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RESEARCH PAPER

Analysis of the ecological vulnerability of the western Hainan Island based on its landscape pattern and ecosystem sensitivity

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Abstract: The ecological vulnerability of the western Hainan Island of China was assessed using a combined approach of landscape pattern and ecosystem sensitivity. Models were developed using the following five factors: reciprocal of fractal dimension (*FD*), isolation (*FI*), fragmentation (*FN*), sensitivity of land desertification (*SD*), and sensitivity of soil erosion (*SW*). The major findings include: (1) the vulnerability of various landscape types was in the following decreasing order: farmland > forestland > water area. This suggests that the ecosystems of farmland and forestland are unstable and sensitive to external disturbances; (2) significantly positive relationships were found between the vulnerability of landscape types (*VI*) and *SD*, *VI* and *FN*, *FN* and *SD*, and *FN* and *EVI* (regional eco-environment vulnerability). This suggests that *FN* and *SD* have considerable effects on *VI* and *EVI* in this case; (3) there is a good agreement between the predicted and the actual distribution of the *EVI* zones. *EVI* value tends to decrease with increasing distance from the coastline and increase with increasing altitude; (4) the landscape pattern and the regional ecological vulnerability in this study is predominantly controlled by human activities, although physical factors such as topography and oceanic influences also play roles in the process; and (5) the establishment of relationships between data with respect to landscape and the regional ecological responses could be beneficial in guiding the ecological construction of this region.

Key Words: landscape pattern; sensitivity; index of vulnerability; Hainan Island of China; ecosystem

Eco-environment provides the basic condition that is necessary for human survival and development and forms the foundation for sustainable development of social economy. At present, in a narrow sense, methods of evaluation of regional environment have mainly focused on the evaluation of environmental pollution at a small scale and involving single factor. Obviously, these methods cannot meet the demand of regional sustainable development; therefore, synthetic quantitative assessment method at a broader regional scale should be investigated. The landscape ecology system (abbreviated as landscape) is considered to be a suitable scope for research[1−4] in regional sustainable development and regional ecological construction. Several scholars have made some significant investigations[5−10] in this regard. By functioning as a biological habitat and providing a suitable environment for human existence, landscape is very comprehensive and has clear regional characteristics, combining and concentrating the internal relationship among several natural elements and human phenomena in a region. If the internal relationship between data on patterns and eco-environment vulnerability is investigated from the point of view of landscape and then relationship is established between the data on landscape and the regional eco-environment response, analysis of the regional environmental problems from a broader, higher level can be carried out, which can provide a novel research approach and basis for its construction. To offer useful practical guidance for the reconstruction of regional environment, utilization of resources, and sustainable development, the ecological vulnerability of the western Hainan Island of China was assessed with a combined method of landscape pattern and ecosystem sensitivity.

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1 Background of study area

The west of Hainan Island of China, lying in between the east of Beibu Gulf and the western parts of the Mt. Wuzhi and Mt. Li, includes five cities (counties): Danzhou, Baisha, Changjiang, Dongfang, and Ledong, with a area about 1.173 × 10^4 km^2. The terrain in the east is higher than that of the west. The step-like landforms are prominent with a succession of littoral plain, terrace, platform, hill, low mountain, and middle mountain from east to west. It belongs to semi-arid tropical monsoon climate, which has obvious dry season and wet season. The dry season is as long as 6–8 months with little precipitation, the average rainfall is only 967.5–1091 mm for several years, while the rainy season in May to October has several rainstorms and the precipitation accounts for 90% annually. Annual average temperature is 24.5–25.2℃, annual evapotranspiration is up to 2525 mm and the annual aridity is 1.97 [11]. Because of cold wave gale, dry-hot wind, and typhoon, the study area has a strong and long windy season. Paddy field is less than dry land and garden plot. Paddy field has a area of 1271.58 km^2, accounting for 41.80% and 10.84% of the farm land and the individual whole area, dry land is 1628.14 km^2, accounting for 53.53% of the farmland and 13.88% of the whole area, the areas of garden plot and forestland are 1628.22, 3802.08 km^2 separately, and accounts for 13.88%, 32.41% of the individual whole area. There are several drought- enduring types of vegetation, such as shrub and grass slope with sparse trees. Distribution of these significant vegetation types shows vertical and horizontal difference characteristics with shrub, grass, and drought-enduring tropical crops in western coastal plains and terraces; fallen-leaved and monsoon rainforests in the hills and basins; evergreen foliage forest, mountain rainforest, and grass slope in the eastern mountainous areas; and bottom land rainforest in valleys. The soil types belong to latosol, dry-red soil, aeolian sandy soil, etc. Both the source material of soils and soils have loose structure and poor consolidation. The eco-environment problems, such as sandy desertification, soil erosion, and vegetation degradation, are relatively serious. Therefore, the eco-environment system is fragile, unstable, and sensitive to external disturbances.

2 Methods

2.1 Classification of landscape types

On the basis of the current land use, the whole district is divided into seven types of landscape: (1) farmland, including paddy field, depending-on-weather field, irrigated field, vegetable plot, and dry land; (2) garden plot, including orchard, tea garden, latex plantation, and other gardens; (3) forestland, including shrubbery, forest, open woodland, and immature plantation, etc.; (4) grassland, including natural grassland and artificial meadow; (5) construction land, including rural settlement, urban land use, industrial land and mining land, saltern, and special area; (6) water area, including river, lake, pit, pond, and reservoir; (7) unused land, such as wasteland, sandy land, marshland, naked rock, naked soil, gravel land, tidal flat, and reef. The traffic land is categorized under other landscape types; for instance, if the traffic land is close to residential area, then it is categorized under residential land, etc.

2.2 Selection of landscape indices

Landscape pattern is a concrete reflection of landscape's spatial heterogeneity, as well as a result of various ecological processes. In this study, some indices that are able to reflect the vulnerability characteristics of the eco-environment are chosen to evaluate the regional ecological vulnerability, such as isolation, fractal dimension, and fragmentation.

(1) Isolation (*FI*)

It refers to the separate degree of different elements or patches in landscape. It may indicate the impact on landscape structure by human activities to a certain extent. The scatter and instability of the landscape are increased with the increase of isolation:

$$FI = D_i / S_i;\ S_i = A_i / A;\ D_i = \frac{1}{2}\sqrt{n / A} \qquad (1)$$

where *FI* is the isolation of landscape; *n* counts for the element of the landscape type; A_i is the area of *i* kind of landscapes; and *A* stands for the total area of the case study.

(2) Reciprocal of fractal dimension (*FD*)

The fractal dimension of landscape, which is calculated in terms of the relationship between area and circumference, indicates the complexity of the landscape shape and the spatial stability of the landscape. The value of fractal dimension belongs to[1,2]. The more the value of the fractal dimension approximates one, the simpler and rulable the geometric shape of the patch tends to be. This suggests that the human disturbance is more severe. On the contrary, the complex of the patch shape and the naturalness of the landscape increase with the approximation to two for the value of fractal dimension. So *FD* can be used to show the disturbance degree for the landscape, high value of *FD* shows that the disturbance is strong:

$$FD = \frac{1}{2\log(P/4)\log A} \qquad (2)$$

where *FD* counts for the reciprocal of fractal dimension; *P* is the patch circumference; and *A* is the patch area.

(3) Fragmentation (*FN*)

It indicates the fragmental degree of certain landscape type at a certain period of time; it also can reflect human interference to landscape to a certain extent. There are several indices for indicating the fragment degree of landscape, such as the density of patch and fragmentation. In this study, fragmentation, which is more comprehensive, is selected:

$$FN = MPS \cdot (N_f - 1)/N_c \qquad (3)$$

where *FN* is the fragmentation of the landscape type; $FN \in [0, 1]$, zero indicates the landscape has not been destroyed at all, one implies the landscape has been totally destroyed; *MPS*(mean patch size) is got by the average area of all patches divided by the minimum patch area in landscapes; N_f is the total number of patch for certain landscape type; and N_c is the ratio of the whole area of landscape to the area of minimum patch.

2.3 Calculation of the ecosystem sensitiveness indices

Pattern index is an overall description of the structural characteristic of the landscape type. Different landscape types might possess the same or similar pattern characteristics, so the landscape pattern information only is not enough to fully explain the vulnerability of the eco-environment. In view of this, some sensitivity indices that can indicate the vulnerability of the regional eco-environment are selected to supplement and revise the evaluation system. According to the background of the study area, the eco-environment of the western Hainan Island of China has two major vulnerability characteristics: sandy desertification and soil erosion. To reduce the interfering information and highlight the major contradictions, two sensitiveness indexes: sandy desertification and soil erosion for the vulnerability of regional eco-environment was selected to improve its landscape ecology assessment.

Sensitivity of land desertification can be evaluated by humid index, soil texture, and sand-blowing days. Sensitivity of soil erosion is based on the Universal Soil Loss Equation (USLE), which has considered comprehensively several factors, such as rainfall erosion force index (*R*), slope length and its grade (*LS*), vegetation cover (*C*) and soil texture (*K*), and the GIS techniques can be used to carry on appraisal. The detailed evaluation indexes, hierarchical standards, and calculating methods of the two sensitivity indices can be seen in the attachment C of "Tentative Regulation Techniques of Eco-functional Regionalization" issued by State Environment Protection Administration of China. In this study, the rainfall erosion force index (*R*) is calculated using Zhou Fu-jian empirical formula, according to the rainfall characteristic of Hainan Island and the relevant researches of Zhao Yu-guo and Yu Wei-min[12]; the value of slope length and its grade (*LS*) is estimated by Mutchler and Murphree formula(1967); the value of soil texture (*K*) is calculated by the formula of Wischmeier and Smith (1978); the C values of herbs and woody plants in different land covers are used the already research results by Zhao Yu-guo, *et al.* and their values are between 0.003 and 1.0[13]. As to management factor (*P*), according to the research results of Zhao Yu-guo [13], we adopt 0.15 for the paddy field and one for other types with few or without protect measures.

The calculating methods of sandy desertification sensitivity and soil erosion sensitivity are listed as follows:

$$SD_i = \sum_{j=1}^{n} \frac{A_{ij}}{A_i} \cdot W_{ij} \tag{4}$$

where SD_i is the sensitivity of sandy desertification for landscape type *i*; A_{ij} shows the area that landscape type *i* distributes on the *j* sensitive level of desertification; A_i counts for the total area of *i* landscape type; W_{ij} is the weight of landscape type *i* to *j* sensitive level of desertification; *i* is landscape type; *j* is the sensitive level of desertification; *n* is the total number of landscape types:

$$SW_i = \sum_{j=1}^{n} \frac{B_{ij}}{B_i} \cdot S_{ij} \tag{5}$$

where SD_i stands for the sensitivity of soil erosion of the landscape type *i*; B_{ij} shows the area that landscape type *i* distributes on *j* sensitive level of soil erosion; B_j is the whole area of landscape type *i*; S_{ij} is the weight of landscape type *j* to *i* sensitive level of soil erosion; *j* is the sensitive level of soil erosion; *i* is landscape type; and *n* is the total number of landscape types:

2.4 Vulnerability model of landscape type

According to the meanings of the landscape pattern indexes and the connections between the landscape pattern indexes and the eco-environment response, we adopt multiple weighting sums for pattern indexes and sensitiveness indexes to assess the vulnerability of regional landscape type:

$$VI_i = \alpha \cdot FI_i + \beta \cdot FD_i + \gamma \cdot FN_i + \delta \cdot SD_i + \varphi \cdot SW_i \tag{6}$$

where VI_i is the vulnerability index of landscape type *i*; *FI*, FD_i, FN_i, SD_i, and SW_i stand for isolation, reciprocal of fractal dimension, fragmentation, sensitivity of land desertification, and sensitivity of soil, respectively; α, β, γ, δ, and φ are weights.

2.5 Vulnerability model of regional ecology environment

The vulnerability indexes of the landscape types can only demonstrate the vulnerability characteristics of each landscape type, and cannot reflect the eco-environment vulnerability characteristics of the whole area from spatial level. For this reason, eco-environment vulnerability spatial model of landscape types should be constructed to establish the relationship between the comprehensive eco-environment vulnerability of region and the vulnerability indexes of the landscape types. The calculating model is as follow [6]:

$$EVI = \sum_{j=1}^{n} \frac{A_i}{TA} \cdot VI_{ij} \tag{7}$$

where *EVI* is the vulnerability of regional eco-environment; A_j is the area of landscape type *i* in the sample plot; *TA* is the whole area of sample plot; and VI_i is the vulnerability index of the landscape type *i*.

Based on the area, characteristics of landscape pattern, and ecosystem in this study, a system sampling method of full covering with 8 km × 8 km grids is used to acquire the distribution information of the eco-environment vulnerability characteristic in the whole area. The value of comprehensive vulnerability index in each grid is regarded as the eco-environment vulnerability index of the sample plot's central point.

And then, the syntheses vulnerability map of the whole district is obtained with Ordinary Kringing interpolation in ArcGIS 8.3.

3 Data preparation and Data process

In this study, the data include 1:200000 digital land use map in 1998; 1:200000 administrative map; 1:200000 digital topographic map; 1:200000 soil types and soil texture map; 1:200000 vegetation types map, and meteorological data of all counties and cities in case study. The data are disposed with ArcGIS 8.3 and ArcView 3.2a. The disposal process of data is like Fig. 1.

4 Result analyses

4.1 Vulnerability analysis of landscape types

The weight is calculated after the statistic of patch number, patch area, and patch circumference for each landscape with ArcView 3.2a. Weights of different sensitive levels in the sensitivity indexes are divided into five weight vectors: insensitiveness (0.04), slight sensitiveness (0.12), intermediate sensitiveness (0.2), high sensitiveness (0.28), and extreme sensitiveness (0.36) in terms of the relative weight rate of one, three, five, seven, nine, and the sum of weights at all levels is one. The weights in the vulnerability indexes of the landscape type are $\alpha = 0.2219$, $\beta = 0.1201$, $\gamma = 0.2174$, $\delta = 0.2220$, $\varphi = 0.2186$ with factor analysis. Vulnerability indexes of the landscape types are as follows (Table 1).

The value of *FD* in grassland is the biggest among all landscapes, and the next is water area. This indicates grassland and water area have been considerably effected. For economic benefit, the natural grasslands are converted to meadows, and grasslands are occupied by the farmland, garden plot, and construction nearby, therefore the grassland border is strongly disturbed by human activities. Because of the long dry season,

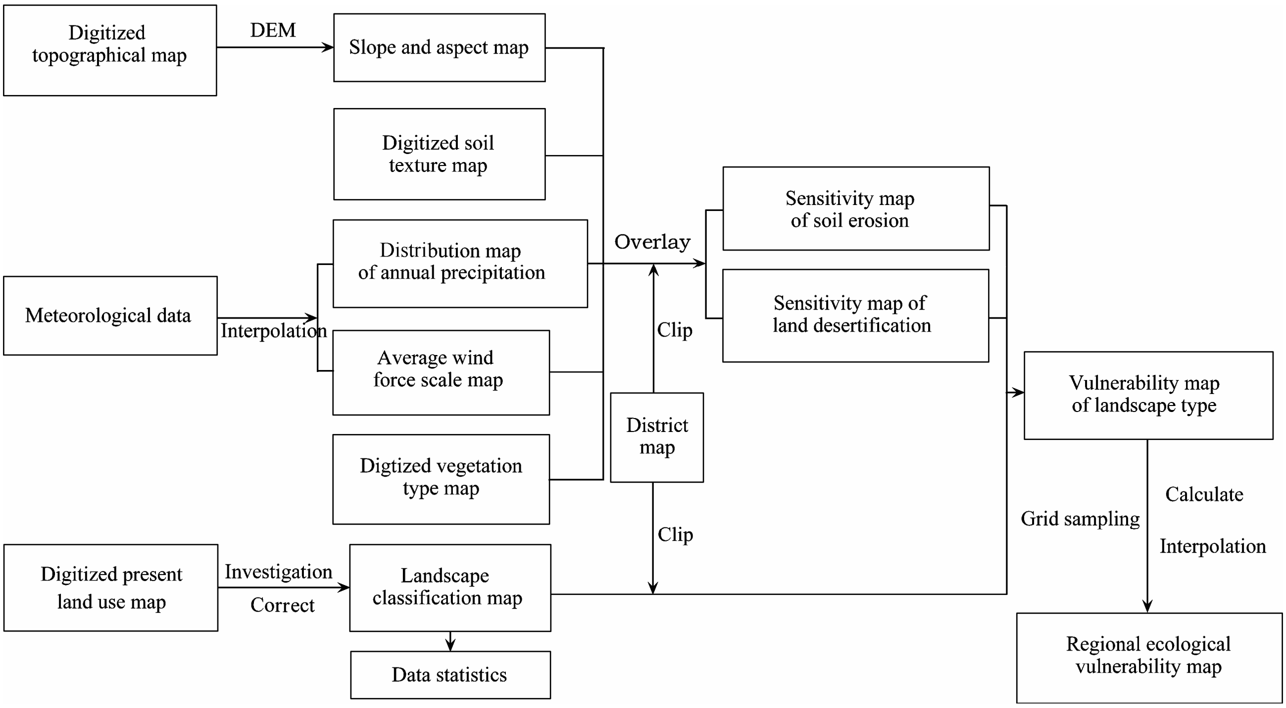

Fig. 1 Data processing techniques

Table 1 Vulnerability indexes of the landscape types

	Farmland	Garden plot	Construction area	Forestland	Grassland	Water area	Unused land
FD	0.7262	0.7454	0.7497	0.7439	0.8119	0.7639	0.7498
FI	0.0007	0.0007	0.0040	0.0003	0.0030	0.0014	0.0016
FN	0.3127	0.1054	0.2036	0.2572	0.0063	0.0244	0.0887
SD	0.1690	0.1343	0.1681	0.1240	0.1233	0.1405	0.1151
SW	0.0408	0.0430	0.0418	0.0972	0.1051	0.0404	0.1025
VI	0.2018	0.1518	0.1816	0.1941	0.1499	0.1374	0.1576

FD: reciprocal of fractal dimension; *FI*: isolation; *FN*: fragmentation; *SD*: sensitivity of sandy desertification; *SW*: sensitivity of water erosion; *VI*: vulnerability index of landscape types several pits, ponds, and reservoirs are dug to guarantee the water used for production and living. *FN* of the farmland is the highest, and the next is forestland. *FN* and *FI* of garden plot are relatively small, with garden plot distributing on the hills and platforms of the Danzhou city in blocks. Big as the *FN* value of farmland is, the isolation of farmland is small because of its tendency of concentrated distribution. The value of *FI* in construction land is the biggest, the next is grassland, and the forestland is the smallest. These manifest that human activities have had a strong impact on the farmland, construction area, forestland, and grassland. The vulnerability of various landscape types was in the following decreasing order: farmland > forestland > construction area > unused land > garden plot > grassland > water area. This suggests that the ecosystems of farmland and forestland are unstable and therefore sensitive to external disturbances. With the extensive management and land use, the ecosystems of farmland and forestland probably degraded toward desert after strong external disturbances. Owing to drought, inconvenient irrigation and strong disturbances, the farmland mainly concentrated on the western plains and terraces in the case study has become the most vulnerable and sensitive in desertification. The natural forests in the study area are distributed on 500–1500 meters mountains, the artificial forests concentrate on the hills under 500 meters. The quality of natural and artificial forests declines greatly, with a descending of forest cover from 0.8 to 0.4, which accounting for 60%–70% of the whole forest area. With the long-term excessive artificial influence, the ecosystem stability of the forestland decreases considerably, while its vulnerability is increased. The sensitivity of soil erosion of grassland is the biggest among landscape types. In fact, the main cause of grassland in the western Hainan Island is the succession of vegetation instead of climate, since the tropical forests had been cut for several times in the history. Soil erosion is increasing with the succession of vegetation and the decrease of forest cover.

4.2 Correlation analysis of vulnerability indices

The correlation coefficients are statistically calculated to investigate the relationships within the vulnerability indexes, and the result is listed in Table 2.

Significant positive relationships were found between *VI* and *SD*, *VI* and *FN*, *FN* and *SD*, and *FN* and *EVI*. This suggests that *FN* and *SD* have considerable effects on *VI* and *EVI* in this case. Yet the relationships between *FD* and *VI*, *FI* and *VI*, and *SW* and *VI* are negative. There are weak positive relationships between *FI* and *SW* and *FI* and *EVI*. These show *FD*, *SW,* and *FI* have small effects on *VI* and *EVI*. Significant positive relationships were also found between *SD* and *FN*, *FI* and *FD*, *SW* and *FD*, and this indicates that there are strong mutual facilitations between sandy desertification and *FN*, soil erosion and human disturbance. Because of the contradiction between rainfall and drought, significant negative relationships were found between *SW,* which is controlled by precipitation and *SD,* which is dominated by drought.

From the above-mentioned analysis, the combination of *SD* and *FN* can suggests there is a close relationship between the landscape information and the vulnerability response of regional eco-environment. This relationship is that the human activities could become a decisive factor for variations of vulnerability and landscape pattern under the semi-arid natural background.

4.3 Vulnerability analysis of the regional eco-environment

The continuous vulnerability distribution map of regional eco-environment is obtained by the interpolation of 194 vulnerability values, which is calculated with the vulnerability model of regional eco-environment and grid sampling. Then, based on the characteristic analysis of the vulnerability indices, the continuous vulnerability distribution map of regional eco-environment is divided into five zones with equal interval. The five zones are Ⅰ zone (range: *EVI* = 0.1523–0.1616, same as follows), Ⅱ zone (0.1616–0.1709), Ⅲ zone (0.1709–0.1803), Ⅳ zone (0.1803–0.1896), and Ⅴ zone (0.1896–0.1989) (Fig. 2).

The result of division indicates, the area of Ⅰ zone is extremely small, only accounting for 0.25% of the whole area; the area of Ⅱ zone accounts for 4.18%; the area of Ⅲ zone is about 21.72%; the area of Ⅳ zone is the largest among all the five zones and it accounts for 45.24%; the area of Ⅴ zone is relatively large, too, and it accounts for 28.61%.

Table 2 Pearson correlation coefficients expressing the relationships between vulnerability indices

	FI	*FN*	*SD*	*SW*	*VI*	*EVI*
FD	0.5155*	– 0.7681*	– 0.4437*	0.4823*	– 0.6052*	– 0. 3289
FI	1	– 0.3031	0.2508	0.0151	– 0.1807	0. 1241
FN		1	0.5630*	– 0.2470	0.9694*	0. 8149*
SD			1	– 0.7994*	0.4940*	0. 4395*
SW				1	– 0.0621	0. 2995
VI					1	0. 9237*

⋆ Correlation is significant at the 0.05 level (2-tailed);*FD*: reciprocal of fractal dimension; *FI*: isolation; *FN*: fragmentation; *SD*: sensitivity of sandy desertification; *SW*: sensitivity of water erosion; *VI*: vulnerability index of landscape type; *VI*: vulnerability index of regional eco-environment

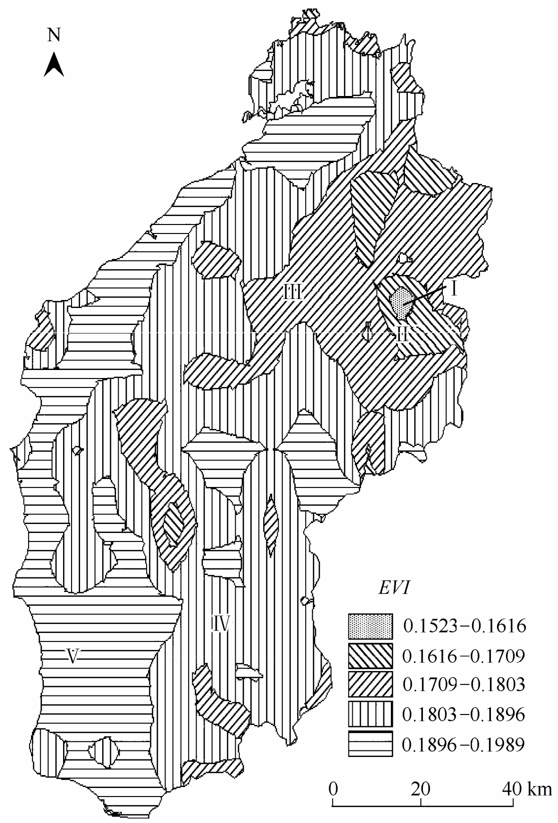

Fig. 2 Distribution of the regional eco-environment vulnerability in the western Hainan Island of China

Ⅰ: the first zone; Ⅱ: the second zone; Ⅲ: the third zone; Ⅳ: the fourth zone; Ⅴ: the fifth zone; EVI: vulnerability index of regional eco-environment

On the horizontal distribution, the zones of Ⅰ, Ⅱ, Ⅲ mainly centre in the northeast part of the study area. Among them, Ⅰ zone and Ⅱ zone mostly distribute in or near the area of reservoirs, ponds, partly on the hills and platforms with artificial forest. Vegetation types on the outer of Ⅰ zone and Ⅱ zone are mostly shrubbery and artificial forests. Vegetations in Ⅲ zone mainly are artificial forests, too. Soil in zones of Ⅰ, Ⅱ, and Ⅲ is moderately stony latosol. Ⅳ zone distributes throughout the middle part of the study area from north to south. Vegetation types of Ⅳ zone are monsoon rainforests and shrubbery, and the soil of Ⅳ zone is heavy stony latosol. The distribution of Ⅴ zone is mainly concentrated along the coast, like an arc shape of narrow north and wide south, especially large within Dong-fang City and Le-dong County in the southwest of the case. The major vegetation types of this zone are artificial forests, such as *Casuarina equisetifolia*, *Eucalyptus tereticornis Smith,* and *Anacardium occidentale*. The secondary vegetation types are coastal sparse grass and desert steppe. The soil types of Ⅴ zone are dry-red soil, strand sandy soil. In addition, there are a few mountain areas in the east and middle parts belonging to Ⅴ zone. Vegetation types in these areas mostly are monsoon rainforests and mountain meadow, the soil is heavy stony latosolic red soil. So on the whole, vulnerability of eco-environment distributes mainly parallel to the coastline like banding, the vulnerability of eco- environment increases with the decrease of distance to coastline. The distribution characteristics suggest that the sea is one of the major factors that control the eco-environment in the study area at regional scale. It is the regional counterclockwise cold ocean current and the strong sea breeze and land breeze that contribute to the main natural calamities in the study area.

On the vertical distribution, comparing with landform map, the vulnerability division of Ⅴ zone distributes on the upper of low- and middle- mountains（>600 m）; the base of low- and middle- mountains, interlock areas of hills and platforms are distributed by Ⅳ zone; Ⅲ zone lies in the hills and platforms completely; Ⅰ zone and Ⅱ zone lie in the among valleys and basins; but the banding vulnerability division of Ⅴ zone can be seen on the littoral plains and coastal terraces again. The vulnerability division shows a distribution characteristic of "high → middle → low → high" from east-west section. Such vertical distribution characteristic indicates that the landform is also one of the major factors that control the eco-environment in the case. Actually, the soil texture and state of sheet flows are decided by the variation of the landform, and this may have an influence on the growth of the regional vegetation and the stability of ecosystem.

5 Discussions and Conclusions

(1) Significant negative relationship was found between *FD* and *VI*; meanwhile there is a weakly negative relationship between *FI* and *VI*. This suggests *FD* and *FI*, especially *FD* are not good to reflect *VI* from the meaning of landscape ecology. While significant positive relationship was found between *FN* and *VI*. This shows intensity of human activity may increase the value of *VI* in the case. To further verify whether the pattern indexes could indicate *EVI* clearly, the values of *EVI* were calculated in each sample plot by grid sampling (8 km × 8 km) at random. Twenty samples were implemented in each landscape type, and the mean value of 20 samples was regarded as the value of *EVI* for each landscape type. Pearson correlation coefficients between mean values of 20 samples and other indexes were analyzed as Table. 2. There are positive relationships within indexes except *FD* and *EVI*. Among them, the relationship between *FI* and *EVI* is smaller (0.1241); the relationship between *SW* and *EVI* is slightly big (0.2995). Significant or extremely significant positive relationships could be found between *SD* and *EVI*, *FN* and *EVI*, and *VI* and *EVI*. *FN* and *SD* are good indicators for both *VI* and *EVI*, and *FI* has a common indication effect for *EVI*, while *FD* gives a poor indication for both *VI* and *EVI*. *SW* gives an inconspicuous indication for *VI*, but excellent indication for *EVI*.

(2) Significant positive relationships were found between

VI and *SD*, *VI* and *FN*, *EVI* and *SD*, and *EVI* and *FN*. This suggests that *FN* and *SD* have considerable effects on *VI* and *EVI* in this case. The factors influencing *SD* are climate, topography, soil structure, and human activity. Among them, climatic change offers a background for desertification, but human activity is the most active and most important regulative factor. *FN* is a static fragmental indicator of the landscape on certain space and certain time. The interior cause of fragment is the combinational effect of the natural and the human factors. Climate is a macro background factor of *EVI* and the characteristic of landscape, but not a decisive factor in the case. Hainan Island were almost covered lush tropical natural forests in history, desertification only existed in recent years. According to the investigation, there were lush forests on the hills and platforms 80 years ago, but now the forests have been degraded to savanna, even desert. Therefore, the soil erosion is becoming serious problem. Excess use for long time is a major cause for this change. Thus variations of the landscape characteristic and *EVI* in the case are mainly controlled by the human activity. There is a good agreement between the predicted and the actual distribution of *EVI* zones with vulnerability models. *EVI* value tends to decrease with increasing distance from the coastline and increase with increasing altitude. This shows regional ecological vulnerability in the study is controlled by physical factors such as topography and ocean besides human activities. Topography controls not only the reassignment of water and heat but also the distribution of vegetation and the process of soil form. Meanwhile it influences the structure and the pattern of agriculture. The variation of elevation in this case causes the vertical zonations of soil and vegetation. Continuous mountains have caused Bengal monsoon's rain shadow region in the east of Truong Son Ra in Indo-China Peninsula and South Sea monsoon's rain shadow region west of Wuzhi mountains the semi-dried tropical monsoon climate. Meanwhile, the Beibu Bay ocean current flows through the coastal waters to the west of the case, it further strengthens the semi-dried tropical monsoon climate that controlled by topography. In addition, the combinational effect of topography and sea causes the venturi effect of the Beibu Gulf, which can strengthen the wind force in the case during the winter monsoon. This strengthens western strand district the wind velocity of sand blowing, also accelerates evaporation speed of water, and becomes another inducing factor for the spread of sandy desertification finally. In sum, there is good information feedback between the pattern indexes of regional ecological vulnerability and the driving forces of vulnerability.

(3) By establishing relationships between the pattern information of landscape and the response of regional eco-environment, this article attempted to suggest a novel research approach and research thinking for regional constructions of eco-environment and to further popularize the practical application of the landscape ecology. Analysis shows the pattern indexes may give a good indication for the vulnerability of regional eco-environment on the whole, but several indexes are poor indicators. So selecting the pattern indices of landscape for vulnerability analysis of regional eco-environment is still needed to further investigated. In addition, the integrated information of the pattern indexes also has a good indication for the interior relationships between the pattern indexes and the driving factors of regional eco-environment vulnerability, but interaction mechanisms within the driving factors of vulnerability, together with the integrated impact mechanisms that driving factors act on regional ecological vulnerability, still remains to further study.

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References

[1] Turner M G. Landscape heterogeneity and disturbance. New York: Spring- verlag, 1987.

[2] Farina A. Principle and Method in Landscape Ecology. Landon: Chapman and Hall, 1998.

[3] Xiao D N, Xie F J, Wei J B. Regional ecological construction and mission of landscape ecology. Chinese Journal of Applied Ecology, 2004, 15(10): 1731–1736.

[4] Zhang Y F, Ren Z Y. Regional ecological security on landscape scale. Journal of Northwest University (Natural Science Edition), 2005, 35(6): 815–818.

[5] Di B F, Yang Z, Ai N S, *et al*. Evaluation on Degraded Ecosystem in Jinshajiang Xerothermic Valley Using RS and GIS—A Case Study of Yuanmou County in Yunnan. Scientia Geographica Sinica, 2005, 25(4): 484–489.

[6] Wang J Y, Zhao G X, Du C X. Analysis on the Regional Eco-environment Vulnerability Based on the Information of Spatial Structure of Landscapes—A Case Study in Kenli Country Located in the Yellow River Delt. Arid Zone Research, 2005, 22(3): 317–320.

[7] Zhao Q, Ding D S, Huang Q H. Preliminary Study on Quantitative Assessment of Regional Eco-environment—A Case Study of Longmen County in Guangdong Province. Areal Research and Development, 2005, 24(6): 104–108.

[8] Wei J B, Xiao D N. Landscape pattern and its functioning after ecological reconstruction in black soil region of northeast China. Chinese Journal of Applied Ecology, 2005, 16(9): 1699–1705.

[9] Meng J J, Shen W M, Wu X Q. Integrated Landscape Ecology

Evaluation Based on RS/GIS of Three-Gorge Area. Acta Scientiarum Naturalium Universitatis Pekinensis, 2005, 41(2): 295–302.

[10] Liu X W, Zhou H R. Study on Assessing Index System and Method of Regional Eco-environment Quality Based on Landscape Case Study of Typical Area in the Lower and Middle Reaches of the Tarim River. Research of Soiland Water Conservation, 2005, 12(2): 7–10.

[11] Li S, Sun W, Li F, *et al.* Study on the Characteristics and the Cause of Sandy Desertified Land in the West of Hainan Island. Acta Geigraphica Sinica, 2005, 60(3): 433–444.

[12] Yu W M, Qi Z P. Assessment of Soil Erosion in Hainan Island on Basis of SOTER. Journal of Soil and Water Conservation, 2003, 19(6): 51–54.

[13] Zhao Y G, Zhang G L, Gong Z T. SOTER-Dased Soil Water Erosion Simulation and Contribution Factor Analysis in Hainan Island. Chinese Journal of Soil Science, 2003, 34(3): 219–224.