

ECOSYSTEM HEALTH ASSESSMENT IN INNER MONGOLIA REGION BASED ON REMOTE SENSING AND GIS

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ABSTRACT:

Ecosystem health is an important index of the regional sustainable development. In view of the singularity of indicator selection caused by the limited application of remote sensing and GIS at present, this paper took the Pressure-State-Response (PSR) model as reference, and revised the model in multi-analysis foundation. The pressure, vigor, organization structure, response and resilience were selected as the indicators of ecosystem health. This study distilled the vegetation index, image interpretation, change detection by remote sensing and GIS. The comprehensive assessment factors were developed with the integration of the social economic and demographic data, and some concepts of landscape ecology were introduced in this process. Finally, we analyzed the ecosystem health in Ordos area through ecosystem structure analysis, human footprint effect analysis, response analysis, resilience analysis, indicators extraction and system health assessment.

1. INTRODCUTION

Nowadays, with serious contamination and deterioration of global environment, regional ecosystem health has been concerned a lot and become an important index of regional sustainable development. The concept of ecosystem health was first developed as an ecological system which is healthy and free from 'distress syndrome' if it is stable and sustainable (Rapport, 1989; Rapport, 1999). And with the development of ecology, the concept of ecosystem health has been expanded to a comprehensive conception of ecology, economy and population. Rapport (Rapport, 1989; Rapport, 1999) considered ecosystem would include two parts: meeting the reasonable needs of humankind and maintaining the organization of itself. In this paper we propose a healthy ecosystem is the one that has the ability to maintain its structure (organization), function (vigor) and landscape level over time in the face of external stress (resilient) (Costanza, et al. 1999), also it is not threatening to the other surrounding ecosystem and could keep humankind and other organic coenosis healthy.

At present, studies on ecosystem health mainly focus on the integration with other ecological theories, such as the assessment of regional ecosystem health using remote sensing and GIS. Based on remote sensing and GIS, the health assessment of grassland ecosystem (Chen, et al. 2005), lake ecosystem (Xu, et al. 2005), coastal ecosystem (Tamara, et al. 2004), river ecosystem (Wu, et al. 2007), city ecosystem (Liu, et al. 2006) were developed. Presently, although the study of ecosystem health steps towards modeling and quantifying, there are some problems about establishment of assessment system, choice and singularity of evaluating indicators, which need to be further discussed.

2. DATA USED

2.1 Study area

In this paper, the Ordos city, Inner Mongolia, China, was used for the study. The area studied is 106°42'40"E-111°27'20"E longitude by 37°35'24"N- 40°51'40"N latitude. Ordos has an area of 86,752 km² and covers the bigger part of the Ordos plateau. The area of Ordos city can roughly be divided into a hilly area in the east, high plateaus in the west and center, sandy deserts in the north and south and the plains at the southern bank of the Yellow river. The highest elevation (2,149m) is located in the west, the lowest point (850m) in the east. The annual rainfall is 300-400mm in the eastern part and 190-350 mm in the western part. Most of the rain falls between July and September. The ecosystem in this area is healthy or not means a lot to the whole north region of China.

2.2 Data Source

The data used in this study includes MODIS/Aqua vegetation index 16days 250m products from July 2001 to July 2005 provided by NASA, 1:250,000 land use map of 2005, 1:250,000 contour map, 1:250,000 vector graph of river and road, distribution of grassland pattern, local precipitation and evaporation data in 2004 and 2005, demographic and GDP data in 2004 and 2005. And DEM data could be extracted from contour map through ArcGIS spatial analysis tool.

2.3 Selection of the assessment units

The assessment units of ecosystem include administrative region unit, watershed unit, landscape unit and grid unit. In view of one watershed unit, the consistence in climate, hydrology and terrain means much to the regional ecosystem

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assessment. With 1:250,000 DEM data, ArcGIS hydrology tool was used to extract the area border, and 19 sub-watersheds were got as the final assessment units with administrative map as reference (Figure 1).

3. METHODS

3.1 Conceptual framework of ecosystem health assessment

For the requirement of environmental management and decision making, scientist designed numerous conceptual frameworks. In all of these frameworks, the Pressure-State-Response (PSR) model (OECD, 1993) reached the most extensive agreement and was widely used in wetland ecosystem assessment (Mai, et al. 2005), evaluation of land use (Zhou, et al. 2002), ecological security assessment (Zuo, et al. 2002) for its clarity causal relationship. But the PSR model also has shortage, for instance, it can not classify the entire index clearly, and the response indicators are difficult to quantify etc. Furthermore, PSR model is founded for environmental problem, it is not suitable to social issue. Therefore, the “Driving forces-State-Response” model (OECD, 1993) and the “Driving forces-Pressures-State-Impacts-Response” model (EEA, 1998) were developed on the basis of PSR model.

Based on current situation and needs we required, we revised the PSR model (Figure 2) and regarded it as our conceptual framework. “Effect” index was introduced in the revised model, “Effect” shows the ability of self-recovery within an ecosystem, it contains resilience and nature response. In this way, we took the ecosystem’s self-recovery into account when calculated the response index. At the same, the pressure index was subdivided into nature pressure and artificial pressure, the state index was subdivided into vigor and organizational structure. So, the revised model has a better pertinence in indicator selection and accords with the conception of ecosystem health well.

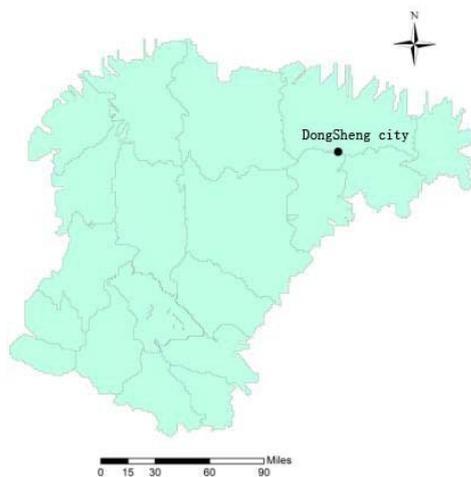


Figure 1. Result of sub-watershed extraction in Ordos city

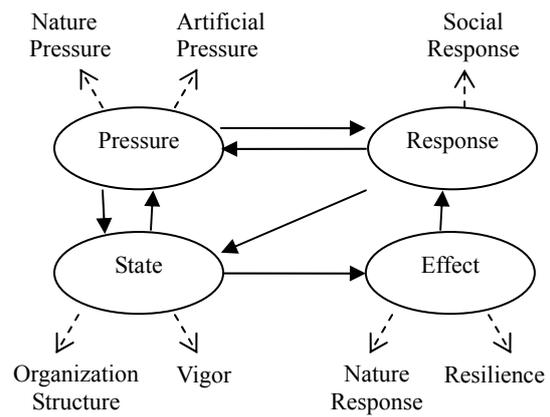


Figure 2. The revised PSR model

3.2 Establishment of assessment indicator system

Based on the concerned principles and methods of establishing ecosystem health assessment index system, the assessment indicator system was established (Table 1).

		Assessment indicator	
Pressure	Nature pressure	Area ratio of damaged land	Desertification index
		Artificial pressure	
	Population density		
	Traffic impact index		
	Ratio of theoretical and practical stocking rates		
Human footprint index			
State	Vigor	Vegetation coverage	Annual precipitation-evaporation ratio
		Net Primary Productivity	
		Organization structure	
	Distribution of grassland pattern		
	Landscape diversity index		
Effect	Resilience	Patch density index	Difference of NDVI
		Land use/land cover evaluation	
	Nature response	Soil erosion index	Ratio of grassland degradation
		Soil and water conservation index	
		Area ratio of natural reserve	
Response	Social response	Afforestation index	GDP per capita

Table 1 Assessment indicator system

3.3 Evaluation Standard

Generally speaking, there are two methods to quantify the evaluation of objects: relative method and direct evaluation method. Since structure and function of grassland ecosystem is extremely complex, and absolute value researches of many indicators are immature. The relative evaluation method was adopted here, and the study areas were ranked as I to V from good to bad with final ecosystem health indexes.

3.4 Evaluation Method

Ecosystem is a complex organization and open system, which has close and inseparable relations and functions to external environment, so the method combined with qualitative and

quantitative concepts is the best way to learn and evaluate it presently. The index weighting method, Analytic Hierarchy Process (AHP) and eigenvalue of group decision-making method are usually used at present. Principal Component Analysis was adopted here. This is a useful technique for reducing multidimensional indicators to lower dimensions with most information and weighting indicators properly. Meanwhile, it could find main contradiction and useful information through correlation analysis of indicators.

4. RESULTS AND ANALYSIS

With the assessment indicator system, the ecosystem health indexes of Ordos area were extracted from the following process:

4.1 Pressure Indicators Analysis

Based on MODIS/Terra NDVI data of Ordos area, threshold extraction was used to get the desertification area and distribution, the accuracy assessment of remote sensing investigation is 85% with statistic data as reference.

Meanwhile, according to the 1:250,000 general road map and research experience, a buffer with 300m as radius was generated, and traffic impact index was got through calculating the ratio of the road buffer zone area in assessment units.

The human footprint index was got from the ratio of artificial landscape (farmland, building lot) in one assessment unit, on the basis of 1:250,000 land use map.

Finally, Principal Component Analysis (PCA) of these indicators was done in SPSS. From the weight statistic result (Table 2), we can see, the main pressures of study area come from artificial one, specifically speaking, are human footprint index, population density, ratio of theoretical and practical stocking rates, that means the study area is facing population growth and over-grazing presently. The desertification pressure is the main part of natural one. In summary, the regional environmental management should focus on coordination of population growth, environment protection and desertification controlling. Presently, the situation in middle and south-west part is serious (Figure 3), because these areas are mainly desert plateau, sand and desert. As the desert expanding, the ecosystem is in danger.

Index	Weight
Human footprint index	0.35
Population density	0.32
Stocking rates	0.34
Desertification index	0.25
Traffic impact index	0.17
Ratio of damaged land	0.23

Table 2. Pressure indicators weight statistic result

4.2 State Indicators Analysis

Combined distribution of grassland pattern with theoretical stocking rate, the largest grassland pattern (desert steppe) was

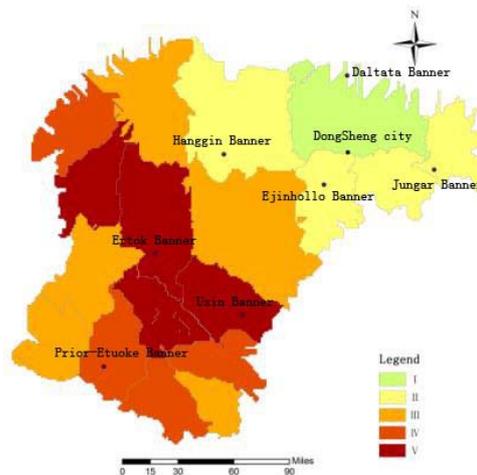


Figure 3. Result of Comprehensive Pressure analysis in Ordos city

chosen and the value of the different grassland pattern was got by Eq. (1):

$$R_i = \frac{S_i}{S} \tag{1}$$

Where R_i = the vigor value of grassland i
 S_i = the theoretical stocking rate of grassland
 S = stocking rate of desert steppe

Landscape diversity and patch density index was derived from following process. First, ArcGIS was used to overlay and integrate land use, DEM and grassland pattern data, after slope and roughness extraction, landscape software FRAGSTATS was used to get Shannon's Diversity Index (SHDI), Shannon's Evenness Index (SHEI) and Patch Richness Density (PRD), then the two indexes were got from PCA.

Then, PCA of these indicators was done in SPSS and pressure index distribution of study area was got (Figure 4). As we can see from Table 3, the contributing value of the pressure indicator is mainly from annual precipitation-evaporation ratio and the next are grassland pattern and vegetation coverage. The whole study area belongs to drought and rainless region, afforestation models adaptable to local conditions should be adopted, such as *salix matsudama*, *salix mongolica*, *hippophae rhamnoides* etc. From the final result, we can see, the state indicators in north-east part of study area are the best, and these in the middle and south part are the worst.

Index	Weight
Patch density index	0.10
precipitation-evaporation ratio	0.39
Landscape diversity index	0.11
Vegetation coverage	0.28
Net Primary Productivity	0.22
Grassland pattern	0.31

Table 3. State indicators weight statistic result

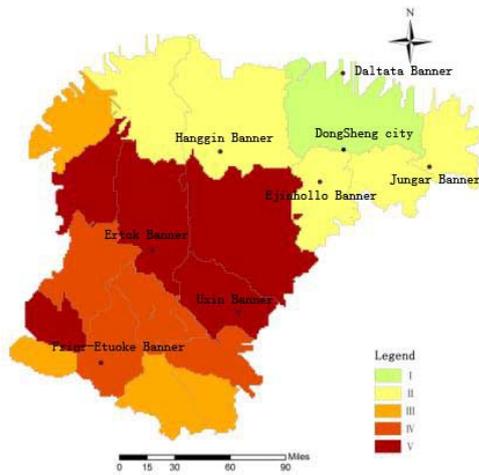


Figure 4. Evaluation map for State indicators in Ordos city

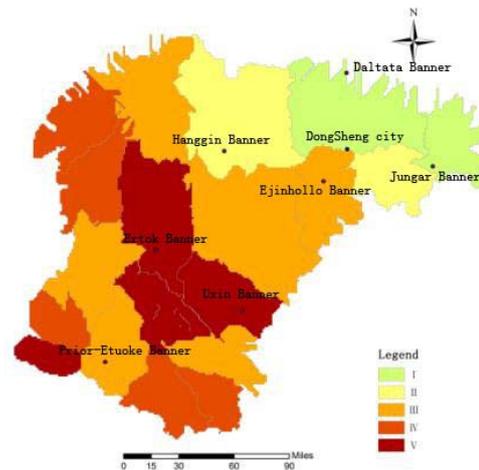


Figure 5. Result of Effect indicators analysis in Ordos city

4.3 Effect Indicators Analysis

The MODIS/Terra NDVI products from 2001 to 2005 of each assessment unit were used to get its range by extremum, which is the difference of NDVI, one of effect indicators.

Meanwhile, land resilience could be characterized by land use/land cover evaluation (Chi, et al. 2007).

Soil erosion index and soil and water conservation index was derived from 1:250,000 regional DEM data respectively, including slope above 25%, length of river, surface roughness, curvature etc.

Finally we analyze these indicators with PCA and get regional state distribution (Figure 5). Among them, contributing value of pressure indicator is mainly from soil and water conservation index and soil erosion index (Table 4) and 50%-60% area has serious soil erosion problem, so, afforestation, strengthen soil and water conservation is vital to the regional ecosystem health. The state of north-east part of study area is the best, which nears the south bank of Yellow River and has sufficient water resources, but the soil and water conservation should be emphasized to reduce sand input to Yellow River.

Index	Weight
Ratio of grassland degradation	0.16
Soil and water conservation index	0.39
Difference of NDVI	0.26
Land use/land cover evaluation	0.22
Soil erosion index	0.31

Table 4. Effect indicators weight statistic result

These response indicators come from regional social economic data and generate distribution by CPA (Figure 6). The area ratio of natural reserve and afforestation index counts the most part in the response indicators (Table 5). The response of north-east part is the best and the south-west part is the worst, and strengthens enclosure and afforestation could improve the response indicators.

Index	Weight
Area ratio of natural reserve	0.62
Afforestation index	0.58
GDP per capita	0.37

Table 5. Response indicators weight statistic result

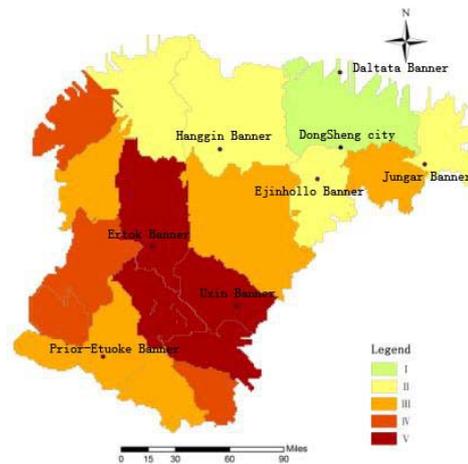


Figure 6. Evaluation map for Response indicators in Ordos city

Compute a PCA of Pressure, State, Effect and Response indicators, multiply each quantifiable value by its weight and summarize, then comprehensive value of each assessing unit was got by Eq.(2):

$$HI = \sum_{i=1}^n W_i \times C_i \quad (2)$$

Where HI= comprehensive index of ecosystem health

W_i = weight of indicator i

C_i = quantitative and dimensionless value of indicators

The ecosystem health of Ordos region was got by these data

(Figure 7). As we can see, the environment in most part of Ordos city is really tough, sub-watershed with good ecosystem health only counts 18% of the whole area (Table 6). These sub-watersheds mainly locate on the south bank plain of Yellow River or hill and gully area, and reducing soil erosion is an effective way to improve the ecosystem health in these areas. The area of assessment units under class III takes 82% of the whole part, which locates mainly on Mu Us Desert, Hobq desert and plateau. Actions such as artificial sand precautions, afforestation, and soil and water conservation should be taken in these areas. Furthermore, with economic data from 2003 to 2006, we can see, the study area is rich in coal resources and the relating industry accounts for a large proportion in the whole regional government revenue. However, during the process of coal mining, vegetation cover and landscape consistence are destroyed, the change of this situation needs good coordination of resource use, environment protection and population growth.

Class	Area Ratio
I	13%
II	5%
III	22%
IV	38%
V	22%

Table 6. Area ratio of ecosystem health assessment result in Ordos city

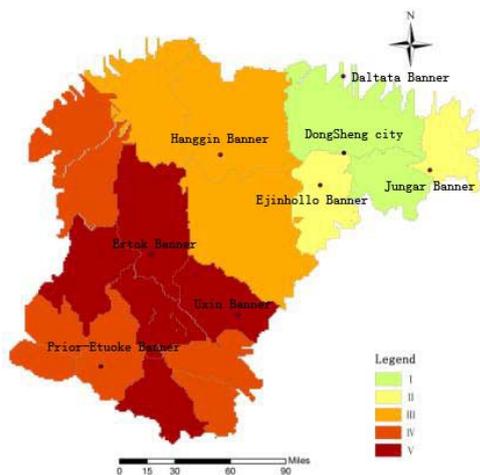


Figure 7. Classification map of ecosystem health in Ordos city

4. CONCLUSIONS

As we can see from this study, ecosystem healthy can be evaluated by Pressures-State-Effect-Response (PSER) model. In the process of assessment, easiness to quantify and being independent are the standard of indicator selection. Remote sensing and GIS technology provide excellent method to quantify indicators. Although parameters in process could be got from data inversion by remote sensing, ground monitoring data is also needed to improve inversion accuracy and availability.

The indicators selection and system establishment varies in time and space, so the selected indicator should be time-varying, meanwhile, the difference in ecosystem types should result in the different selected key indicators and standards. The index

system and a series of indicators established in this paper can just guide the ecosystem management in grassland area in temperate inland areas. Among the process of indicators selection and quantification, we can see, for some indicators, such as vigor and organization structure, it is easy to measure. But other indicators, such as resilience, nature response are hard to grasp, which needs further discussion and research.

Besides the practicability of conceptual model, standard selection and indicator system building is also key to the success of ecosystem health assessment. This study only ranks the internal ecosystem health of study area, but does not build the correlation between ecological level and health values. A uniform assessment standard and relating indicator system must be built quickly with the help of remote sensing and GIS.

This study adopted watershed as assessment unit, because each watershed has unique geomorphology and consistent ecology features, it is important in ecosystem health assessment. However, sub-watershed division would be different according to the scale of DEM data, so the method of grid assessment unit could be introduced to implement the spatial feature of ecosystem health assessment in further study.

Overall, ecosystem health assessment is critical to regional environment protection and sustainable development, as a new research topic, combing traditional ecology principals with remote sensing, GIS technology, landscape ecology and ecosystem service evaluation, it would has great development.

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