Land Eco-sensitivity Assessment of Ecological Cities Based on LUCC

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Abstract Land eco-sensitivity assessment is an important method in analyzing regional eco-environmental safety. This article is based on the studies of land use and coverage change (LUCC) with the interpretation result from Landsat images. It analyzes the land use degree of Shangluo City and gives the land eco-sensitivity classification, which includes soil and water conservation, disaster prevention and eco-environmental protection. Then an improved classification model is taken through the gray model and the variation coefficient. By comparing sensitivity in each level of land use degree change, the ecological recovery mode in study area is analyzed. The results show: the land use degree in Shangluo City has been declining from 1990 to 2009, with large area converted form cropland to forest, environment becomes better; the sensitivities of zoning based on the index level shows the medium sensitive area was largest. According to the variation coefficient gives the more reasonable proportion, the zoning was improved based on uncertainties. Because of the least amount of land use degradation area was taken in high sensitive region, it is considered that the ecological construction model in study area was still worth discussing. The healthy ecological development mode is proposed that low sensitive region should be protected while high sensitive region should receive high attention, so as to further improve the regional ecological security and improve the living environment efficiently.

Key words Land use degree, Sensitivity assessment, Shangluo City

Since the *LUCC Science/Research Plan* jointly issued by International Geosphere-Biosphere Program (IGBP) and International Human Dimensions Programme on Global Environmental Change, scholars both at home and abroad have undertaken a series of researches on spatio-temporal change, drive mechanism, and eco-environmental effect. In the research of eco-environmental effect, the sensitivity assessment is a major method for analyzing stability of regional eco-environment[1] and important part of ecological security zoning. Land eco-sensitivity assessment can effectively promote sustainable use of land resources through adjusting structural distribution of land development and protection. However, present land eco-sensitivity assessment analysis is mainly based on static land use pattern, few researches touch on land use and coverage change (LUCC), so it fails to reflect the relationship between sensitivity zoning and dynamic change of land coverage. Besides, most existing methods choose targets based on analytic hierarchy process (AHP), Experts Grading Method (EGM) and Delphi method, thus it is required to further improve processing of continuous variables and basis for final level classification. Through applying LUCC research methods into land eco-sensitivity assessment, we can combine different sensitivity patterns and changes of land use degree, and compare and analyze spatial distribution of ecological protection from the perspective of time.

Shangluo City, situated in the Qin Mountains, has remarkable ecological service function[2]. Thanks to guaranteeing water source of Mid-route of South-to-North Water Transfer Project and construction of ecological tourism city, local government constantly makes favorable policies for ecological protection. In this paper, based on LUCC theories and with the aid of remote sensing images of study region in three periods (1990, 2000 and 2009), we analyzed current situations of land use in the study area, and conducted land eco-sensitivity assessment and zoning in combination with DEM and relevant drawings. According to dynamic statistics of land use in sensitive regions, we analyzed continuation in time and reasonableness in space of ecological protection, and put forward recommendation for ecological construction distribution pattern of ecological cities.

1 Data preparation

1.1 General information of study area The Qin Mountains are a major east-west mountain range in southern Shaanxi province of China. The mountains provide a natural boundary between the North and South of the country, support a huge variety of plant and wildlife, and have effective ecological service function. Situated in southeast of the Qin Mountains, Shangluo City is a prefecture-level city in Shaanxi Province. It covers an area of 19 293 km^2. In 2010, the total population of Shangluo City was 2.44 million. It administers Shangzhou District, Luonan County, Danfeng County, Shangnan County, Shanyang County, Zhen'an County, and Zuoshui County. In general, the land in Shangluo City descends from northwest to southeast. It has few high mountains and many low hills. The

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highest point is up to 2 802.1 m, and the lowest point is 216.4 m. The annual temperature is 7.8 to 14.0 ℃ with annual range of temperature 23 to 25 ℃ and annual precipitation of 706.1 to 844.6 mm mainly in April to October. The annual total solar radiation is up to 501.6 to 1518.3 kJ/cm^2, annual average sunshine reaches 1 874 to 2 123 hours, so it can satisfy demand of plant growth. As important ecological protection zone in Shaanxi Province and water supply conservation base of South-to-North Water Diversion Project, Shangluo City has poor economic condition and favorable ecological foundation. Thus, it is of great significance to environmental protection and ecological construction.

1.2 Data source This study adopted landsat-5TM images of 1990, 2000 and 2009 in Shangluo City. These images were taken in April to September and sourced from Data Application Environmental Center of Chinese Academy of Science. ETM + images of 2009 had been recovered by this Center, so it basically eliminates influence of sensor damage after 2003. Besides, we selected 30 m resolution DEM data supplied by this Center. Precipitation data was taken from average monthly data of 96 meteorological stations during 1980 to 2000, and calculated average monthly data of precipitation during these 20 years. The soil erosion degree was selected from the soil distribution map in *Annals of Shangluo Region*. Besides, soil was classified with reference to Chinese soil database of Nanjing Institute of Soil Science. The occurrence ratio of geological disasters and spatial position of ecological protection zone or water conservation area were taken from *Prevention and Control Plan for Geological Disasters in Shangluo Region and Overall Plan for Land Use in Shangluo Region* (2006 *to* 2020).

1.3 Data processing Through supervised classification and man-machine interaction, we divided land use of the study area into cultivated land, forest land, waters, construction land and unused land. We tested 500 random grids and overall interpretation precision higher than 85%. We spliced 30m resolution DEM data and generated the slope map. There are 10 types of soil distribution. It is cinnamon soil, brown soil and yellow brown soil in sequence of strong to weak erosion. Zoning of occurrence ratio of geological disasters also takes account of times of disasters and amount of loss. We scanned and vectorized these three drawings of geological disaster occurrence ratio, ecological protection zone and water conservation area, and soil distribution types. In the projection registration, the parent map was based on previous land type interpretation results to ensure precision. The precipitation data adopted interpolation by Kriging Method, and the results were converted into 30 m resolution grid images after vector boundary cutting of Shangluo City. Finally, we converted all images to Albers projection, the central meridian was set at 33°E, and two central parallels were set at 33°N and 343°N respectively.

2 Analysis on land use and coverage changes

Based on remote sensing images, we obtained changes of land use area of the study area during these 19 years: during 1990 to 2009, cultivated land of the study area constantly decreased; forest land and construction land increased, and the growth rate of construction land exceeded a half; waters and grassland area fluctuated but did not reduce generally; and the non-used land decreased greatly. In addition, there are big differences in changes of land types during different periods. During 1990 to 2000, the cultivated land decreased only about 3%, while it reduced for more than 20% after 2000. This is mainly because of policy of conversion of degraded farm land into forest after 1990. The construction land grew by more than 20% and 24% in the first 10 years and the last 9 years, indicating rapid urban expansion in recent years. The growth rate of forest land reached 3.4% and 6.24% separately. Since the base number of forest land is large, it is known that forest scale expanded greatly. From the superposition of interpretation images of 1990 to 2009, it can be known that the proportion of cultivated land converted forest land into the total conversion area is up to 43.97%. Since the total conversion area includes transferred-in area and transferred-out area (which are equal to each other), we can get that the cultivated land converted to forest land and garden area accounts for 87.94% of the total land area change.

With simple quantity change of land types, it is difficult to measure the utility of human activities, so we should analyze land use intensity of the study area. According to integrated analysis method of land use degree raised by Liu Jiyuan *et al*, we can substitute the land use degree grading index table (Table 1) into land use degree integrated index model and land use degree change model, and obtain land use degree and changes of the study area[3,4]. The higher index of the land use degree, the higher intensity of land use. The model is as follows:

$$L_j = 100 \times \sum_{i=1}^{n} A_i \times C_i$$

$$\Delta L_{b-a} = L_b - L_a = 100 \times \left(\sum_{i=1}^{n} A_i \times C_{ib} - \sum_{i=1}^{n} A_i \times C_{ia} \right)$$

$$R = \frac{\sum_{i=1}^{n} (A_i \times C_{ib} - \sum_{i=1}^{n} (A_i \times C_{ia}}{\sum_{i=1}^{n} (A_i \times C_{ia}}$$

where L_j signifies integrated index of land use degree of the study area; A_i is the grading index of the *i*-th grade land use degree; C_i refers to the percentage of land use types; n is the number of grading. L_b and L_a is integrated index of land use degree in time *b* and a respectively; C_{ib} and C_{ia} are the percentage of land use types of the *i*-th grade land in time *b* and *a*. If $\Delta L_{b-a} > 0$ or $R_j > 0$, the land use of the study area is at the development stage; otherwise, it stays at adjustment or decline stage.

The integrated index of land use of the study districts and counties calculated as per the above formula (Table 2) shows that the higher the land intensity, the more violent human activities. The rate of change in land use degree of Shangluo City is below 0, indicating that the overall land use in Shangluo City stays at regulation or decline stage. The rate of change in land use degree of Luonan County is higher than 0, indicating that this county still remains development period. Zhen'an County has the minimal change of land use, indicating its fastest of de-

cline or the maximum regulation amplitude. In the context that the overall land use in the whole country stays at the development stage, the land use degree in the study takes on decline trend. This is resulted from substantial reduction of cultivated land and dramatic increase of forest land in 19 years, especially in recent 9 years in the study area. Compared with the increase in construction land, the increase in forest land has the absolute advantage. This indicates that the policies of conceding the land to forestry and grass or autonomous management of fruit orchards have produced an obvious effect.

Table 1 Grading of land use degree

Grade	Unused land	Forestland, grassland and water areas	Agricultural land	Urban land use
Land use types	Unused land or that is difficult to be used	Forestland, grassland and water areas	Cultivated land, garden land, and artificial grassland	Residential area, industrial, mining and transportation land
Grading index	1	2	3	4

Table 2 Changes and rate of change of land use degree of Shangluo City

Area	1990	2000	2009	Changes of land use degree during 19 years	Rate of change of land use degree during 19 years
Luonan	207.06	207.05	209.47	2.41	1.2
Shangzhou	212.71	212.79	211.63	−1.08	−0.5
Danfeng	208.91	209.19	207.42	−1.49	−0.7
Zuoshui	210.58	210.79	205.44	−5.15	−2.4
Shangnan	209.60	209.60	204.21	−5.39	−2.6
Shanyang	214.11	213.94	209.07	−5.04	−2.4
Zhen'an	219.77	219.58	212.19	−7.58	−3.4
The whole city	212.32	212.33	208.83	−3.49	−1.6

3 Land eco-sensitivity assessment

3.1 Assessment index Sensitivity assessment should make clear types and possibility of main ecological and environmental problems in the study area, including sensitivity of desertification, sensitivity of freezing-thaw erosion area, sensitivity of water loss and soil erosion, sensitivity of acid rain, and sensitivity of stony desertification[5]. Situated in the Qin Mountains, Shangluo City has dense vegetation and ecological service value is high, and there is no problem of desertification and salinization. However, high terrain, steep slope and abundant rainfall in the study area lead to severe water loss and soil erosion, and frequent occurrence of geological disasters, such as landslide, debris flow, *etc.* In addition, Shangluo City lies in the area of Mid-route of South-to-North Water Transfer Project, so the water supply conservation and ecological protection are of great significance in the study area. Therefore, we took the annual precipitation, altitude above sea level, slope grading, land use pattern, water loss and soil erosion intensity, geological disasters, and construction of ecological protection zone and water supply conservation base as the assessment factors[6−15], shown in Table 3.

Table 3 Single factor grading standard for ecological and environmental sensitivity in the study area

Index	Factor	Not sensitive	Slightly sensitive	Moderately sensitive	Highly sensitive	Extremely sensitive
Water and soil sensitivity	Annual precipitation // mm	–	≤800	800 to 900	≥900	–
	Slope grading // (°)	0 to 8	8 to 15	15 −25	25 −35	≥35
	Land coverage type	Water areas and construction land	Sparse words and forest land	Garden land and irrigated field	Waste grass land	Dry land, bare rock, industrial and mining land
	Soil erosion degree	Slight	Moderate	High	Severe	Extremely severe
Disaster sensitivity	Annual precipitation // mm	–	≤800	800 to 900	≥900	–
	Slope grading // (°)	0 to 8	8 to 15	15 to 25	25 to 35	≥35
	Occurrence ratio of geological disasters	Not probable	Less probable	–	Probable	Highly probable
Ecological and environmental sensitivity	Altitude above sea level // m	≤720	720 to 1100	1100 to 1500	1500 to 2250	≥2250
	Ecological protection zone and water supply conservation base	Not	–	City or county level	Provincial level	National level

(i) Sensitivity of water and soil. In the study area, the annual precipitation is 700 to 1 000 mm, the rate of change in precipitation is high, and droughts and floods occur alternately, all of which bring certain negative impact on ecological environment. Thus, we divide the sensitivity of water and soil into slight, medium and high levels. Land use pattern, especially the distribution of cultivated land, is closely related to land slope. Trough image interpretation of superimposed slope maps, we can clearly observe the reasonableness of the land coverage in the study area. According to the soil erosion modulus, we divide the soil erosion degree into five levels, and the study shows that the area of soil erosion accounts for more than 80% of the total study area.

(ii) Sensitivity of geological disasters. Due to rainfall and topographical slope, geological disasters such as landslide and debris flow occur frequently. According to occurrence rate of geological disasters, we divide the areas into four levels, and the study indicates that areas with probable and higher level of occurrence take up more than 50% of the total study area.

(iii) Ecological and environmental sensitivity. The study area has numerous animal and plant types, and the vertical difference is significant. Area below 720 m is river-nearby land; area in 720 to 1 100 m is hilly area; and 2 250 m is the boundary of birch forest and China fir forest between south slope and north slope of the Qin Mountains. According to *Regulations on Ecological and Environmental Protection of the Qin Mountains in Shaanxi Province*, Zhongshan ecological functional zone of coniferous and broad-leaved mixed forest at altitude of 1 500 to 2 600 m is restricted development area.

3.2 Index classification based sensitivity assessment We used 1, 2, 3, 4 and 5 to denote five levels of sensitivity. According to expert scoring and in combination with experience and actual local situations, the precipitation, slope, coverage and soil erosion in the sensitivity of water loss and soil erosion were separately assigned with weight of 0.2, 0.15, 0.15 and 0.5; the precipitation, slope, and occurrence rate of disasters in the sensitivity of geological disasters were assigned with weight of 0.15, 0.15 and 0.7; and the altitude above sea level and protection zone in the ecological and environmental sensitivity were assigned with weight of 0.2 and 0.8. Finally, all drawings and data were converted into grid format with 30 m resolution. Through calculation as per the following formula:

$$P = \sum_{i}^{n} (A_i \times W_i)$$

where P signifies the eco-sensitivity assessment value; A is the index contribution value; W refers to weights of factors.

Superposition results (Table 4) show that P value of sensitivity of water loss and soil erosion is in 1.2 to 4.15, and nearly 90% area is in the range of 2 to 4; P value of sensitivity of geological disasters is in 1.4 to 4.85, and 42% area reaches 4 or higher; P value of ecological and environmental sensitivity is in the range of 1 to 5. Divided by 3 after superposition of these three indexes, we got the integrated sensitivity distribution map (Fig. 1). Since the obtained P value is in the range of 1.45 to 4.17, we divided the study area into low sensitivity area (1.45 to 2), moderate sensitive area (2 to 3), and high sensitive area (3 to 4.17).

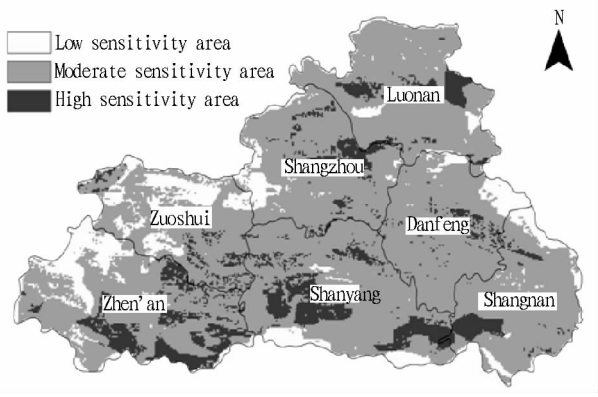

Fig. 1 Sensitivity grading of the study area

Table 4 Sensitivity grading of the study area

Type	Water and soil sensitivity	Disaster sensitivity	Ecological and environmental sensitivity	Integrated sensitivity
Min. P	1.2	1.3	1	1.45
Max. P	4.15	4.85	5	4.17
Weight	1/3	1/3	1/3	1

Through calculation of the county-wide integrated sensitivity, it is known that the moderate sensitivity area covers a larger part in the whole city, and each county exceeds 60%; Zuoshui County occupies the largest part of the low sensitivity area, about 26% of the county area; Shanyang County and Zhen'an County cover the larger part of the high sensitivity area, about 19.7% and 18.7% of the county area respectively. Shangnan and Luonan counties belong to the high sensitivity area because there is Shangnan Xinkailing Natural Protection Zone and Luonan Giant Salamander Reserve; Zhen'an and Shanyang counties belong to high water and soil sensitivity area and high geological disaster sensitivity area mainly because of landslide and debris flow; the west section of Shangzhou area belongs to high sensitivity area because the ecological and environmental sensitivity is high in Erlongshan Reservoir Protection Zone, and the east section belongs high sensitivity area of geological disasters and water loss and soil erosion.

3.3 Uncertainty based sensitivity assessment In the index classification, we graded the continuous variables. For example, the precipitation of 799 mm and 801 mm belongs to two different levels, while 801 mm and 899 mm belong to the same level, which are obviously contrary to actual utility. Therefore, based on uncertainty of continuous variables, we calculated the grey correlation of variables for continuous part in the sensitivity indexes by the grey system method[16]. With the optimal index set $C^*(k)$ of the k-th factor was taken as reference series of numbers, we assessed the correlation between $C(k)$ and the optimal set by the following formula:

$$\zeta = \frac{\min_i \min_k |C^*(k) - C(k)| + \sigma \max_i \max_k |C^*(k) - C(k)}{|C^*(k) - C(k) + \sigma \max_i \max_k |C^*(k) - C(k)}$$

where $\zeta_i(k)$ refers to the correlation between the k-th assessment factor in the i-th unit and the optimal value; $C(k)$ denotes

the unit attribute; σ is the identification coefficient (generally 0.5). This study unit is pixel in size, and reference number series is the pixel corresponding to the most sensitive part. The closer the correlation, the higher the sensitivity, and the result is in the range of [0, 1]. Other sensitive factors were also standardized to the range of [0, 1], so the sensitivity range was narrowed from [1, 5] to [0, 1].

Large yard stick ecological security grading has relatively uniform division criterion, while the city-wide ecological sensitivity calculation is comparatively flexible and focuses on internal spatial difference. Artificial scoring and assessment will generally cause many variables to be concentrated on certain interval, consequently most areas are in a certain one or two grades. This study took the objective coefficient of variation as the weight to expand difference in different pixels, so as obtain favorable discrimination. The formula is as follows:

$$w = \frac{v}{\sum_{i=1}^{n} v} = \frac{S/\bar{x}}{\sum_{i=1}^{n} (S_i/\bar{x})}$$

where *w* signifies the weight of factor, *v* stands for the coefficient of variation, and *S* is the standard deviation. And *w* is in the range of [0, 1].

To remove some extreme values, we took townships as grid units, carried out regional statistics under Arcmap, and calculated the coefficient of variation for the statistical results. The precipitation, slope, coverage and soil erosion in the sensitivity of water loss and soil erosion were separately assigned with weight of 0.21, 0.07, 0.17 and 0.55; the precipitation, slope, and occurrence rate of disasters in the sensitivity of geological disasters were assigned with weight of 0.28, 0.09 and 0.63; and the altitude above sea level and protection zone in the ecological and environmental sensitivity were assigned with weight of 0.98 and 0.02. The integrated sensitivity, obtained through dividing by 3 after superposition of these three indexes, was in the interval of 0.1 to 0.78. In accordance with the geometric grading method that distributes quantity more evenly, we took 0.2 and 0.4 as breaking points, and obtained the improved integrated sensitivity distribution map (Fig. 2). Compared with the index classification based sensitivity assessment, the uncertainty based assessment method has more scientific basis and higher credibility. Since the obtained 30 m resolution image has less discrete arc points, the sensitive areas are relatively centralized, so it is more convenient to make planning for city-wide environmental protection and ecological construction in space.

4 LUCC response of ecological sensitive areas

Since the grade of land use degree is 1 to 4, we subtracted the land use degree pixel by pixel from 2009 to 1990, and obtained 7 grades from −3 to 3 of the land use degree. Through fitting with the improved integrated sensitivity distribution map, we found that the land use degree is zero and not changed, so it is not counted, and the rest can indicate 3 levels and 6 grades, as shown in Table 5. It shows that the change of

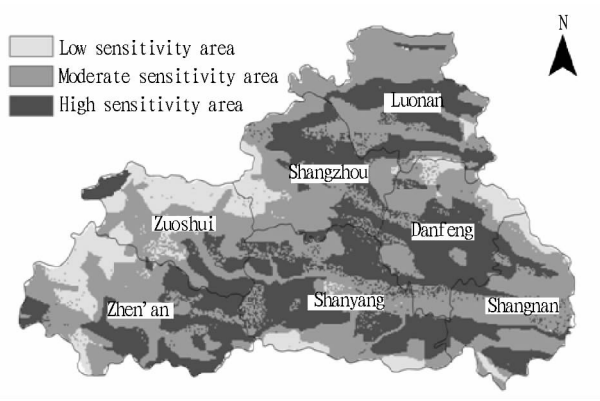

Fig. 2 Improved sensitivity grading of the study area

land use degree is mainly low level evolution and degradation; moderate evolution only takes a small portion; high level evolution and degradation are extremely small in quantity. Thus, the overall land intensity in the study area decreases, but there is significant regional difference in heave amplitude. The low level degradation refers to one-level degradation of land use degree, mainly shown in the conversion of cultivated land into forest land. The low level evolution means one-level upgrade of land use degree, including afforestation in unused land, urban enlargement through occupying cultivated land, and reclamation of grassland and water areas. Moderate evolution refers to consecutive rise of two levels during 19 years, including conversion of unused land into cultivated land, transformation of forest land, grassland, and water areas into residential area/industrial and mining land, proving that reclamation of cultivated land and mining industry development in recent years have achieved certain tangible results.

Table 5 Changes of land use degree in the sensitive areas (5%)

Changes of intensity	Low sensitive area	Moderate sensitive area	High sensitive area	Total
High degradation	0.01	0.02	0.01	0.01
Moderate degradation	0.05	0.21	0.15	0.17
Low degradation	75.69	77.38	71.46	74.73
Low evolution	19.18	13.71	16.27	15.14
Moderate evolution	5.06	8.66	12.10	9.93
High evolution	0.01	0.02	0.01	0.01

Through statistics of eco-sensitivity zoning, it can clearly reflect the spatial difference in changes of land use degree. In the high sensitive area, the low level degradation rate is the lowest and moderate upgrade rate is the highest, indicating that the slowest decline area of intensity is high sensitive area, while in the moderate and low sensitive areas, the intensity drops faster. Since the higher land intensity means more human activities, the higher land sensitivity will brings slower in reduction of human activity intensity. Besides, due to accumulation effect of intensive land use, the higher the intensity, the less economic to reduce its intensity. Therefore, it will cost more for reducing land use degree for areas with higher land intensity. This also explains the reason that low level degradation

accounts for more than 70%, while the moderate degradation takes up less than 1%. Since the sensitivity value is generally closely connected with human activities, based on the law that it will cost more for ecological restoration in areas with more intense human activities, the ecological restoration should focus on moderate and low level sensitive areas, which have less opportunity cost. However, to conduct ecological and environmental construction in low eco-sensitive areas, the ecological security effect is obviously lower than that in high eco-sensitive areas. Therefore, this method is unreasonable from the perspective of ecological security. It is true that ecological restoration effect is outstanding in the study area, but the distribution pattern of the ecological construction is still worth discussing.

5 Conclusions and discussion

The land eco-sensitivity assessment provides reference for reasonable allocation of regional land resources. Shangluo City has put forward building ecological tourism city and gradually strengthened the protection of ecology in recent years. Through LUCC relevant models and eco-sensitive zoning, we selected water, soil, disasters, ecology and environment as assessment elements, and obtained the relation between land use degree and land eco-sensitivity in the counties of the study area. (i) There is the degradation trend of land use degree in the study area. Much cultivated land transformed into forest land and garden land, and constant improvement of the ecology and environment indicate that construction of ecological city in the study area has made certain practical achievement. (ii) There is still the problem of land ecological security in the study area. Although the high sensitive area is limited, there is serious problem of water loss and soil erosion, geological disasters, and high pressure of ecological protection. (iii) The grey model is applied to reduce the uncertainty of assessment factors and the coefficient of variation is taken as weight to expand the internal difference, to improve the grade of eco-sensitivity and increase the discrimination of sensitivity assessment. (iv) The ecological restoration of the study area focuses on moderate and low level sensitive areas because high sensitive area costs much more.

At present, there is still no universal assessment index system for eco-sensitivity assessment in the country, province, city, county or township, so it is necessary to select reasonable assessment indexes in accordance with actual conditions of the study area. Through study, we found that annual changes are not great in precipitation, slope, geological disasters and soil structure in the study area, thus changing the land coverage vegetation type and reducing the land use degree are the most effective approaches to improving the ecological security in a certain time in future. However, the ecological utility brought about by reducing the land use degree is different in different regions. With widespread ecological and environmental construction the whole country, it becomes harder to reflect actual utility of ecological construction in water and soil conservation, water supply conservation, and windbreak and sand-fixation merely taking tree planting and afforestation area as the criteria for judging the achievements. Healthy ecological development model should be concentration on protection in low sensitive areas and construction in high sensitive areas, to further improve regional ecological security and improve the living environment. For those areas where the ecological security is difficult to be improved, ecological migration will be a practical and effective policy and measure.

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