A Model based on Ecological Service Evaluation

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Abstract

In order to protect the ecological environment on which we depend, we must balance ecological and economic benefits in the process of land development and utilization. Firstly, we establish an ESV assessment model based on the unit area value equivalent factor, which is evaluated through nine aspects: climate regulation, gas regulation, water conservation, soil formation and conservation, waste treatment, biodiversity conservation, food production, raw materials, and entertainment culture, and then we use AHP to determine the weight of each factor. Finally, we take China as an example to evaluate China's ecosystem through the ecosystem service assessment model.

Keywords

Ecological Service; Land Development; ESV.

1. Introduction

The biosphere provides many natural processes to maintain a healthy and sustainable environment for human life, which are known as ecosystem services. During the process of human development, people continue to developing and utilizing natural resources, and once ignored the bad efforts of these practices on the biosphere. At present, the land use situation in the world is shown in Figure 1.

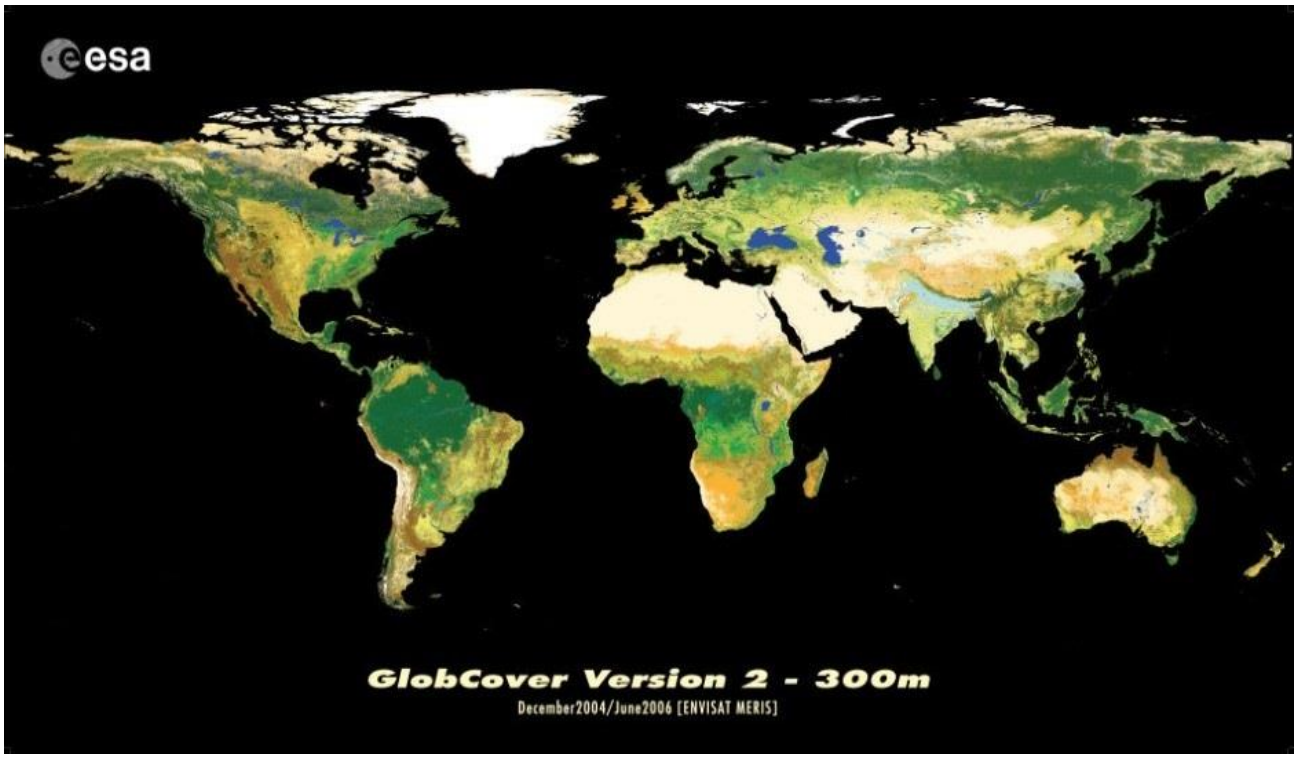

Figure 1. World land use map

In order to protect the ecological environment on which we depend, we must balance ecological and economic benefits in the process of land development and utilization. It requires us to consider the environmental cost in addition to the economic cost when considering the cost budget of the project.

So we will create an ecological service valuation model based on unit area value equivalent factor. We use the nine types of ecological service functions of climate regulation, gas regulation, water conservation, soil formation and protection, waste disposal, biodiversity conservation, food production, raw materials and entertainment culture as the indicator for assessing the ecological service value of ecosystems. Then we determine the weight of each indicator by using the analytic hierarchy process to obtain the model which is based on Costanza model to evaluate ecological service value.

Next, we take China as an example, we use the ecological service valuation model to evaluate the ecological service value of China's ecosystems and verify the effectiveness of the assessment model.

2. Ecological Service Valuation Model Based on the AHP

2.1 Ecological services valuation model is based on unit area value equivalent factor.

The value of ecological services is the value of the living-support products and services that humans obtain through the structure, process and functions of ecosystems. It is not only the most important indicator of ecological safety assessment, but also of great significance for our lives.

Ecological services valuation (ESV) has two methods to evaluate. The first one is the functional value evaluation method, and the second one is the equivalent factor evaluation method. Since the evaluation method based on functional value that is difficult to unify the standards and parameters, so we adopt the equivalent factor evaluation method which based on the Costanza model and the analytic hierarchy process (AHP).

Based on the unit area value equivalent factor method is on the basis of different kinds of ecological service functions. And then the equivalent factors of each service function of different types of ecosystems is evaluated by quantifiable criteria. After that we can combine with the distribution area of ecosystems to evaluate ESV.

2.2 Determine the equivalent factor.

At first, we refer to Xie Gaodi's functional classification on Costanza ecological services which are divided into nine aspects about them. They are climate regulation, gas regulation, water conservation, soil formation and protection, waste treatment, biodiversity conservation, food production, raw materials and entertainment culture.

The equivalent factor is determined by setting the economic value of the food production of the land with an average yield of 1 hm^2 to 1 standard equivalent. Then the other types of ecological service functions calculate the equivalent factors based on the ratio of their service functions value to the equivalent economic value.

2.3 Determine the equivalent value of each function

We suppose a functional service of an ecosystem consists of n elements, so the equivalent value of this service function according to the standard farmland food production equivalent value is:

$$\mathrm{N}_a = \sum_{i=1}^{n} R_i t_i. \quad (1)$$

According to formula (1), we can calculate the equivalent factor for each ecological service function by combining the economic value of each equivalent in different regions. Thus, the equivalent value of other service functions of the six types of ecosystems in each region is:

$$N_{ij} = n_{ij} N_a (i = 1, 2, \dots, 9;\ j = 1,2, \dots ,6), \quad (2)$$

$$N_{ij} = n_{ij} \sum_{i=1}^{n} R_i t_i \ (i = 1, 2, \dots, 9;\ j = 1,2, \dots) \quad (3)$$

3. Determine the weight of ecosystem services

3.1 Determine the weight based on the analytic hierarchy process (AHP)

1. Determine the weight of each indicator

We can get the target layer - the criterion layer and the index inter-layer discriminant matrix, as shown in Table 1.

Table 1. Ecosystem service value evaluation indicator system table

Target layer	Criteria layer (level one indicator)	Factor layer (level two indicator)
The value of ecological services A	Supply service B_1	Food production C_{11}
		Raw materials C_{12}
	Adjustment service B_2	Water conservation C_{21}
		Gas regulation C_{22}
		Climate regulation C_{23}
		Waste disposal C_{24}
	Supporting service B_3	Soil formation and protection C_{31}
		Biodiversity conservation C_{32}
	Cultural service B_4	Entertainment culture C_{41}

According to the analytic hierarchy process (AHP), we synthesize each level of indicators at first, and then get evaluating indicator weight vector for each level which are:

$$w^* = (0.14731, 0.49481, 0.29079, 0.06709),$$
$$w_1^* = (0.2, 0.8),$$
$$w_2^* = (0.27408, 0.10446, 0.14979, 0.47167),$$
$$w_3^* = (0.33333,\ 0.66667),$$
$$w_4^* = (1).$$

After calculating that we can get the consistency test index CI are 0.0059182, 0, 0.032273, 0, 0. And the consistency ratio of evaluation matrix A, B_2 are: 0.0065758, 0.035859. All of them are less than 0.1, this result comply with the corresponding consistency test standards.Finally, we get the weight distribution table of each indicator as shown in Table 2.

Table 2. Indicators weight distribution table

Level one indicator	w^*	level two indicator	w_i^*	w_i
B_1	0.14731	C_{11}	0.2	0.02946
		C_{12}	0.8	0.11785
B_2	0.49481	C_{21}	0.27408	0.13562
		C_{22}	0.10446	0.05169
		C_{23}	0.149779	0.07412
		C_{24}	0.47167	0.23338
B_3	0.29079	C_{31}	0.33333	0.09693
		C_{32}	0.66667	0.19386
B_4	0.06789	C_{41}	1	0.06709

3.2 Ecological services valuation model based on Costanza model

We can get the final formula to evaluate the value of the ecological services is:

$$N_j = S_j \sum_{i=1}^{9} w_i\, n_{ij}\ (j = 1,2,\dots,6) \quad (4)$$

$$N = \sum_{j=1}^{6} N_j\ \ (j = 1,2,\dots,6), \quad (5)$$

$$N = \sum_{j=1}^{6}\ \left(S_j \sum_{i=1}^{9} w_i\, n_{ij}\right). \quad (6)$$

We take China as an example to verify the effectiveness of the ecological services valuation model based on the Costanza model and the analytic hierarchy process (AHP) by evaluating the value of China's ecological services.

3.3 China land overview

China is located in the southeastern part of the Asian continent. It faces the Pacific Ocean to the east and the Asian continent to the northwest. From the latitude and longitude, China is located between 3°51' north latitude and 53°34' north latitude, 73° east longitude 135°05' east longitude, and the Tropic of Cancer crosses southern China. The total land area of China is about $9.6 \times 10^8\ hm^2$. It's terrain is

generally low in the west and high in the east. According to rough estimates, the area of mountains, plateaus and hills accounts for 69% of the total land area, and flat land accounts for about 31%.

We obtain the forest area is $1.25 \times 10^8 \mathrm{hm}^2$, the grassland area is $3.93 \times 10^8 \mathrm{hm}^2$, the wasteland area is $1.93 \times 10^8 \mathrm{hm}^2$, the water area is $3.0 \times 10^8 \mathrm{hm}^2$ and the wetland area is $0.536 \times 10^8 \mathrm{hm}^2$ of China by querying the data.

3.4 China's ecosystem services evaluation

We can refer to the above process to get China's terrestrial ecosystem per unit area ecological services value equivalent table (as shown in Table 3. The calculation data we obtained comes from the statistics of 《China Statistical Yearbook 2018》 [5] 《National Agricultural Product Cost-Return Data 2018》 and《China Forestry Statistical Yearbook 2018》.

Table 3. China's terrestrial ecosystem per unit area, Ecological services value equivalent table (unit:10^4 yuan /hm^2)

	Forest ecosystem	Grassland ecosystem	Farmland ecosystem	Wetland ecosystem	Watershed ecosystem	Wilderness ecosystem
Gas regulation	3.5	0.8	0.5	1.8	0	0
Climate regulation	2.7	0.9	0.89	17.1	0.46	0
Water conservation	3.2	0.8	0.6	15.5	20.38	0.03
Soil formation and protection	3.9	1.95	1.46	1.71	0.01	0.02
Waste disposal	1.31	1.31	1.64	18.18	18.18	0.01
Biodiversity conservation	3.26	1.09	0.71	2.5	2.49	0.34
Food production	0.1	0.3	1	0.3	0.1	0.01
Raw materials	2.6	0.05	0.1	0.07	0.01	0
Entertainment culture.	1.28	0.04	0.01	5.55	4.34	0.01
Total	21.85	7.24	6.91	62.71	45.97	0.42

We assume that China's farmland ecosystem has three crops, namely rice, corn and wheat. Then we can calculate the ecological service value (N_1) of the food production service function equivalent:

$$\mathrm{N}_1 = R_1 t_1 + R_2 t_2 + R_3 t_3,$$

Using this formula, we can calculate the equivalent value of food production service in China's farmland ecosystem is 3.76×10^7 yuan.

Let us combine the weight of various ecological services derived from the analytic hierarchy process (AHP). After that we can get China's terrestrial ecosystem per unit area ecological services value equivalent table equivalence equivalent table (as shown in Table 4).

Table 4. China's terrestrial ecosystem per unit area ecological services value equivalent table equivalence equivalent table

Indicator	$\mathrm{w_i}$	Forest ecosystem	Grassland ecosystem	Farmland ecosystem	Wetland ecosystem	Watershed ecosystem	Wilderness ecosystem
Food production C_{11}	0.02946	0.1	0.3	1	0.3	0.1	0.01
Raw materials C_{12}	0.11785	2.6	1.5	0.1	0.7	0.01	0
Water conservation C_{21}	0.13562	3.2	0.8	0.6	15.5	20.38	0.03
Gas regulation C_{22}	0.05169	3.5	0.8	0.5	1.8	0	0
Climate regulation C_{23}	0.07412	2.7	0.9	0.89	17.1	0.46	0
Waste disposal C_{24}	0.23338	1.31	1.31	1.64	18.18	18.18	0.01
Soil formation and protection C_{31}	0.09693	3.9	1.95	1.46	1.71	0.01	0.02
Biodiversity conservation C_{32}	0.19386	3.26	1.09	0.71	2.5	2.49	0.34
Entertainment culture C_{41}	0.06709	1.28	0.04	0.01	5.55	4.34	0.01
Total	1	21.85	7.24	6.91	62.71	45.97	0.42

It is known that the area of China's forest ecosystem is $1.25 \times 10^8 hm^2$. So we can use formula (1) (2) (3) to calculate the equivalent value of forest ecological services (N_1) is: $N_1 = S_1 \sum_{i=1}^{9} w_i n_{i1}$. And then we substitute the values in the Table 10, we will get the equivalent value of forest ecological services is 3.16×10^{12} yuan.

Therefore, we can finally calculate the ecological services value of six different types of ecosystems by using the equivalent factor method, the Costanza model and the analytic hierarchy process (AHP). The result as shown in Figure 2.

Since the total area of China used to be only the land area and the area of the ocean was neglected. In fact, the area of water is about one-third of the land area. Because the value of ecological services is related to area, the value of watershed ecosystems is far ahead of the value of the remaining five types of ecosystems.

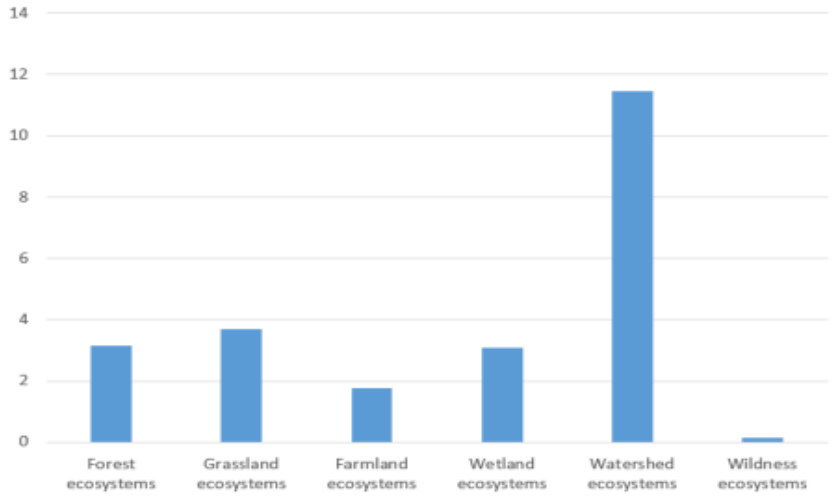

Figure 2. Service function value of different types of ecosystems

Since we want to adjust the assessment of the value of ecological services according to the current situation, we combine the analytic hierarchy process (AHP) to determine the weight of nine service functions. For example, we believe that the value of environmental protection and ecological benefits is more important nowadays for ecosystems. Therefore, the sum of waste treatment, water conservation and biodiversity conservation is as high as 85%. Finally, we calculate the value of the nine types of ecosystem services as shown in Figure 3.

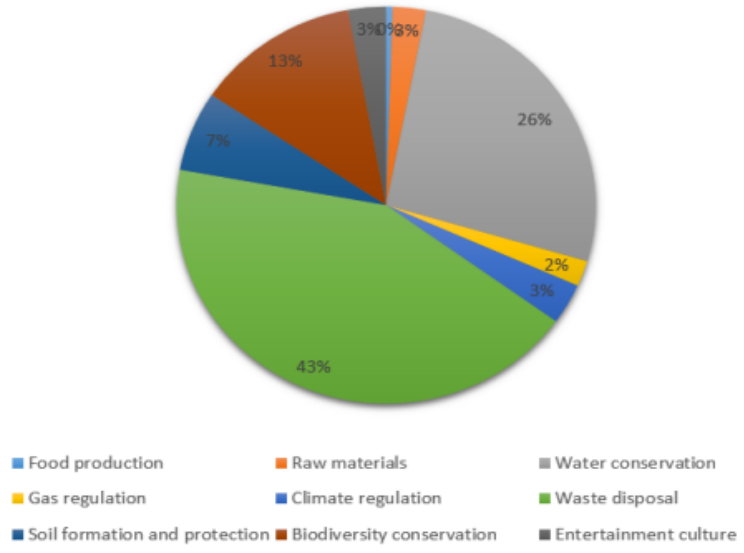

Figure 3. Value of the various ecological service functions

The above three service functions of the wetland ecosystem are more prominent. Although the area of wetland ecosystem is smaller than the others, its value is similar to the forest and grassland ecosystem. The value of the farmland ecosystem in these three service functions are not prominent, so its ecological services value is relatively backward. The lowest is the wasteland ecosystem. Because most of the wasteland is still in an undeveloped state, the amount of functional value exerted is small, and the value of itself is small, too.

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