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RESEARCH ARTICLE

Integrated assessment and changes of ecological environment in the Daning River Watershed

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Abstract Based on Remote Sensing (RS), Geographical Information Systems (GIS), and the Spatial Principal Component Analysis (SPCA) method, the integrated assessment and changes in the ecological environment of Daning River Watershed are studied in this paper. The watershed is located in the Three Gorge Area in China. The result of the integrated assessment showed that level 9 had the biggest proportion in the year 1990, which was about 40%. In the year 2000, however, there were no levels with a proportion significantly bigger than the others. By comparing the assessment results in 1990 and 2000, it is discovered that the ecological environment in Daning River Watershed in 1990 was better than that in 2000.

Keywords Daning River watershed, remote sensing, GIS, spatial principal component analysis, eco-environmental integrated assessment

1 Introduction

The quality of the regional ecological environment is the foundation of sustainable development. The study on the quality and the evolution of the regional ecological environment will help the government establish developmental plans for watersheds. The regional ecological environment represents the interaction between human beings and the natural environment (Moore et al., 1993; Ma, 1998). The interaction between nature and humanity affects the quality of the regional ecological environment in varying types and degrees. Therefore, the integrated effect should be considered when the regional ecological environment is assessed.

The study of the assessment of the regional ecological environment started in the 1980s, and developed in the 1990s. There were many techniques used to assess the regional ecological environment such as superposed assessment, integrated index, cluster analysis, nature degree, and landscape ecology (Zuo, 2004). Recently, researchers (Huang et al., 2000; Wang et al., 2002; Wang et al., 2004) have used the method of principal component analysis to assess the regional ecological environment and they have made some progress. As for the theory and method of assessment, some researchers have recently begun applying techniques such as landscape ecology, remote sensing (RS) and Geographical Information Systems (GIS) to assess the regional ecological environment (Lathrop, 1998; Shi et al., 1999; Smith, 2000; Bryan, 2003). The techniques in this area of research developed rapidly.

Most of the existing assessment researches in the regional ecological environment are based on the boundary of the districts where the watersheds are instead of the actual watersheds. In the study of natural science, the watershed is regarded as a whole object. The integrated assessment of the ecological environment based on the watershed will help keep sustainable development and control of water pollution, especially the watershed's non-point pollution source. Based on RS, GIS and the method of Spatial Principal Component Analysis (SPCA), the integrated assessment and changes between 1990 and 2000 in the ecological environment of the Daning River Watershed are studied in this paper.

2 Study site

The Daning River, which originates from Wuxi County in Chongqing Region, flows to the Yangtze River, east of Wushan County (Fig. 1). The length of the river is 202 km and its watershed area is 4415.84 km^2, which include the Three Gorges (Qutang Gorge, Wu Gorge and Xiling Gorge) of the Yangtze River. The watershed of Daning lies in a subtropical zone and the climate is moist. The average annual precipitation is about 1000 mm and the average annual

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temperature is 19.8°C. The morphology of the watershed is found in the mountainous region that lies to east of the Sichuan Basin, and its topography shows that its southern and northern parts are higher than its middle area.

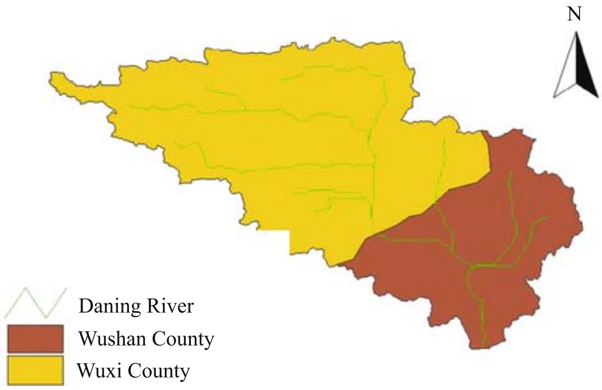

Fig. 1 Watershed of Daning River

Recently, water bloom phenomenon has been occurring in the Daning River because of water pollution that threatens the ecological safety of the Three Georges Area. Maintaining a good ecological environment is not only the basis of promoting watershed economy and sustainable development but it also affects the safety of the ecological environment of the Three Georges Region and the long-term operation of the Three Georges project. However, the ecological environment of the Daning River watershed is now very badly damaged because of the long-term exploitation of its environmental resources. Because of this, more attention should be paid to the protection of the ecological environment in the Daning River watershed.

3 Assessment index system and assessment method

3.1 Assessment index system and data

There are many factors that affect the quality of the ecological environment. All of them point to both natural and human factors, indicating that the quality of the ecological environment involves the typical complex system of the nature-economy-society interaction. In order to validly assess a regional ecological environment, both natural and human factors should be considered when an assessment index system is being established. Referring to a previous research (Gessler et al., 1995; Wilson and Gallant, 1996; Bellmann, 2000; Huang et al., 2000; Wang et al., 2002; Zuo, 2004; Wang, 2004), the assessment index of this research is based on climate, hydrology, soil, landuse, and topographical analysis of the ecological environment, geographic characteristic, spatial scale and data source. There are also ten factors taken from data on climate, vegetation, topography and human population: the sum of the temperatures more than 0°C, sum of the temperatures more than 10°C, annual temperature, annual precipitation, moisture index, slope, aspect, elevation, landuse, and vegetation index. The assessment index system and data source are listed in Table 1.

Table 1 Assessment index system and data source

First index	Second index	Third index	Data source
Nature factor	Climate	sum of temperature more than 0°C	Weather station
		sum of temperature more than 10°C	Weather station
		Annual temperature	Weather station
		Moist index	Weather station
		Annual precipitation	Weather station
	Topography	Elevation	DEM data
		Slope	DEM data
		Aspect	DEM data
Human being factor	Vegetation	NDVI	Landsat TM
	Landuse	Landuse	Landsat TM

3.2 data standardization

In order to quantifiably assess the quality of the ecological environment in the Daning River watershed, the thematic map of different factors should be created by use of the spatial database. Then, an integrated assessment of the ecological environment in the Daning River watershed can be carried out by use of principal component analysis based on the GIS analysis tool. Because the characteristics and units of different thematic maps are diverse, they cannot directly be used to assess the ecological environment. Before the actual analysis and assessment, the factors that are used to assess the ecological environment are standardized by use of some criteria. The ordinary standardized function of these factors is

$$Q_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \times 10 \tag{1}$$

where, Q_i is the standardized value of class i of a given factor, X_i is the coding value of class i of a given factor, $X_{\min}$ is the minimum coding value of a given factor, $X_{\max}$ is the maximum coding value of a given factor.

All the factors that are used to assess the ecological environment are standardized between 1 and 10. The characteristics and units of the different thematic maps are eliminated, thereby enhancing the reliability of the ecological environment assessment in the Daning River watershed.

3.3 Spatial principal component analysis

Principal component analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible (Johnson and Wichern, 1998). Based on the spatial data, spatial principal component analysis (SPCA) transforms a number of (possibly) correlated spatial variables into a (smaller) number of uncorrelated integrated indexes with rotating spatial coordinate. The smaller number of uncorrelated integrated indexes can keep most information of the number of (possibly) correlated spatial variables.

The basic principle of PCA is the transformation of a number (N) of correlated variables X_i into a (smaller) number (M) of uncorrelated variables Y_j ($M<N$). The smaller number of uncorrelated variables Y_j can keep most information of the number of (possibly) correlated spatial variables X_i. Then, a number (N) of correlated variables X_i are reduced into a (smaller) number (M) of uncorrelated variables Y_j. Y_j is often called the principal component. During the integrated ecological environment assessment, the integrated assessment index is defined as the weighted sum of these M principal components. The weight is denoted as the variance proportion of the principal components

$$E = a_1Y_1 + a_2Y_2 + \cdots + a_jY_j \quad (j = 1,2,\cdots,M) \tag{2}$$

Where, E is the integrated assessment index of the ecological environment; Y_j is the principal component of j, and a_j is the variance proportion of the j principal components.

With the development of geographic information technology, it is possible to assess the ecological environment by integrating several factors. Supported by the GRID module of the ArcGIS workstation, a number of (possibly) correlated spatial variables can be transformed into a (smaller) number of uncorrelated integrated indexes by rotating the spatial coordinate and using the function of the SPCA in GRID. The smaller number of uncorrelated integrated indexes can keep most information on the number of (possibly) correlated spatial variables. During this research, the assessment unit is the raster of 100 m×100 m. The result of the integrated assessment of the ecological environment not only uncovers the quality of the ecological environment but also reflects its spatial diversity.

4 Results and discussion

4.1 Spatial principal component analysis

Supported by the GRID module of the ArcGIS workstation, different integrated indexes are calculated using the function of the SPCA of GRID module.

First, the sum of the temperatures that are more than 0°C, the sum of the temperatures that are more than 10°C, and the annual temperature are transformed into the energy index. The annual precipitation and moisture index are transformed into the water index. Slope, aspect and elevation are transformed into the topographic index and landuse and NDVI are transformed into the landcover index by use of the SPCA method. Then, the energy index and the water index are transformed into the climate index also by use of the SPCA method. Finally, the climate index, landcover index and topographic index are transformed into an integrated ecological environment index in the Daning River watershed. The assessment results of 1990 and 2000 are listed in Table 2.

Among the calculated integrated index of the ecological environment in Table 2, the cumulative contributions of the former two SPCA are 86.6% and 93.5% respectively. The smaller number of uncorrelated integrated indexes can keep most information on the number of (possibly) correlated spatial variables.

4.2 Assessment result and spatial distribution

Supported by the ArcGIS, an integrated assessment degree map (Fig. 2) and statistical table (Table 3) of the ecological environment in the Daning River watershed are calculated by use of the data in Table 2 and formula (2). Then, the Daning River watershed is divided into ten degrees of ecological environment quality areas based on the value of the ecological environment index.

Table 2 Eigenvalue, variance and cumulative of SPCA

Index	SPCA	1990			2000		
		Eigenvalue	Variance	Cumulative	Eigenvalue	Variance	Cumulative
Energy index	SPCA1	5.679	0.997	0.997	6.225	0.997	0.997
	SPCA2	0.014	0.002	0.999	0.012	0.002	0.999
	SPCA3	0.006	0.001	1.000	0.006	0.001	1.000
Water index	SPCA1	3.552	0.970	0.970	3.856	0.997	0.997
	SPCA2	0.109	0.030	1.000	0.012	0.003	1.000
Topography index	SPCA1	6.561	0.533	0.533	6.561	0.533	0.533
	SPCA2	3.330	0.271	0.804	3.330	0.271	0.804
	SPCA3	2.415	0.196	1.000	2.415	0.196	1.000
Climate index	SPCA1	5.346	0.688	0.688	5.683	0.700	0.700
	SPCA2	2.421	0.312	1.000	2.436	0.300	1.000
Landcover index	SPCA1	8.520	0.970	0.970	7.926	0.756	0.756
	SPCA2	0.267	0.030	1.000	2.553	0.244	1.000
Ecological environment index	SPCA1	6.207	0.620	0.620	5.845	0.729	0.729
	SPCA2	2.458	0.246	0.866	1.654	0.206	0.935
	SPCA3	1.340	0.134	1.000	0.522	0.065	1.000

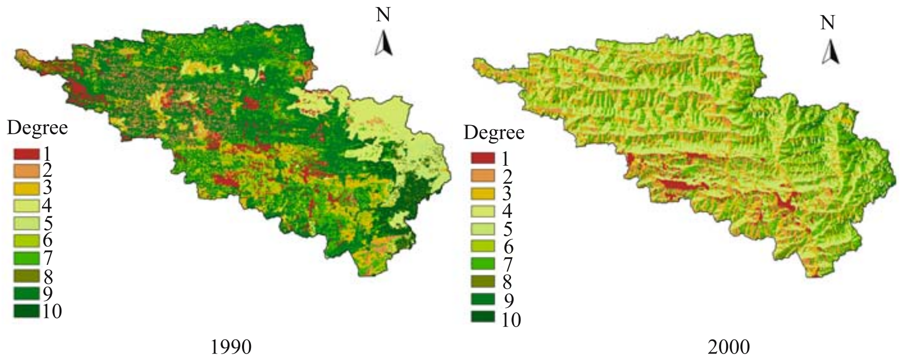

Fig. 2 Integrated assessment degree map of ecological environment in the Daning River Watershed

Table 3 Integrated assessment of ecological environment

Degree	1990		2000	
	Area/km²	Proportion	Area/km²	Proportion
1	290.881	0.066	160.975	0.036
2	254.532	0.058	402.793	0.091
3	397.069	0.090	583.945	0.132
4	459.954	0.104	648.656	0.147
5	146.955	0.033	768.248	0.174
6	212.926	0.048	718.238	0.163
7	627.912	0.142	655.804	0.149
8	61.588	0.014	374.530	0.085
9	1743.096	0.395	94.957	0.022
10	220.929	0.050	7.697	0.002
Total	4415.843	1.000	4415.843	1.000

In Fig. 2 and Table 3, it is shown that there exist some differences in the area proportion and spatial distribution among the different degrees of the integrated assessment in the Daning River watershed in 1990. The biggest area proportion in all the degrees is degree 9. The proportion of degree 9 is about 40% and is mainly distributed in the upper reaches of the Daning River in Wuxi County. In contrast to degree 9, the area proportions of the other degrees are smaller and their spatial distributions have no notable characteristics. In Fig. 2 and Table 3, it is shown that there also exist some differences in the area proportion and spatial distribution among the different degrees of the integrated assessment in the Daning River watershed in 2000.

There is no degree whose area proportion is very notable. The degrees with bigger area proportions are from degree 3 to degree 7, with degree 5 having the biggest area proportion of about 20%. In relation to spatial distribution, degree 1 is mainly distributed in the lower reaches of the Daning River, south of Wuxi County and Wushan County. The spatial distributions of the other degrees have no notable characteristics.

4.3 Ecological environment changes

Based on Table 3, the comparison result of the ecological environment assessment of the different degrees between 1990 and 2000 can be calculated (Fig. 3).

It is shown that the ecological environment in 1990 is better than that in 2000 based on the comparison of the results of the integrated assessment of the ecological environment between 1990 and 2000. The ecological environment in the Daning River watershed has degenerated from 1990 to 2000. If degree 1, degree 2 and degree 3 are regarded as class III, degree 4, degree 5, degree 6 and degree 7 are regarded as class II, degree 8, and degree 9 and degree 10 are regarded as class I, the proportions of the different classes in 1990 are 0.459, 0.328, and 0.213, respectively, and the proportions of the different classes in 1990 are 0.108, 0.632, and 0.260, respectively. The results of the integrated assessment of the ecological environment in the Daning River watershed is mainly class I in 1990 and the proportion is about 50%. However, the result of the integrated assessment of the ecological environment in the Daning River watershed is mainly

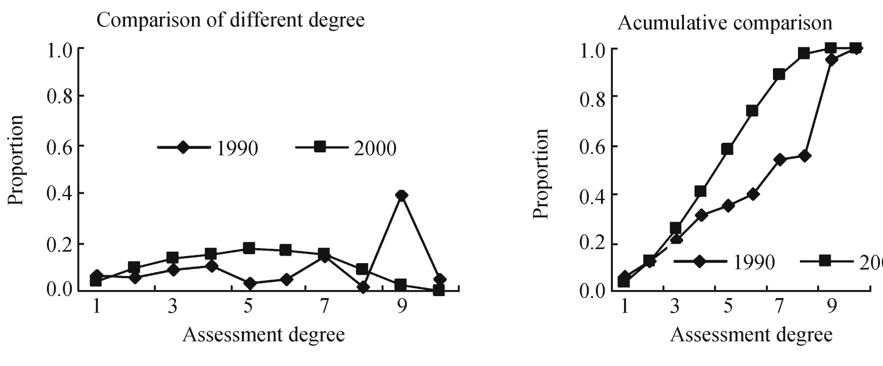

Fig. 3 Comparison of different degree of ecological environment between 1990 and 2000

class II in 2000 and the proportion is more than 60%. It is can concluded that the ecological environment in the Daning River watershed has degenerated from the big proportion of class I in 1990 to the bigger proportion of class II in 2000.

5 Conclusions

Some differences exist in the area proportion and spatial distribution among the different degrees of the integrated assessment in the Daning River watershed in 1990. The biggest area proportion of all the degrees is degree 9. The proportion of degree 9 is about 40% and is mainly distributed in the upper reaches of the Daning River in Wuxi County. In contrast to degree 9, the area proportions of the other degrees are smaller and their spatial distributions have no notable characteristics. Some differences also exist in the area proportion and spatial distribution among different degrees of the integrated assessment in the Daning River watershed in 2000. There is no degree whose area proportion is very notable. The degrees with bigger area proportions are from degree 3 to degree 7 and the degree with the biggest area proportion is degree 5 (about 20%). In relation to spatial distribution, degree 1 is mainly distributed in the lower reaches of the Daning River south of Wuxi County and Wushan County. The spatial distributions of the other degrees have no notable characteristics.

In comparison, it is shown that the ecological environment in 1990 is better than that in 2000 based on the result of the integrated assessment between 1990 and 2000. The ecological environment in the Daning River watershed has degenerated from 1990 to 2000. The result of the integrated assessment of the ecological environment in the Daning River watershed is mainly class I in 1990 and the proportion is about 50%. However, the result of the integrated assessment of the ecological environment in the Daning River watershed is mainly class II in 2000 and the proportion is more than 60%. It can be concluded that the ecological environment in the Daning River watershed had degenerated from the big proportion of class I in 1990 to the bigger proportion of class II 2000.

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