality. The best quality of eco-environment in Hunan was located in the eastern four units, including Changsha county, Shuangpai county, Yanling county and Liling county, and next 16 units in the southern were of good levels. Twenty-two regions of bad eco-environment quality were distributed in the Dongting Lake area including Nanxian county, Yuanjiang city and Jingshi city (three of that), and in the west and the southwest of Hunan. The lowest levels of eco-environment quality in Hunan were distributed in the northwestern eight units, including five units in the Dongting Lake area. The spatial pattern of eco-environment quality was better and better from the west to the east (Fig. 16). The best quality was in the east region while the grade of eco-environment quality evaluation was mostly good or better in the east region and worse in the northwest region.

It was noticeable for us that the evaluation results of natural situation and social economy level in Dongting Lake area were good, while the synthetic quality of eco-environment was middle, and a few of bad or worse. The reason was that the deep effect of disaster or environmental pollution counteracted the advantages of natural environment and social economy. For this type of regions, some measures should be strengthened, including reducing the application of agricultural chemical fertilizer, protecting from flood.

5. Discussion and summary

By combining AHP with GIS method, the study approached the research on the current condition of eco-environmental quality of Hunan Province, located in middle China. The results showed that:

(1) This methodology combining the AHP with GIS provided an improvement method for synthetic evaluation of eco-environment quality, which developed the GIS capability of spatial analysis and the AHP capability of multi-layers analysis. The evaluation results and the distribution pattern of regional eco-environment quality could be obtained with the method by the spatial analysis module. Therefore, the method could be very interesting to policy makers involved in regional eco-environmental quality evaluation, especially taking the county administrative division as the basic evaluation unit, because it could allow decision makers to clearly know current status of the integrated quality of their regional eco-environment, and to help administrators resolve some problems about the regional eco-environmental improvement.

(2) The synthetic evaluation of eco-environment quality for Hunan Province showed that region numbers of middle, bad and worse grade approximated to 2/3 of the total area, which basically accorded with the properties and actual situation of the eco-environmental system. The eco-environmental quality of Hunan Province gradually decreased from the east to the west with some differences in partial regions. Natural situation was the main functional factor on the evaluation of eco-environment, while other factors such as disaster, environmental pollution and social economy were secondary indices affecting the synthetic eco-environment of Hunan Province. As results, we should adjust measures to local conditions, and strengthen environmental protection and ecological construction for frail eco-environmental regions, such as Dongting Lake area and backward areas in the west of Hunan Province.

(3) Eco-environment was a large multi-element system, and exchanges of material, energy and information existed among various subsystems of the large system. Owing to system complexity, selecting proper factors as far as possible to establish comprehensive index system was important to eco-environment assessment. According to the representative features of regional eco-environment and main environmental problems in Hunan Province, the improvement of evaluation index system was established in this paper, including natural conditions, disasters, environmental pollution and social economic aspects. Based on the results, natural environment and human economic activities were the most significant factors affecting eco-environmental quality. Nevertheless disaster and pollution were also regarded as sensitive factors to decide the regional eco-environment quality in some particular areas. By appropriate adjustment of some factors, evaluation index system in this research could be applied to other regions for the integrated assessment of ecological environment.

(4) Certainly, some insufficiencies were found in this research. Although taking county administrative division, as the basic evaluation unit was beneficial to regional government to know the situation of eco-environment, it was difficult to know the county's internal spatial pattern and eco-environmental change when applying the programs to eco-environment protection according to research results. Therefore, evaluation accuracy could be enhanced by applying the polygon overlap analysis to strengthen regional internal research.

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