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ANALYSIS AND EVALUATION OF LAND USE AND LANDSCAPE PATTERN CHANGES IN CAOHAI WATERSHED

YANG Guang[1,3], SONG Ge[1,2,3※], CUI Wei [4], Baiyinbaoligao[4] and CHEN Wenxue[4]

[1] College of Resources and Environment of Northeast Agricultural University, Harbin, 150030;
[2] Northeastern University School of Humanities and Law, Shenyang, 110819;
[3] Heilongjiang Village and Town Development and Research Center, Harbin, 150030;
[4] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Beijing, 100038.

Email: 13945180612@163.com

ABSTRACT

With the remote sensing images of the Caohai watershed in Weining of Guizhou Province in 1992, 2001 and 2013 and based on the ArcGIS Platform, the paper establishes the land-use transfer matrix, quantitatively analyzes the features of the land use changes in time and space in the recent 20 years, applies the theory of landscape ecology, selects the fragmentation index, shape feature index and diversity index, makes use of the FRAGSTATS Software to quantitatively analyze the landscape spatial pattern and the dynamic changes of the Caohai watershed, evaluates the influence of land use changes upon the landscape patterns and puts forth the suggestions for sustainable development and utilization as well as eco-environmental protection.

Keywords: Land-use and land-cover change, Landscape pattern, Ecology, Remote sensing, Caohai watershed.

1. INTRODUCTION

Land-use/land-cover change (LUCC) is deemed to be one of the main determinants of global changes and exerts vital impact on the ecological system, the global biogeochemical cycle and climatic change as well as the human vulnerability (Benjamin M, Terry L, Thomas R, *et al*, 2013). LUCC not merely objectively records that the mankind has changed the spatial pattern of the characteristics of the earth's surface but also reproduces the process of the dynamic changes of the landscape of the earth's surface in both time and space. The landscape pattern of land use and its changes comprehensively reflect the regional eco-environmental system under the interaction between the nature and the human factor. They are both the results of various interference factors and influence the ecological process and the fringe effects of the region (Shi Peijun, Jiang Yuan, Wang Jingai *et.al*, 2004). The research on the landscape pattern of the regional land is an effective measure to reveal the land-use/land-cover change, the ecological regime and the special variability characteristics and boasts the crucial theoretical and realistic significance for the sustainable utilization of the regional land resources and the resumption and reconstruction of the damaged ecological system (Feng Yixing, Luo Geping, Zhou Decheng, *et al*, 2010).

Caohai is situated in the Weining Yi, Hui and Miao Autonomous Region of Guizhou. It is the third largest plateau lake of China. The lake region covers an area of 23.25km^2 and the watershed takes an area of 130.30km^2. The Caohai wetland is composed of water, swamp, meadow, abundant water animals or plants and aquatic biocenosis and is a typical representative of the subtropical plateau wetland ecosystem of China. Among the subtropical plateau wetland ecosystems of China in negligible quantity, the vulnerability, typicality, importance, ecological diversity and climatic particularity etc. of the ecological environment boast representative significance. The Caohai wetland was listed in *The Action Plan for Biodiversity Protection in China (the White Book)* as the important wetland of Grade I protection (2005).

Influenced by human activities and the changes of the natural environment, the Caohai watershed is endangered by a series of ecological problems such as water and soil erosion, sedimentation in the lake region, water pollution aggravation and threat of invasion of alien species etc. in recent years that affect the ecological environmental safety in the Caohai watershed and the sustainable social and economic development. To promote the protection of the ecological environment of the Caohai wetland, Guizhou Forestry Department organized the scientific investigation team in 2005 to make in-depth investigation and research on the soil, water, animals and plants, zoning and management of the protection zone and the tourist resources etc. and completed 26 monographic studies (Zhang Huahai, Li Mingjing, Yao Songlin, 2007). In recent years some scholars have analyzed the changes of the ecological environment of the Caohai wetland and the corresponding reasons from the perspectives of soil erosion (Wei Haixia, Gao Huarui, 2012), water environmental pollution (Xu Song, Gaoying, 2009), aquatic organism (Pan Hong, 2005) and birds (Luo Zukui, Li Xingyuan, Zhang Wenhua, *et al*, 2011) etc. But the afore-said research focused on a certain domain of ecology and started from the angles of macroscale and land use. Few works made quantitative analysis and research of the influence of human activities upon the ecological environment of Caohai.

The present paper adopts the remote sensing and GIS technologies, analyzes the dynamic changes and the relationship of transfer of land use in the Caohai watershed in the latest 20 years, applies the landscape pattern index to analyze the changes of the landscape pattern in Caohai watershed and the influence of changes of land use upon the landscape pattern and proposes to protect the ecological environment of the Caohai watershed. The thinking and methods of the research serve as reference for the research on the ecological environmental protection of other watersheds.

2. ANALYSIS OF CHANGES IN LAND USE OF THE CAOHAI WATERSHED IN THE LATEST 20 YEARS

2.1 The land use pattern of the Caohai watershed

The TM image (of a resolution ratio of 30m) of August 1992, the ETM image (of a resolution ratio of 15m) of June 2001 and the Image Earth remote-sensing image (of a resolution ratio of 2.5m) in May 2013 explained and extracted the land use status of the Caohai watershed through the treatment of image color composition, geometric rectification and information enhancement etc. with the results shown in Fig.1 (Guo Yuan, Lin Changhu, He Tengbing, *et al*, 2011). The results of the statistical analyses of the land of all sorts in the three years are indicated in Table 1.

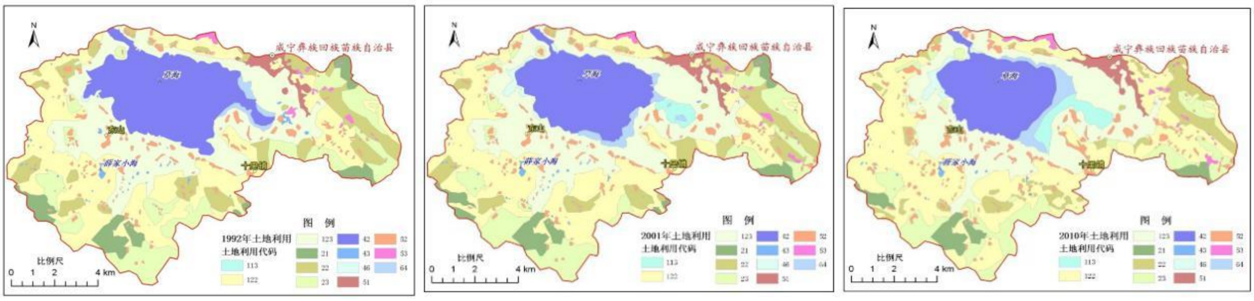

Figure 1. Land use distribution in the Caohai watershed

Notes: 113-paddy field on plain; 122- dry land on hill; 123-dry land on plain; 21-forest land; 22-shrubwood; 23-open forest land; 42-lake; 43-reservoir swag; 46-beach; 51-urban land; 52-rural residential area; 53-other construction land; 64-swampland.

The analysis reveals that the land in Caohai watershed is primarily the arable land that accounts for about 55% and takes on a trend of increase over the years; the forest land (roughly 20% of the total) and water (approximately 15% of the total) follow and display a trend of decrease.

The distribution characteristics of the land use types: Outward the Caohai Lake, the flat dry land extends outward contiguously; the residential land and the dry land of hill are distributed outside or inside the adjacent dry land on plain. Compared with the residential land, the distribution area of dry land of hill is larger and extends longer around the lake basin. The forest land and the dry land on hill are in inlayed distribution. But the altitude of the forest land is higher than that of the dry land on hill.

Table 1. Statistical results of land in the Caohai watershed in 1992, 2001 and 2013

Area (km^2) / Year / Type of land	1992	2001	2013	Increased area in 2013 over 1992
Arable land	63.84	69.19	75.00	17%
Forest land	33.96	31.39	25.40	-25%
Water	24.47	20.29	17.96	-27%
Residential land	6.83	7.70	9.14	34%
Swampland	1.21	1.73	2.78	131%

2.2 Relationship of land use and transfer in the Caohai watershed

The land use and transfer can reflect the mutual conversion and the quantitative relation of different land use types. The tabulate area of the spatial analyst tools of ArcGIS (Tang Guoan, Yang Xin, 2012) is applied to construct the land use transfer matrix of the Caohai watershed from 1992 to 2013, as shown in Table 2.

Table 2. The land use transfer matrix of the Caohai watershed during 1992~2013 (Unit: km^2)

Year		2013													
	Land type	Paddy field on plain	Dry land on hill	Dry land on plain	Forest land	Shrubwood	Open forest land	Lake	Reser-voir swag	Beach	Urban land	Rural residential land	Other construction land	Swampland	Total area
1992	Paddy field on plain		28.43	0.88	0.04	0.63	3.33		0.01		0.22	0.66	0.28		34.47
	Dry land on hill	0.19	2.87	25.42		0.00	0.14	0.05		0.03	0.22	0.41		0.03	29.36
	Dry land on plain		0.60		4.13	1.13	0.00					0.01	0.01		5.88
	Shrubwood		6.29	0.14	0.01	4.48	0.58		0.00		0.13	0.42	0.16		12.20
	Open forest land		4.48	0.27	0.07	2.12	8.65		0.00			0.23	0.05		15.88
	Lake	2.17		1.33				16.61		0.99				2.75	23.85
	Reservoir swag		0.05	0.23			0.00		0.24			0.01			0.54
	Beach			0.06						0.02					0.08
	Urban land		0.15	0.01							1.79				1.95
	Rural residential land		0.00	0.01			0.02					4.05			4.09
	Other construction land		0.09	0.14		0.07			0.00				0.49		0.79
	Swampland	0.57		0.64											1.21
	Total area	2.92	42.96	29.12	4.25	8.43	12.72	16.66	0.25	1.05	2.35	5.80	0.99	2.78	130.30

The priorities are attached to the analysis of the relations of transfer between water, forest land and arable land of larger area.

(1) The relation of water area transfer. The water in the Caohai watershed covered an area of 23.85km^2 in 1992 but only 16.66km^2 in 2013 (thereinto, 0.05km^2 was the area of the former dry land of plain). In the converted water area, the water field covered 2.17km^2, dry land 1.33km^2, beach 0.99km^2 and swampland 2.75km^2. In 2013, the paddy land on plain formed from the former lake and swamp took an area of 2.92km^2.

(2) The relation of forest land conversion. The forest land, shrubwood and open forest land covered 5.88 km^2, 12.20 km^2 and 15.88 km^2 respectively in 1992 that shrank to 4.25km^2, 8.43 km^2 and 12.72 km^2 in 2013 separately. The land was primarily converted into the arable land (including dry land on hill and plain) and inside the forest land. The land shrink in the Caohai watershed mainly resulted from farmland reclamation.

(3) The relation of arable land area transfer. The area of dry land on hill and plain in the Caohai watershed covered 34.47km^2 and 29.36 km^2 separately in 1992 which increased to 42.96km^2 and 29.12 km^2 in 2013 respectively. Additionally the paddy field newly formed from the original lake and swamp took up an area of 2.92km^2. Consequently, the drastic increase in the area of the arable land in the Caohai watershed predominantly sourced from the area of dry land on hill formed from the original shrubwood and the open forest land. The area of the original dry land on plain did not change.

3. THE ECOLOGICAL LANDSCAPE PATTERN CHANGE IN THE CAOHAI WATERSHED

3.1 The landscape pattern and the landscape pattern index

Landscape pattern refers to the spatial allocation of landscape patches of varying sizes. It is the specific presentation of landscape heterogeneity and the product of the long-term effects of the landscape processes. Different landscape patterns exert sharply different effects on the individuals, groups or ecosystems of the landscape. The research on the landscape pattern can reveal the regularity in the landscape of unordered inlaid patches and provide an effective method to discuss the integrality, comprehensiveness and heterogeneity of the landscape when the correlation of the elements cannot be determined and the quantitative analysis of the elements fails.

The landscape pattern index is an important parameter to reflect the landscape pattern and the simple quantitative index reflecting the characteristics of the structural composition and spatial allocation and providing quantitative basis for the scientific measurement of the landscape structure. The landscape pattern index includes two parts, namely the landscape unit characteristic index and the landscape heterogeneity index. The landscape unit characteristic index is applied to describe the characteristics such as the area, perimeter and amount of the patches and the landscape heterogeneity index includes the diversity index, the inlaying degree index, the distance index and the landscape fragmentation index. The quantitative depiction of the landscape pattern by means of these indexes can compare the different landscapes and research their differences in structure, function and process.

3.2 The Caohai watershed landscape pattern index selection

According to different research scales and focus, the landscape index is divided into the patch-level index, the class-level index and the landscape-level index. The present work aims to define the law of the landscape pattern change of the whole watershed. So it selects the landscape-level index. There are many types of landscape pattern indexes currently used. Given the reflected ecological significance and the characteristics of land use types of the Caohai watershed, the fragmentation index, the shape feature index and the diversity index are selected. The specific computing methods and ecological meanings of the indexes are followed:

(1) The fragmentation index. Landscape fragmentation is one of the reasons for the declining biodiversity and the core content of research on landscape ecology and landscape protection. It directly influences the ecological characteristics and process of the landscape in terms of biodiversity, energy flow and material cycle etc. The fragmentation index reflects the complexity of the landscape spatial structure. Through the analysis of the degree of landscape fragmentation, proper evaluation can be made for the stability and human disturbance degree of the landscape from a certain angle.

The research adopts the patch density (PD) index to reflect the degree of fragmentation (PD>0; unit: pcs/km^2).

$$PD = \frac{N}{\mathrm{A}} \times 1000$$

In the above formula, N is the total amount of the patches in the landscape and A is the total area of the landscape (km^2).

(2) The landscape shape index (LSI) is the non-dimensional number whose computational formula is listed below:

$$LSI = \frac{E}{\min E}$$

In the afore-said formula, E is the total length or perimeter of the margin of the landscape (represented by the number of the raster surfaces) including all the landscape boundary lines and background margin Min E is the minimum probable value of E . The LSI is the simple description of the type aggregation index, LSI>=1. When it is 1, it means that there is only 1 patch of this type that is a square or similar to a square. LSI can also be regarded as the measurement of the aggregation or dispersion degree of the patches. With its increase, the patches increasingly disperse.

(3) The Mean Patch Fractal Dimension (MPFD). The index is applied to measure the process that the patch shape influences the internal patches, such as material exchanges. The research adopts the MPFD to measure the complexity of the patch shape.

$$\mathrm{MPFD} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} 2\frac{\ln\left(0.25P_{ij}\right)}{\ln a_{ij}}}{N}$$

In the formula, MPFD is the mean patch fractal dimension; Pij is the perimeter (m^2) of the ij^{th} patch; a_{ij} is the area (m^2) of the ij^{th} patch; N is the total of the patches in the landscape; m is the amount of the landscape type; n is the number of the patches of a certain landscape type. The value of MPFD is 1~2. The closer MPFD is to 1, the simpler the shape of patch is; conversely, the closer MPFD is to 2, the more complex the patch shape is.

(4) The diversity index. It reflects the degree of abundance of the land-use spatial structure and the assertive level of one or more land use types. The Shannon's Diversity Index (SHDI) is adopted with the formula listed below:

$$\mathrm{SHDI} = -\sum_{i=1}^{\mathrm{m}}\left(P_{\mathrm{i}} \ln P_i\right)$$

In the formula, Pi is the proportion of type i patch in the landscape area and m is the total of the patch type. SHDI≥0. The size of the index reflects the amount of the land use types and the proportion changes of all types of land. When there is only one type of land use, its diversity index is 0; when the land use includes two types whose proportions are equal, the diversity index is maximized; the greater differences of the proportions of all types indicate the lower diversity indexes. The value increases with the decline of the diversity and the landscape type is more abundant.

(5) The landscape evenness index. The Shannon's Evenness Index (SHEI) is applied with the expression formula listed in the following:

$$\mathrm{SHEI} = \frac{-\sum_{i=1}^{\mathrm{m}}\left(P_{\mathrm{i}} \ln P_i\right)}{\ln(\mathrm{m})}$$

The meanings of the variables in the formula are the same as those in the afore-mentioned formulas. With the increasing imbalance of the area of patches of different types in the landscape, the index value increasingly approaches 0; when the entire landscape has only one patch, SHEI=0. When the proportion of the area of all types of patch in the landscape increases, SHEI=1.

3.3 Changes of the Caohai watershed landscape structure characteristics

Based on the remote sensing image data of land use in the Caohai watershed of 1992, 2001 and 2013, the FRAGSTATS version 3.3 is applied to analyze the changes of the Caohai watershed landscape structure characteristics. Reference (Zheng Xinqi, Fu Meichen, Yao Hui, *et al*. 2010) collects 763 articles relating to land use in different regions in the latest 30 years in China. The scope of landscape indexes of different regions are determined through calculation and inductive statistics and serve as the reference standards for evaluation.

(1) The fragmentation characteristics. The changes of PD of

the Caohai watershed during 1992 and 2013 are indicated in Fig. 2a. The analysis shows that the PD of the three years generally displays a trend of increase and the landscape fragmentation degree caused by human activities deepened and slowed down after 2001. Compared with the reference threshold value (0.91~1.54) of the landscape index of the southwest region, the present landscape fragmentation degree of the Caohai area is generally at a higher level.

(2) The shape characteristics. The changes of the LSI in the Caohai watershed during 1992~2013 are shown in Fig.2b and the changes of the MPFD are illustrated in Fig.2c. The analysis indicates that the MPFD of the Caohai watershed basically maintains at roughly 1.02. Compared with the reference threshold value (1.50~1.61) of the landscape in southwestern regions, the shapes of the present patches in the Caohai watershed are comparatively easy, which reflects the stronger influence of human activities. The LSI basically maintains at 150 or so, indicating that the dispersion of patches is greater. The above LSI reflects the greater impact of the human activities upon the ecological landscape pattern of the Caohai watershed.

(3) The diversity characteristics. The changes of the SHDI of the Caohai watershed during 1992~2013 are indicated in Fig.2d and the changes of the SHEI are given in Fig.2e. The analysis reveals that the SHDI for years stays around 3.5. Compared with the reference threshold value (1.07~1.93) of the landscape in southwestern region, the present landscape diversity in the Caohai watershed stays at a good level on the whole. Especially after 2001, the rise of the diversity index was good for sustainable development of the landscape system. The SHEI was around 0.8. Compared with the reference threshold value (0.53~68.69) of the landscape in southwestern region, the current SHEI is at an inferior level in the Caohai watershed, which is related with the high proportion of the individual land use type (e.g. arable land).

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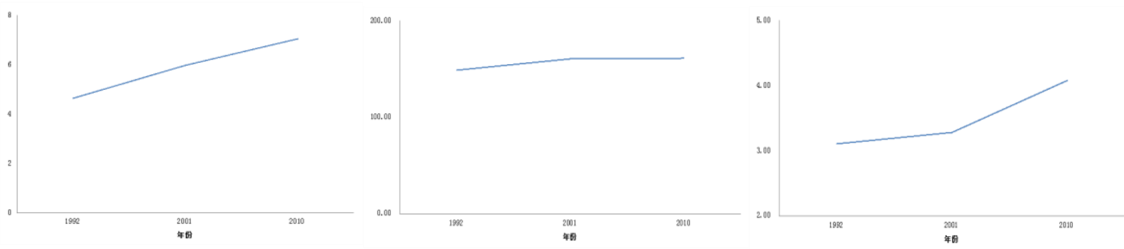
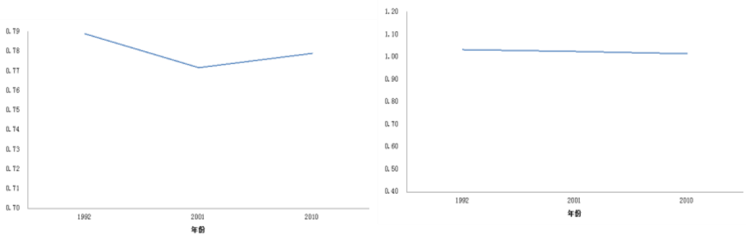


a) PD (pcs/ km^2) b) MPFD c)LSI



d) SHDI e) SHEI

Figure 2. Changes of the LSI in the Caohai watershed over the years

4. THE ANALYSIS OF THE INFLUENCE OF THE LAND USE CHANGES UPON THE LANDSCAPE PATTERN IN THE CAOHAI WATERSHED

The analysis of the changes of land use and landscape pattern in the Caohai watershed shows that the land use changes in time and space directly lead to the changes of the landscape pattern. The arable land is the largest type of land use with a proportion of over 60% and in all directions around the lake area, which leads to the low level of landscape fragmentation and landscape evenness of the whole watershed in the southwestern region. Besides, the area of the arable land rose by 17% during the 20 years developed chiefly from the reclamation of the shrubwood and the open forest land in the east and south of the watershed and the paddy fields in the upper reaches of the lake. These factors aggravate the landscape fragmentation of the area. The arable land is a man-made landscape of regular shapes, whose excessive proportion leads to the low level of LSI in the southwestern regions. In the latest 20 years, the water surface area of Caohai decreased by 27% and the swags in the southern lake almost disappeared and converted into farmland and swampland, which exacerbated the landscape heterogeneity. The residential construction land increased by 34% in area with its scope of distribution extending to the upper reaches of the watershed, which intensified landscape fragmentation and lowered the landscape diversity.

5. CONCLUSIONS AND DISCUSSION

The research makes use of the satellite remote sensing image information, applies the land-use transfer matrix and the landscape pattern index, analyzes the changes of land use and landscape pattern in the latest 20 years and gets to the following conclusion and suggestions:

(1) The research takes the satellite sensing image data as the basic information source to establish the land-use transfer matrix to make quantitative analysis of the change characteristics of the land in time and space, selects the landscape pattern index to make a quantitative analysis of the succession characteristics of the landscape pattern, profoundly and effectively reveals the ecological effects of land use and provides vigorous support for the sustainable development and utilization and the decisions of eco-environmental protection in the region.

(2) The present land development and utilization rate of the Caohai watershed is high. Thereinto, the arable land and the residential construction land take up 65% of the area of the watershed. The increased area primarily comes from the shrubwood and the open forest land, the added paddy field sources from lakes and swamps and the raised residential construction land is transferred from forest land. The above human activities lead to a shrink of the forest land and the water area by 25% and 27% respectively, generating lake swampiness (the swamp increased by 131%) and destruction of the original natural ecosystem.

(3) The land use changes of all types in the Caohai watershed in time and space directly lead to the landscape pattern changes. The landscape fragmentation of the Caohai watershed stays at a high level in southwestern China, which manifests the higher human disturbance. In terms of the LSI, the PD is simpler and the dispersion of the patches is greater. However its landscape diversity keeps at a good level in southwestern China. After 2001, the diversity index increased, which benefited the sustainable development of the ecosystem in the Caohai watershed; the SHEI stayed at a bad level in southwestern China, which was related with the imbalanced land use types and an excessive proportion of the arable land in the watershed. If related rectifying measures were not promptly taken, the inhabitation and existence of the biotic population and the sustainable development of the ecosystem would be severely threatened.

(4) It is advised to integrate watershed space planning and landscape pattern management, reasonably adjust the land development mode and the agricultural industrial structure, develop the eco-agriculture and expand the area of the wetland and swamp wetland of Caohai Lake through returning the grain plots to forestry, grassland and water to contain the tendency of landscape fragmentation and enhance the landscape stability.

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