Health Assessment of a Small Watershed on the Loess Plateau*

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Abstract: A health ecosystem is the aim of building a nice Loess Plateau with green mountain and clear river. This paper, taking Zhifanggou small watershed as an example, by using the AHP (Analytic Hierarchy Process) selecting the woodland and pasture cover, area of fundamental cropland, soil anti-scourability, soil organic matter, output/input, crop yield, net incomes of per capita and benefit of reducing the soil erosion etc. analyzed the improvement process in ecosystem rehabilitation. The result showed that after about 20 years of soil conservation practice and restoration, the ecosystem health index of the watershed has improved from 0.178 in 1985 to 0.707 in 1999 experiencing initial restoration, stable improvement and coming to fine development period. This research introduced the new indicators of soil anti-scourability, soil organic matter content and gave the different weight value of indicators in health index calculation in restoration process.

Keywords: health assessment, loess plateau, analytic hierarchy process

1 Introduction

SOIL erosion is a serious worldwide environmental problem and a major threat to the sustainability of agriculture. The Loess Plateau, with its deep and loose loess, is facing a continuous loss of land and productivity due to severe soil erosion. Rehabilitation of a health ecosystem is the aim of building a nice Loess Plateau with green mountain and clear river. Realizing the extent and severeness of this problem, the government of the P.R. of China promotes a control measurement to control soil erosion. It is a success approach to take on the controlled small watershed as a model to demonstrate and promote other similar watersheds' development. After the three "five year project" in Zhi Fanggou watershed, significant economic, social and ecological benefits have been gained (Liu, 1999a). However, there are still no proper methods (Hunsaker, C.T. & Carpenter, D.E., 1990; Liu *et al*., 1999b; Walker, J. & Reuter, D.J., 1996) to comprehensively assess the system health situation of the controlled area.

Since the appearance of the definition of ecosystem health from 1980s, it has brought great interest to ecologist, economist, sociologist, politician and environmental manager (Constansa *et al*., 1992). They proposed all kinds of opinions to the definition, diagnostic criteria and method according to their knowledge and experience (Xu & Tao, 2000). The scientists of CSIRO in Australia proposed the definition of watershed health. A healthy watershed is one that can recover form perturbations. It is economically viable and environmentally self-sustaining (Walker & Reuter, 1996). Watershed health is an important component of ecosystem health. The objection of research on watershed health is to understand the function and process of the watershed ecosystem, analysis the environmental effect of the ecosystem after restoration, and predict its development tendency. The research result will provide scientific basis to decision-making for local government and watershed managers.

The zhi Fanggou watershed (36°53′ N, 109°17′ E) is situated on the middle part of the loess plateau in northern Shaanxi province in China. The watershed has an area of 8.27 km^2 and an altitude between 1,000 m—1,350 m. There are significant topographic variations with typical loess hills and gully landforms within the study area. Land use types including slope cropland, fallow land, grassland, shrub land, orchard land and woodland consist of mosaic patterns. Crops are mainly potatoes (*Solanum*

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tuberosum), beans (*Phaseolus valgaris*), maize (*Zea mays L.*) and millet (*Panicum miliaceum*). The forest, artificial woods, is dominated by Locust trees (*Robinia pseudoacacia L.*). The grassland is mainly covered by annuals such as sweet wormwood (*Artemisia annua L.*), annual fleabane (*Erigeron annuus Pers.*) and sandy needlegrass (*Stipa glareosa p. Smirn*). Littleleaf peashrub (*caragana microphylla*) in shrub land and apple tree (*Malus pumila mill*) in orchard are present. Fallow land slowly came into being after cultivated plots were abandoned two and three years ago.

The region has a semiarid continental climate with an average annual temperature of 8.8℃. Monthly mean temperatures range from 22.5℃ in July to –7℃ in January. The average annual precipitation is 483.9mm with 60 percent of the rainfall falls between July and September. There are 159 frost-free days and an average of 2,415 hours of sunshine each year.

The soils, developing on wind-accumulated loess parent material, are thick at an average of 50 m—80 m. The most common soil in the watershed is loess with texture of fine silt and silt soil. It is weekly resistant to erosion. The erosion rate is extreme serious at about 10,000—12,000 tons・km^{-2}・yr^{-1} (Jiang *et al*.,1990).

2 Methods

As a system analysis tool, AHP (Analytic Hierarchy Process) can divide complicated question into several different components, sum up the components to the basis layer (measures to be decided) and superior layers, then rank the sequence of the components and give them weight values according to the relation and subjection of the components. Analytic Hierarchy Process was used as follows (Zhao *et al*., 1986):

(1) Building up Analytic Hierarchy model

Complicated question was divided into several different components and then summed up to objective layer, criteria layer, index layer, scenario layer and measurement layer. The relation of these layers was structured by a graph.

(2) Structuring matrix

Ranking the sequence of the components according to the relation and subjection of the components. Then comparing the comparative importance of each two factors and give them marks (see Table1). Structuring matrix of these marks and calculating the maximum eigenvalue and eigenvector of the matrix. Then the weighted values of the factors in one layer compared to the factor in superior layer can be calculated.

Table 1 The mark and its meaning in judgment matrix

Mark	Meaning
1	The two factors are equally important
3	One factor is slightly important than the other one
5	One factor is important than the other one obviously
7	One factor is important than the other one intensively
9	One factor is important than the other one extremely
2，4，6，8	Median of the judgment above

(3) Consistency test

① Consistency test to single taxis

Where, *CI* is the index of consistency, λ_{max} is maximum eigenvalue the matrix, *n* is the rank value of the matrix, *RI* is mean random index of consistency, *CR* is random consistency ratio (see Table 2).

$$CR = \frac{CI}{RI} < 0.10 \qquad CI = \frac{\lambda_{max} - n}{n-1}$$

The matrix is consistent if *CR* <0.10. Otherwise, the matrix is not consistent and should be regulated.

② Consistency test to overall taxis

Consistency test to overall taxis is conducted from the top layer to the interior layers. The random ratio of consistency can be obtained as follows:

$$CR=CI_j / RI_j$$

Where, CI_j is the consistency index of the factors in interior layer compared to the factor j in superior layer, RI_j is the corresponding mean random index of consistency. Similarly, when $RI<0.1$, the overall taxis of the hierarchy is consistent.

Table 2 Mean random index of consistency

Rank value	1	2	3	4	5	6	7	8	9
CR	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3 Result

Watershed health diagnosis is an important aspect of watershed management. It is an assessment approach to the health situation of environmental quality based on the monitoring to the eco-environment in watershed. "Health ", the ultimate objective of watershed management, means the structure and function of the watershed system can keep relative stabilization and sustainable development under the bad influence of outer factors.

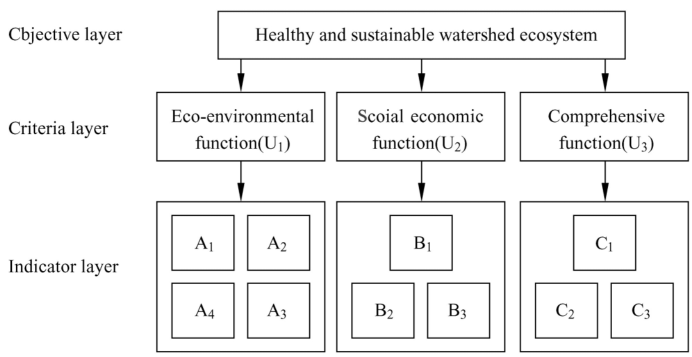
In order to appreciate the benefit of integrated control measurement and establish corresponding eco-system rehabilitation measurements, it is necessary to assess the health situation of the watershed. In this paper HPA was used to assess the Zhifanggou watershed quantitatively.

3.1 Identifying and selecting indicators

Health indicator should reflect the driving forces that influence the sustainable development of the eco-economic system and should reveal the system development tendency. Therefore, Identifying and selecting indicators should be objective and quantitative. Considering the characteristic of hilly-gullied area of the Loess Plateau and the requirement of eco-environment rehabilitation, based on the principle of objection, science, universality, independency and maneuverability, four economic indicators (vegetation coverage, realizing ratio of fundamental cropland, soil anti-scourability and soil organic content), 3 social-economic indicators (Ratio of output/input in agriculture, Net income per capita, Potential realizing ratio of yield) and 3 comprehensive indicators(Resistible capacity of the system, The efficiency of integrated control measurement in decreasing soil loss, Total income of industry and bywork), were selected in this paper.

3.2 Building up health assessment model

The HPA model for the eco-economic system health assessment in Zhifanggou watershed was as following:



Where, the indicators for eco-environmental function included vegetation coverage (A_1), the realizing ratio of fundamental cropland (A_2), soil anti-scourability (A_3) and soil organic matter content (A_4). The indicators for social economic function included the ratio of output/input in agriculture (B_1), the realizing ratio of potential food production (B_2) and net income per capita (B_3). The indicators for comprehensive function were resistible capacity of the system (C_1), efficiency of integrated control measurement in decreasing soil loss (C_2) and total income of industry and bywork (C_3).

3.3 Calculating weight of indicators

Based on the idea that the driving forces varied in different development stages during the construction of soil and water conservational eco-agriculture, the judging matrix was built up with the grade that was marked by experimental experts in soil and water conservation according to the different development stages . The result of consistency test using the maximum eigenvalue and eigenvector of the matrix demonstrated that the matrix was consistent. The weight of indicators was calculated from the matrix (see Table 3).

Table 3 The weight of indexes in different periods in the procession of ecosystem rehabilitation

	1	2	3	4	5	6	7	8	9	10
Initial restoration	0.0233	0.1129	0.0157	0.0314	0.0684	0.2762	0.2986	0.0186	0.0764	0.0783
Stable improvement	0.0349	0.1313	0.0338	0.0676	0.0555	0.2033	0.2086	0.0319	0.1185	0.1145
Fine development	0.0510	0.1545	0.0437	0.0874	0.0513	0.1820	0.1723	0.0388	0.1119	0.1072

Note: The numbers 1 to 10 in the Table means plant coverage, fundamental cropland per capita, soil anti-scourability, soil organic content, input/output in agriculture, potential probability of food achievement, net income per capita, system anti-adversibility, benefit of reducing soil erosion by integrated control, total income of industry and bywork.

3.4 Health assessment

It is necessary to unify the unit of the indicators in calculating the health index. The minimum and maximum values of the indicators (indicators criteria) were defined according to the research results on soil conservation and eco-environment rehabilitation, the historical and current values of the indicators in the watershed as well as national regional development policy (see Table 4).

The dimensionless values of the indicators were obtained from the marks of the unifying Table. The health index (see Fig.1) was calculated as following:

$$I = \sum_{i=1}^{10} (W_i \times V_i)$$

Where I is health index. W_i is the weight of the indicator. V_i is the dimensionless value of the indicator.

According to the research result (Zhao, 1996) and practical situation of the social-economic development, health situation of eco-ecological system in Zhifanggou watershed was classified as vicious circle that was the stage before the integrated control, frailness relatively, stabilization, good and fine development that were the stages after the integrated control (see Table 5).

The research result demonstrated that the restoration procession of the eco-system in Zhifanggou watershed experienced three stages, i.e., initial restoration（1985—1988） with a health index of 0.55, stable improvement（1989—1993）with a health index of 0.55—0.70 and good development period （1994— ）.

Table 4 Dimension unifying table of indicators

No.	Mark	1	2	3	4	5	6	7
1	Vegetation coverage (%)	<5	10	15	20	35	50	>70
2	Realizing ratio of fundamental cropland (%)	<10	20	30	50	55	60	>75
3	Soil anti-scourability (min • l/g)	<0.30	0.40	0.50	0.60	0.80	1.0	>2.0
4	O.M. (%)	<0.4	0.5	0.6	0.7	0.8	0.8	>1
5	Ratio of output/input in agriculture	11(2.0)	10(2.5)	9(3.0)	8(3.5)	7(4.0)	6(4.5)	5
6	Realizing ratio of potential food production (%)	<5	10	15	20	35	50	>75
7	Net income per capita (Yuan)	<100	200	500	1,000	1,500	2,000	>3,000
8	Resistible capacity of the system (%)	<5	10	15	20	35	50	>75
9	Efficiency reducing soil loss (%)	<5	10	15	20	35	50	>75
10	Total income of industry and bywork ($\times 10^3$RMB yuan)	<1	2	5	15	30	60	>140

Table 5 Health classification of eco-ecological system in Zhifanggou watershed

Item	Vicious circle	Frailness	Relatively stabilization	Good	Fine development
Health value	<0.15	0.15—0.35	0.35—0.55	0.55—0.70	>0.70

4 Discussion

During the process of continuous construction of ecological agriculture with soil and water conservation in Zhi Fanggou watershed, the health index of the eco-economic system is increasing step by step. In this paper, an improved method, which is different from that in former study (Liu and Zheng, 1998), was used in assessing the health situation of the watershed. First, in the assessing of the eco-economic system, two different weight of the indicators was marked according to the two different development stages the system, which made the weight to be more practical. Second, soil anti-scourability and soil organic matter content were introduced in this research. Normally, it spent more time in the improvement of soil ecological environment than that of economical and other ecological situation. That is why the health index calculated in this paper is lower than that in former research.

The variety of health situation in Zhi Fanggou watershed was showed clearly in Fig.1. Based on the dynamic curve, a five-development stage was divided, i.e., vicious circle period, fragile period, comparatively stable period, favorable period and benign circle period. This division was different from that in former research (Lu, Liang and Wang, 1990). We divided the stable period into comparatively stable and favorable period, which could show the development characteristic of the health situation in this period. The health assessing result in this paper was coincident with restoration practice in the watershed. The result provided a scientific support to the grading implement theory of soil and water conservational eco-agriculture in the region. The result also indicated that the degenerated eco-system in the Loess Plateau could be restored into fine development after 20 years' implement of integrated control measurement.

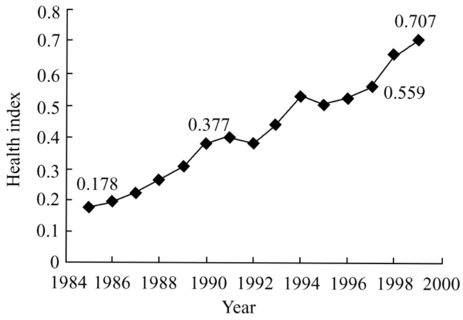


Fig.1 The dynamics of health indexes of eco-ecological system in Zhifanggou watershed

5 Conclusion

(1) During the process of continuous construction of ecological agriculture with soil and water conservation in Zhi Fanggou watershed, the health index of the eco-economic system is increasing step by step, from 0.178 in1985 to 0.377 in 1990 and up to 0.707 in 1999.

(2) The development of the health situation in the eco-economic system can be divided into five stages: vicious circle period, fragile period, comparatively stable period, favorable period and benign circle period. At present, the system is coming into benign circle period.

(3) The method used in this paper provides a success example firstly for eco-economic health assessment in similar region. However, in different region, such as gullied plateau area, the indicators for health assessment may be different and further research is necessary.

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