Assessment of Service Value of Ecosystem in Karst Ecological Control Areas

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Abstract To investigate the characteristics of service value of the karst rocky desertification ecosystem, we take water conservation, soil conservation, carbon-fixation and oxygen-production, production of organic matter, and purification of atmospheric environment as function indicators, to conduct quantitative assessment and analysis of service function value of ecosystem in Bijie Yachi, Qingzhen Hongfenghu and Guanling-Zhenfeng Huajiang demonstration areas in Guizhou Province, using remote sensing and field monitoring data in 2006. The results show that the rate of contribution of water conservation, soil conservation, carbon-fixation and oxygen-production functions to regional service value is high (37.05%, 36.68% and 23.15%, respectively); the rate of contribution of production of organic matter and purification of atmospheric environment functions to regional service value is low (2.80% and 0.32%, respectively). The ranking of landscape in terms of service value per unit area is as follows: forestland (23.353 9 million yuan) > shrub land (10.630 1 million yuan) > grassland (5.036 7 million yuan) > dry land (3.381 2 million yuan) > farmland (2.508 8 million yuan). The ranking of demonstration areas in terms of service value per unit area is as follows: Yachi Demonstration Area (12.44 million yuan) > Hongfenghu Demonstration Area (5.91 million yuan) > Huajiang Demonstration Area (4.4 million yuan). It is negatively correlated with rocky desertification incidence within the region. The results also indicate that in the process of restoring and reconstructing the ecological environment in rocky desertification areas, increasing the area of forest vegetation, promoting the conversion of dry land and farmland into forestland, shrub land and grassland, will contribute to enhancement in ecological service value.

Key words Service functions, Value, Rocky desertification ecosystem, Ecological restoration, Rocky desertification incidence

The karst rocky desertification ecosystem, one of the fragile subsystems in terrestrial ecosystems, is a unified whole arising from continuous circulation of materials and energy flow between the karst rocky desertification biocoenosis and the karst rocky desertification environment. The service functions of rocky desertification ecosystem refer to the environmental conditions and utility that mankind depend on for survival and development, forming in the rocky desertification the ecological environment; the value typifies the ability of ecosystem to provide direct or indirect products and services for human. Rocky desertification is a special type of desert in the world, whose essence is the reduction or loss of ecosystem function[1]. Through vigorously carrying out comprehensive rocky desertification harness projects by the state, it has conspicuously improved the ecological environment in the rocky desertification areas. The value of service functions of ecosystem is a monetary manifestation of eco-efficiency, which can directly reflect the effect of comprehensive control of rocky desertification. At present, some research institutions and scholars have conducted researches of the assessment of service function value of ecosystem in rocky desertification areas[2-4], the temporal and spatial variation of service function value of ecosystem[4]; the relationship between the ecological service value and environmental factors[5-6]; the response of the ecological service value to land use[7-10]. However, there are few studies on the relationship between the ecological service function value of rocky desertification and the incidence of rocky desertification.

This article selects three typical integrated rocky desertification control demonstration areas as examples, and conducts integrated analysis of the data concerning various types of landscape in the period preceding the implementation of rocky desertification project in 2006, using the methods of remote sensing and ground monitoring to obtain the basic data. And this article assesses the ecological service function value preceding the implementation of integrated rocky desertification control project, and makes preliminary analysis of the relationship between service function value of ecosystem and incidence of rocky desertification.

1 Overview of the study area

Due to differences in development characteristics of Guizhou karst and the ecological environment, this article selects three integrated rocky desertification control demonstration areas as the study areas (Warm and cool karst plateau and mountain ecological environment, dry in spring and wet in summer – Yachi Demonstration Area; mild karst hill and basin ecological environment, semi-dry in spring and wet in summer – Hongfenghu Demonstration Area; dry hot karst plateau and valley ecological environment – Guanling – Zhenfeng Huajiang Demonstration Area), which are typical in terms of karst development and ecological environment structure (Fig. 1).

Due to difference in topography, climate, hydrology and other environmental factors in demonstration areas, there are

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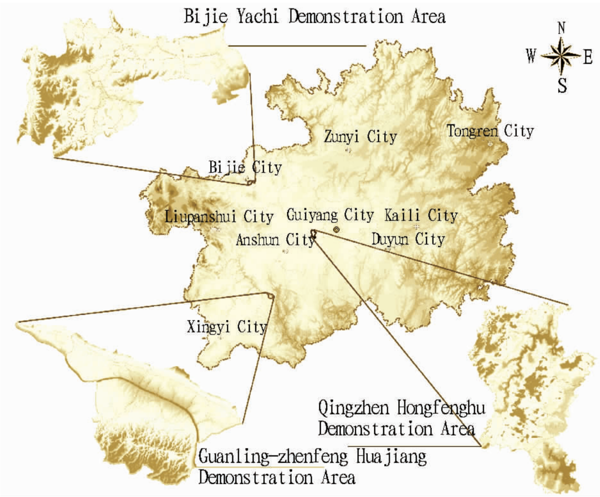

Fig.1 Location map of the study area

some differences in the ecological environment.

The total area of Yachi Demonstration Area is 41.52 km^2, and the rocky desertification area accounts for 24.64% of the total area (gentle and potential rocky desertification); the terrain within the region is uneven, with elevation of 1 400 – 1 700 m; the climate is cool and moist, with the average annual temperature of 14.03 ° C, and average annual rainfall of 863mm; the vegetation is mostly subtropical evergreen broadleaf forest, and the secondary forest is destructed seriously, with high rate of land reclamation, and great soil erosion.

The total area of Hongfenghu Demonstration Area is 60.44 km^2, and the rocky desertification area accounts for 25.12 % of the total area (gentle and moderate rocky desertification); the proportion of depression area in the region is large, with elevation of 1 240 – 1 450 m; the climate is moderate and the rainfall is abundant, with the average annual temperature of 14℃, and average annual rainfall of 1 200 mm; the vegetation is damaged badly, with high rate of land reclamation, and great soil erosion.

The total area of Huajiang Demonstration Area is 51.62 km^2, and the rocky desertification area accounts for 54.71 % of the total area (moderate and intense rocky desertification); the earth's surface in the region is much more fractured, and the terrain within the region is undulating, with elevation of 500 – 1 200 m and relative height difference of 700 m; the climate is hot and dry, with the average annual temperature of 18.4℃, and average annual rainfall of 1 100 mm; the vegetation is damaged seriously and the soil is eroded greatly, basically in a state of no forest being destroyed, and no soil being eroded, resulting in extremely fragile ecological environment.

2 Data and methods

2.1 Data source and processing

2.1.1 Data source. The area of various types of landscape, rocky desertification data and field monitoring data involved in this article, are mainly from SPOT remote sensing image interpretation in 2006 and the ecological monitoring in August 2006 by Guizhou Normal University.

2.1.2 Data processing. First, as for the processing of remote sensing data, on the basis of SPOT remote sensing image in 2006, by virtue of ARCGIS, ArcView 3.3 and other kinds of human-computer interactive interpretation and data processing software, supplemented with 1:50 000 administrative region map, 1:10 000 topographic map, land use map, soil map, geological map, slope map, GPS observation database and other related data, we conduct remote sensing image interpretation under ERDAS 8.6 software, using remote sensing application analysis principles and methods[11]. According to the earth's surface mulch characteristics and spectral characteristics in the rocky desertification areas, the types of landscape in the study area are divided into forestland, shrub land, grassland, farmland and dry land. After the statistical analysis, the area of all types of landscape and the area of rocky desertification are obtained. The incidence of rocky desertification is equal to the area of rocky desertification divided by the total area of land in the study area.

Second, on the basis of remote sensing monitoring data concerning different types of rocky desertification landscape, 25 field monitoring sample plots are established under all types of landscape in three typical integrated rocky desertification control demonstration areas. The monitoring content includes vegetation cover, plant biomass, soil erosion, soil depth, soil type, soil porosity and so on. We conduct soil sampling, bringing the soil samples back to the laboratory for physical and chemical soil experiments, to obtain N, P, K content in the soil.

2.2 The assessment methods

2.2.1 Evaluation indicators. On the basis of the status quo of the rocky desertification environment and data acquisition, we make statistical analysis of various kinds of evaluation indicators in the literatures[3-10,12-16], doctoral thesis[2], and the related data concerning the service functions of ecosystem in the current karst areas, and select those well-directed indicators with high frequency of use, to form 5 evaluation indicators (water conservation, soil conservation, carbon-fixation and oxygen-production, production of organic matter, and purification of atmospheric environment), and 8 second-level indicators (water conservation, topsoil conservation, fertility maintenance, CO_2 absorption, oxygen production, production of organic matter, SO_2 absorption and capability of detaining dust).

2.2.2 Value assessment

2.2.2.1 Single service function of ecosystem.

(i) Value of water conservation.

Using Li Jinchang's assessment method[17], we estimate the water conservation amount of ecosystem (Qw). Then according to the water conservancy unit price of implementing the integrated rocky desertification control project in the study area (the construction of 1 m^3 reservoir will cost 140 yuan, and the use term of the pool is 10 years), we calculate the water conservation value at 140 $Qw/10$ (yuan/km^2 · a), using substitutional engineering method.

(ii) Value of soil conservation.

a. Value of topsoil conservation. Using Li Jinchang's assessment method[17], we estimate the soil conservation amount of ecosystem (Qs). Then taking the average thickness of China's cultivated soil (0.5m) as the soil thickness for planting crops[18], we estimate the area of arable land maintained by the soil (S), using the opportunity cost method. Taking the gain of the major local cash crops in local areas as the unit price (the average of gain of crops per unit area in three demonstration areas: 0.5 yuan/m^2), we get the value of topsoil conservation at 0.5S(yuan/km^2 · a).

b. Value of fertility maintenance. According to N, P, K content in the soil, and the proportion of nitrogen, phosphorus, potassium being converted into fertilizer (79/14, 506/162 and 174/78, respectively)[16], we estimate the ammonium bicarbonate (QN), superphosphate (QP), and potassium sulfate amount (Q_K). In the light of the average selling price of the local three fertilizers (286 yuan/t, 365 yuan/t and 365 yuan/t, respectively), we get the value of fertility maintenance at 286 Q_N +365 Q_P +365 Q_K(yuan/km^2 · a), using the market price method[18]. The value of soil conservation is the sum of value of topsoil conservation and value of fertility maintenance.

(iii) Value of carbon-fixation and oxygen-production.

According to the photosynthesis reaction equation, the formation of 1 g dry matter, needs to absorb 1.62 g CO_2 and release 1.2g O_2; according to the net primary productivity of plant NPP, we estimate CO_2(Q_C) absorbed and O_2(Q_O) produced. Using the shadow price method[8] (The price of CO_2: 1 200 yuan/t; the price of O_2: 1 000 yuan/t)[19], we get the value of carbon-fixation and oxygen-production at 1200 Q_C + 1000 Q_O(yuan/km^2 · a).

(iv) Value of organic matter production.

Using alternative energy method[18], the net primary productivity of plant NPP is yield capacity of organic matter of vegetation. According to Li Jinchang's assessment method[17], one gram dry weight of land plants is equivalent to about 6.7kJ of energy. We convert this value into the heat of standard coal (The converted heat of standard coal is 10 kJ/g), and estimate the equivalent standard coal quality of production of organic matter (QY) (The price of standard coal: 354 yuan/t)[4], we get the value of production of organic matter at 354 QY(yuan/km^2 · a).

(v) Value of atmospheric environment purification.

In the three demonstration areas, the forest vegetation is mostly evergreen broad-leaved forest. In accordance with *Studies Report of China's Basic Condition of Biodiversity*[20], the absorption capacity value of broad-leaved forest to SO_2 is 8.865t/km^2; the capability of detaining dust is 1 011 t/km^2. We conduct calculation (The control costs of SO_2 is 1200 yuan/t; the cost of cleaning up the dust is 150 yuan/t)[19], to get the value of atmospheric environment purification at 1200 ×8.865 +150 × 1011 (yuan/km^2 · a).

2.2.2.2 Service function of landscape ecosystem. The service function value of landscape ecosystem refers to the sum of function value of all single-item services, and the calculation formula is as follows:

$$V_l = \sum_{i=1}^{5} V_i \times S_l \quad (1)$$

where V_l is the function value of item i ecosystem service in landscape per unit area (yuan/km^2 · a); S_l is the area of landscape (km^2).

2.2.2.3 Service function of regional ecology. The function value of regional ecosystem service is the sum of function value of all landscape ecosystem services, and the calculation formula is as follows:

$$V = \sum_{i=1}^{5}\sum_{j=1}^{5} V_{ij} \times S_j \quad (2)$$

where V_{ij} is the function value of ecological service i in landscape type j per unit area (yuan/km^2 · a); S_j is the area of landscape type j (km^2).

3 Results and analysis

3.1 Function value of single service Through analysis of the function value of all single services in the study area, we can find that the value of three service functions (carbon-fixation and oxygen-production, soil conservation, and water conservation) is high. In 2006, the value of the three service functions in the study area was 3.71×10^8 yuan (accounting for 37.05% of the total value), 3.67×10^8 yuan (accounting for 36.68% of the total value), 2.32×10^8 yuan (accounting for 23.15% of the total value), respectively; the production value of organic matter is low, accounting for 2.80%; the function of purification of atmospheric environment shows the worst performance, accounting for less than 1% (Fig.2).

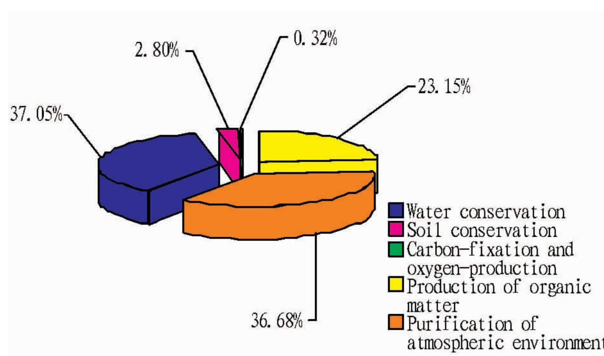

Fig.2 The composition of regional service function value in the study area in 2006

The performance of each single service function in each demonstration area is also the same. In 2006, the value of three functions (carbon-fixation and oxygen-production, soil conservation, and water conservation) and the rate of contribution of them to the total regional value, in Yachi Demonstration Area, Hongfenghu Demonstration Area and Huajiang Demonstration Area, were 1.06×10^8 yuan (22.05%), 2.78×10^8 yuan(57.90%), and 8.74×10^7 yuan (18.21%); 1.37×10^8 yuan(43.11%), 8.26×10^7 yuan (26.03%), and 8.60×10^7 yuan(27.10%); 1.28×10^8 yuan(62.99%), 6.58×10^6 yuan (3.23%) and 5.84×10^7 yuan(28.66%). The contribution rate of production of organic matter in three demonstration areas was 1.66%, 3.25% and 4.75%, respectively; the contribution rate of function value of purification of atmospheric environment in three demonstration areas was less than 1% (0.17%, 0.52% and 0.37%, respectively) (Table 1). It indicates that in comparison with the functions of production of organic matter and purification of atmospheric environment, the functions of carbon-fixation and oxygen-production, soil conservation, and water conservation of the rocky desertification ecosystem are brought into play well.

Table 1 The single service function value in three Demonstration Areas in 2006 104 yuan/year

The study area	Landscape type	Water conservation	Soil conservation	Carbon-fixation and oxygen-production	Production of organic matter	Purification of atmospheric environment	Total service value
Bijie Yachi	Forestland	4.67×10^3	1.61×10^4	1.40×10^3	1.05×10^2	8.3×10	2.24×10^4
Demonstration	Shrub land	3.77×10^3	1.08×10^4	2.32×10^3	1.75×10^2	–	1.70×10^4
Area	Grassland	3.01×10^2	9.32×10^2	1.22×10^2	9	–	1.36×10^3
	Dry land	–	–	6.28×10^3	4.74×10^2	–	6.76×10^3
	Farmland	–	–	4.67×10^2	3.5×10	–	5.02×10^2
	Total	8.74×10^3	2.78×10^4	1.06×10^4	7.99×10^2	8.3×10	4.80×10^4
Qingzhen Hongfenghu	Forestland	2.42×10^3	1.00×10^3	8.75×10^2	6.6×10	1.64×10^2	4.54×10^3
	Shrub land	4.80×10^3	6.03×10^3	2.73×10^3	2.06×10^2	–	1.38×10^4
Demonstration	Grassland	1.37×10^3	1.22×10^3	8.82×10^2	6.7×10	–	3.55×10^3
Area	Dry land	–	–	6.27×10^3	4.73×10^2	–	6.74×10^3
	Farmland	–	–	2.92×10^3	2.2×10^2	–	3.14×10^3
	Total	8.60×10^3	8.26×10^3	1.37×10^4	1.03×10^3	1.64×10^2	3.17×10^4
Guanling – Zhenfeng	Forestland	1.62×10^3	2.41×10^2	1.25×10^3	9.4×10	7.4×10	3.27×10^3
Huajiang	Shrub land	2.86×10^3	2.75×10^2	4.39×10^3	3.31×10^2	–	7.85×10^3
Demonstration	Grassland	1.36×10^3	1.42×10^2	9.63×10^2	7.3×10	–	2.53×10^3
Area	Dry land	–	–	5.95×10^3	4.49×10^2	–	6.40×10^3
	Farmland	–	–	2.82×10^2	2.1×10	–	3.04×10^2
	Total	5.84×10^3	6.58×10^2	1.28×10^4	9.68×10^2	7.4×10	2.04×10^4

3.2 The service function value of landscape ecosystem

Differences in ecological service function value per unit area can directly reflect the differences in ecosystem functional state of landscape. The service function value of various types of landscape per unit area in the study area in 2006 (Fig. 3) shows that the service value of forestland and shrub land per unit area is far greater than that of other types of landscape; the ranking of landscape in terms of service value per unit area in 2006 is as follows: forestland (23.353 9 million yuan) > shrub land (10.630 1 million yuan) > grassland (5.036 7 million yuan) > dry land (3.381 2 million yuan) > farmland (2.508 8 million yuan).

Compared with the artificial ecosystem (dry land and farmland), the service value, of natural ecosystem within the region (forestland, shrub land and grassland) per unit area, is large. The service value of natural ecosystem is 11.906 million yuan; the service value of the artificial ecosystem is 3.197 3 million yuan. The latter is about 4 times that the former. Obviously, the functional state of the natural ecosystem is better than that of the artificial ecosystem.

The total service value of the landscape ecosystem is not only related to the ecological condition of ecosystem itself, but also related to its distribution area (Table 2). Taking forestland and shrub land as examples, the service value of the two types of landscape per unit area is 23.353 9 million yuan and 10.630 1 million yuan, and the former is about two times that the latter, but since the distribution area of shrub land is about three times that of forestland, the total service value of shrub land (386.4 million yuan) is far larger than the total service value of forestland (301.73 million yuan). So it is with the dry land and grassland.

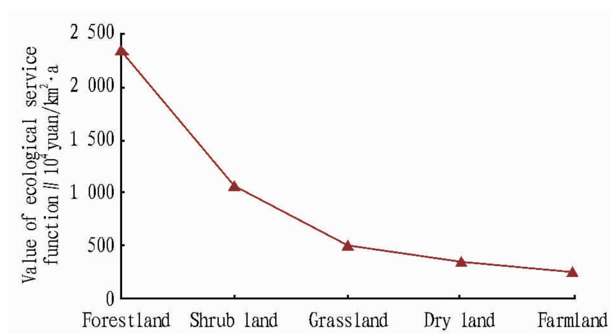

Fig. 3 The service function value of various types of landscape per unit area in the study area in 2006

Table 2 The service function value of landscape ecosystem in the study area in 2006

Landscape type	Area km^2	Service value 10^4 yuan	Service value per unit area 10^4 yuan
Forestland	12.92	30 173	2335.39
Shrub land	36.35	38 640	1063.01
Grassland	14.78	7 444	503.67
Dry land	58.84	19 895	338.12
Farmland	15.72	3 944	250.88
Total	138.61	100 097	722.15

Based on the above analysis, the status of ecological function of forestland and shrub land is the best, which are the major types of landscape making contribution to the regional ecological service value, with contribution rate of 30% and 39%, respectively; the status of ecological function of grassland takes second place, with total service value of 74.44 million yuan, but due to small distribution area, the contribution rate is only 7%; the dry land has the biggest distribution area, with the ecological function value of 198.95 million yuan and contribution rate of 20%; the status of ecological function of farmland is the worst, with the lowest contribution rate (4 %).

3.3 Spatial differences of regional service value The service functions of ecosystem have characteristics of response to the environmental heterogeneity factors. Impacted by different types of topography, climate and other environmental factors, there are conspicuous differences in the status of ecological function in the same type of landscape, finding expression in differences in the size of service value per unit area, which is particularly prominent in forestland, shrub land, grassland and other types of natural landscape.

In 2006, the ranking of demonstration areas in terms of service value of forestland per unit area was as follows: Yachi Demonstration Area (43.59 million yuan) > Hongfenghu Demonstration Area (14.13 million yuan) > Huajiang Demonstration Area (7.15 million yuan). This relationship is reflected in both shrub land and grassland, and the ranking is as follows: Yachi Demonstration Area (16.17 million yuan, 14.2 million yuan) > Hongfenghu Demonstration Area (11.09 million yuan, 6.32 million yuan) > Huajiang Demonstration Area (5.86 million yuan, 3.09 million yuan).

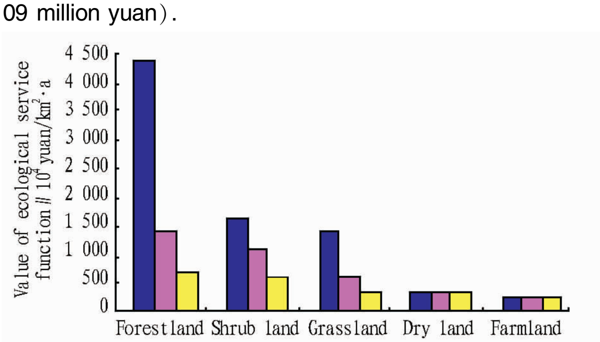

Fig.4 The ecological service value of various types of landscape per unit area in Demonstration Areas Unit: 104 yuan/km^2 · a

Rocky desertification is characteristic phenomenon of land degradation in karst areas, the essence of which is the degradation of ecosystem functions. The incidence and occurrence intensity of rocky desertification have a great impact on regional ecological service value. In three demonstration areas, the incidence of rocky desertification in Yachi Demonstration Area is the lowest (24.64%), and the occurrence intensity is the lowest (Incidence of moderate or intense rocky desertification is 5.48%), but the ecological service value per unit area is the highest (12.44 million yuan). The incidence of rocky desertification in Hongfenghu Demonstration Area takes second place (25.12%), the occurrence intensity also takes second place, and the ecological service value per unit area is 5.91 million yuan. The incidence of rocky desertification in Huajiang Demonstration Area is the highest (54.71%), the occurrence intensity is the severest (Incidence of moderate or intense rocky desertification is 25.28%), and the ecological service value per unit area is the lowest (only 4.4 million yuan). Thus it can be inferred that the lower the incidence of rocky desertification, the lower the intensity, the greater the service value per unit area; the higher the incidence of rocky desertification, the higher the intensity, the smaller the service value per unit area. Therefore, the service value of ecosystem is also closely related to the incidence of rocky desertification in the study area.

4 Conclusions and discussions

4.1 Conclusions First, the karst habitats have the characteristics of discontinuous soil mantle, shallow soil, poor water storage capacity of soil and dry surface, which are unfavorable for the growth of forest trees[21]. In these regions, the vegetation grows slowly, and the functional value of production of organic matter is low. The rocky desertification regions are long affected by human activities. The native vegetation has been damaged and the secondary vegetation is predominant; the distribution area of forestland is small and the crown density is low; this ecosystem has poor ability to absorb harmful substances such as SO_2, that is, the function of purification of atmospheric environment is brought into play poorly.

Second, compared with the artificial ecosystem, the state of ecological function of natural ecosystem in rocky desertification areas is better, and the service value per unit area of the latter is greater than that of the former. Within the natural ecosystem, the service value of forestland is the highest. It is not only related to the distribution area of the two, but also closely related to the basic condition of natural environment. Through long-term ecological process, the natural ecosystem has formed the stable system which can well adapt to local natural conditions and changes, with rich species, complex internal structure, powerful productivity, many types of service function and high service value; the artificial ecosystem is greatly disturbed by human activities, with single species, simple structure, many crops having poor ability to conserve soil and water, and low service value.

Third, topography, soil, vegetation, climate, hydrology and other environmental factors have great impact on the value of ecological services. There are great differences in service value of the environmental types under the impact of different environmental factors. The ecological environment in warm and cool karst plateau, mountain, hill and basin, is conducive to the growth of vegetation, in which the soil and water conservation function of vegetation is strong and the service value per unit area is big. As to the ecological environment in dry hot karst plateau and valley, the surface is extremely uneven, the terrain is undulating and the soil is shallow; the vegetation growth is slow, the soil erosion is serious and the service value per unit area is low. Therefore, there is difference in the functional state of the same landscape in different types of ecological environment, namely, the size of service value per unit area is different, which is particularly evident in three types of landscape (forestland, shrub land and grassland).

Fourth, the size of ecological service value in karst areas is related to the distribution of rocky desertification, affected by incidence and intensity of rocky desertification. In the regions with high incidence and serious intensity of rocky desertification, the soil erosion is serious, making it difficult to give play to the service functions of ecosystem, with low ecological service value, for example, in Huajiang Demonstration Area, the incidence of rocky desertification is 54.71%, with low service value, and the service value per unit area is only 4.4 million yuan; on the contrary, in the regions with low incidence and intensity of rocky desertification, the coverage rate of vegetation is high, the ecological function is brought into play well, with high service value, for example, in Yachi Demonstration Area, the service value per unit area is 12.44 million yuan.

4.2 Discussions Due to the limitations of information and data, the indicator system of ecological service function value established is not perfect, only estimating the value of 5 service functions (water conservation, soil conservation, carbon-fixation and oxygen-production, production of organic matter, purification of atmospheric environment). The value of biological diversity and other functions have not yet been calculated. The evaluation results can reflect the tremendous service value the ecosystem provides to human, inspire people to protect the ecological environment with enthusiasm, but the actual value is much larger than this value.

The price standard used is solely based on the market prices and shadow prices of local goods; the derived value is just the value under conditions of the local price, and if we want to conduct comparative study of the derived value and the service value of ecosystem in other regions, we need to unify the price. For example, the shadow price of water conservation is based on the price of water conservancy project in rocky desertification areas, taking 140 yuan/m^3 (use term: 10 years).

The service value of rocky desertification ecosystem is closely related to the incidence of rocky desertification. There are multifarious kinds of ecological environment in China's southern karst areas with the Guizhou Plateau as center; the incidence and intensity of rocky desertification also vary. Under different basic conditions of natural environment, coupled with varying degrees of impact of human activities, there are differences in the spatial distribution of rocky desertification, including disparity in incidence and level of rocky desertification. The correlation between service value of ecosystem and all levels of rocky desertification, the difference in ecological service value in the same level of rocky desertification, and other problems, are yet to be further studied.

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