Ecological Service Evaluation Model Based on Equivalent Factor Method

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Abstract: At present, the majority of land-use projects don't consider the impacts and changes of ecosystem services, however, the costs caused by environmental damage can’t be ignored. In order to quantitatively evaluate the costs of environment , our team establishes an ecological service evaluation model to conduct cost-benefit analysis on land-use development projects.

We use the Equivalent Factor Method(EFM) to build our model. With the help of Costanza’s model,a three-layer index system(the first layer has one index, the second layer has four indexes, and the third layer has eleven indexes) is established to be used as a measurement of the value of ecosystem services. Principal Components Analysis(PCA) is adopted to determine the land composition and weight of a certain project.

Aimed at regions of different sizes, we have adopted the Net Present Value(NPV) income method and the Infinitesimal Method(IM) to carry out cost-benefit analysis.

Since Ecosystem value coefficient（VC） changes with the year, we will rebuild the basic equivalent value table because of changes in biomass to make our model more accurate.

1. Introduction

Ecosystem Services refers to many benefits and assets that humans receive freely from our natural environment and a fully functioning ecosystem. Nonetheless, most land use projects usually don’t consider impacts or changes on ecosystem services. Thus, what they got was an half-baked and unspecified project cost. In this case, to have a model which can estimate the missing environmental cost to take a authentic and comprehensive evaluation of the project is actively requested.

First of all, we need to look up relevant data and find out the indicators to measure the value of ecosystem services through statistical analysis. Based on the model we have established, the value of ecosystem services is linked to the environmental cost of the project so as to calculate the actual economic cost of the project. Then, aimed at different scale land use projects, we will conduct cost-benefit analysis and find out their diversity and internal relations through our model.

Finally, as time passed on, due to the change of various indicators, the model will be optimized and fixed.

2. Model Introduction

By consulting data and using the method of data statistics and Costanza model, a three-layer index system to measure the value of ecosystem services is established, where the first level has one indicator, the second level has four indicators and the third level has eleven indicators. As for the

type of land, we divided it into six categories, including eleven sub - categories.[11] The specific structure is shown in the following figure.

3. Construction of Basic Equivalent Table(BET)

The meaning of the basic equivalent of ecosystem service function value per unit area is that the average annual value equivalent of various service functions per unit area of different types of ecosystems.

On one hand, it mirrors the average annual value of different ecosystems and their various ecosystem services across the country.

On the other hand, biomass mirrors the raw material production capacity of the ecosystem. At the same time, it has an significant effect on other services of the ecosystem in the process of biomass formation and accumulation. Therefore, this study assumes that biomass can reflect the differences in service functions between different types of ecosystems to a large extent. Referring to the following calculation process, the basic equivalent table is obtained as table 2.

↗ Extraction and calculation of statistical data.

↗ The research results of ecosystem service function values directly corresponding to documents and data are calculated on average, and the ratio with standard equivalent is calculated as the basic equivalent of this kind of ecosystem service function

↗ Through literature data calculation, the service function quantity and the value quantity of the unit area ecosystem service function quantity are obtained, and then the service value of the unit area is calculated, and then compared with the standard equivalent value, the basic equivalent value of this type of ecosystem service function is obtained.

Table 2 Ecosystem service equivalent value per unit area

Ecosystem classification		Provisioning service			Regulating service				Supporting service			Cultural service
Primary classification	Secondary classification	P1	P2	P3	R1	R2	R3	R4	S1	S2	S3	C1
Farmland	FA1	0.85	0.40	0.02	0.67	0.36	0.10	0.27	1.03	0.12	0.13	0.06
	FA2	1.36	0.09	-2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
Forest	FO1	0.22	0.52	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	FO2	0.31	0.71	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.60	1.14
	FO3	0.29	0.66	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06
	FO4	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grassland	G1	0.10	0.14	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25
	G2	0.38	0.56	0.31	1.97	5.21	1.72	3.82	2.40	0.18	2.18	0.96
	G3	0.22	0.33	0.18	1.14	3.02	1.00	2.21	1.39	0.11	1.27	0.56
Wetland	WE	0.51	0.50	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73
desert	D1	0.01	0.03	0.02	0.11	0.10	0.31	0.21	0.13	0.01	0.12	0.05
	D2	0.00	0.00	0.00	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01
waters	W1	0.80	0.23	8.29	0.77	2.29	5.55	102.2	0.93	0.07	2.55	1.89
	W2	0.00	0.00	2.16	0.18	0.54	0.16	7.13	0.00	0.00	0.01	0.09

4. Construction of Dynamic Equivalent Tables(DET)

The internal structure and external form of an ecosystem are incessantly changing in different regions and different time periods within the same year, so its ecological service function and its value are also incessantly changing.

Through previous research, ecosystem food production, raw material production,climate regulation, maintenance of nutrient cycling, biodiversity and aesthetic landscape functions are generally positively correlated with biomass, water supply and hydrological regulation and precipitation. Water supply and hydrological regulation are related to precipitation changes, and soil conservation is closely related to precipitation, topographic slope, soil properties and vegetation cover. Based on the above cognition, this study further analyzes the spatial and temporal dynamic factors of NPP, precipitation and soil conservation regulation. Combined with the ecosystem service value basic equivalent table, the time-space dynamic change value equivalent table of ecological services is constructed by the following formula:

$$F_{nij} = \begin{cases} P_{ij} \times F_{n1} \\ R_{ij} \times F_{n2} \\ S_{ij} \times F_{n3} \end{cases} \tag{1}$$

where F_{ij} denotes unit area value equivalent factor of type n ecosystem function in region i, month j.

F_n denotes the n equivalent factor of ecological service value of this kind of ecosystem.

P_{ij} denotes temporal and spatial adjustment factors of NPP in region i, month j of this kind of ecosystem.

R_{ij} denotes temporal and spatial regulation factors of precipitation in region i, month j of this kind of ecosystem.

S_{ij} denotes temporal and spatial regulation factors of soil conservation in region i, month j of this kind of ecosystem.

n1 denotes food production, raw material production, gas regulation, climate regulation, purification of the environment, maintenance of nutrient cycling, maintenance of biodiversity and provision of aesthetic landscape services.

n2 denotes ecological service functions are water supply or hydrological regulation services.

n3 denotes soil retention service function.

4.1 Temporal and spatial adjustment factors of NPP (P_{ij})

$$P_{ij} = B_{ij} / \overline{B} \tag{2}$$

where B_{ij} denotes NPP in region i, month j of this kind of ecosystem. (t·hm^{-2}) $\overline{B}$ denotes average annual NPP of the kind of ecosystems nationwide.(t·hm^{-2})

4.2 Temporal and spatial regulation factors of precipitation (R_{ij})

$$R_{ij} = W_{ij} / \overline{W} \tag{3}$$

where W_{ij} denotes the average precipitation per unit area in region i, month j.(mm·hm^{-2})$\overline{W}$ denotes average annual rainfall per unit area nationwide.(mm·hm^{-2})

4.3 Temporal and spatial regulation factors of soil conservation (S_{ij})

$$S_{ij} = E_{ij} / \overline{E} \tag{4}$$

where E_{ij} denotes soil holding analog quantity in region i, month j.$\overline{E}$ denotes average soil retention analog quantity per unit area nationwide.

5. Ecosystem Value Coefficient(VC)

Definition: The economic value of the annual natural grain output of farmland with a national average output of 1 square meter is 1.

5.1 Economic value of annual grain crops in 1 hm^2 farmland (E_a)

$$E_a = \frac{1}{7}\sum_{i=1}^{n}\frac{m_i p_i q_i}{M}(i = 1,...,n) \tag{5}$$

where E_a denotes the economic value of annual grain crops in 1 farmland.(yuan/ hm^2)

P_i denotes average national price of type i food crops.(yuan/t)

q_i denotes the grain crop yield per unit area of type i .(t/) hm^2

m_i denotes the grain crop area of type i.(hm^2)

M denotes the total grain crop area.(hm^2)

i denotes the type of crops.

5.2 The meaning of $\frac{1}{7}$

The equivalent factor of ecosystem service value is the relative contribution rate of ecosystem potential service value. Considering that the economic value provided by natural ecosystems without human input is 1/ 7 of the economic value of food production services provided by existing single-site plot farming fields, this text sets the equivalent factor of ecosystem service value as 1 / 7 of the output value of farming products per hectare per year.

5.3 Ecosystem value coefficient(VC)

$$VC = DET \times E_a \tag{6}$$

6. Example

Using the above formula to calculate the ecosystem value coefficient of Jiaxing in China.

6.1 Service value per unit area of Jiaxing's land ecosystem

This paper calculates the equivalent value of land ecosystem services based on 1 / 7 of the unit area output value of crops (including grain, oil, medicinal materials, vegetables and melons) with a large planting area in Jiaxing city from 2000 to 2012, and obtains the ecological service value of 3,752.9 yuan / hm^2 per equivalent of land ecosystem in Jiaxing city.

$$E_a = 1/7 \times S = 3752.9(\text{yuan/hm}^2) \tag{7}$$

where S denotes economic value of food production services provided by farmland in unit area.

6.2 The ecosystem value coefficient

$$VC = DET \times E_a \tag{8}$$

The result is as follows.

7. Calculation of Ecosystem Service Value (ESV)

7.1 Calculation Method

Step 1. Determine the type of land

Considering the complexity of the land type in the area where a certain project is located, we adopt the **Principal Component Analysis(PCA)** method to determine the land type and the weight of each type. Moreover, The independence of elements is realized.

$$A = \sum_{i=1}^{k} A \cdot x_k \tag{9}$$

where A denotes the occupied area of the land development and utilization project.(hm^2)

x_k denotes class k land type.

Step 2. Computational formula

On the basis of Costanza's[2] evaluation model, and according to the actual situation in China, a scale of ecological service value per unit area of China's ecosystem is obtained.

$$ESV_f = \sum A_k \Delta VC_{fk} \qquad ESV = \sum A_k \Delta VC_k \tag{10}$$

where VC_k denotes the ecosystem value coefficient.(yuan hm^{-2} a^{-1})

VC_{fk} denotes the item f service function value coefficient of land use type k.(yuan hm^{-2} a^{-1})

ESV_f denotes the item f ecosystem service function value.[1]

7.2 External Cost/Environmental Cost (EC)

$$EC = ESV_1 - ESV_2 \tag{11}$$

where ESV_1 denotes ecosystem service value *before* land project development.

ESV_2 denotes ecosystem service value *after* land project development.

7.3 Total Cost

$$Co = EC + IC \tag{12}$$

7.4 Solve Problems

We adopt **differential element method** to solve the problems.

Assuming that the total length L of a national project route is regarded as the sum of numerous small community projects, the length of each small project is dl. Let's assume that the section i covers an area of A_i.

$$ESV = \sum_i ESV_i$$

$$ESV_i = \sum_k A_{ik} \Delta VC_i \tag{13}$$

where k denotes the type k of the land type.

7.5 Cost-benefit Analysis

Cost-benefit analysis is a method to evaluate the value of a project by comparing the total cost and benefit of the project and find out how to get the maximum benefit with the minimum cost in making investment decision.

The basic principle of cost-benefit analysis method is proposing several schemes to realize a certain expenditure target, calculating the cost and benefit of each scheme by using certain technical methods, and selecting the optimal decision scheme by comparison method and according to certain principles.

7.6 Net Present Value Income Method (NPV)

$$B_i = \sum_{t=0}^{n} \frac{b_i(t) - c_i(t)}{(1+r)^t} - k_i \tag{14}$$

where B_i the total net income that may be generated by a certain project i.

t denotes the year t of project construction and operation.

$b_i(t)$ denotes income from project i in Year t.

$c_i(t)$ denotes cost of project i in Year t.

$1/(1+r)$ denotes the discount coefficient when the interest rate is r.

n denotes the existence period of the analyzed item.

k_i denotes the initial investment capital for project i.

7.7 Conclusion

(I) If B_i is positive, the investment plan is acceptable.

(II) If B_i is negative, the investigation plan is unacceptable. The greater the B_i, the better the investment plan.

(III) By dividing large national projects into several small community projects, we can calculate their costs and conduct cost-benefit analysis.

8. Optimization of Model

8.1 The Influence of Time on Model

Problem A. When the construction period of the project is within one year, but the project is carried out throughout the year, due to the different economic levels of the two years, the economic value of the annual natural grain output of the farmland with the national average yield is different, and the project faces the problem of recalculating the ecosystem value coefficient.

Problem B. When major events occur in the country, the economic value of the annual natural grain output of farmland with average national output will greatly change.

Problem C. When the construction period of the project is too long and the land types are complex and changeable, the time and space will change greatly at the same time, resulting in great changes in the biomass proportion of various ecosystems, which is difficult to calculate with the existing basic equivalent scale.

8.2 Improvement Measures

The consideration of time factor in our model is divided into short-term and long-term aspects:

Solution A. The short-term definition is that the duration of the land development project is within one year. As for the short-term evaluation of ecosystem value and the calculation of environmental cost, since we assume that the national economy is stable and the people's attention to ecosystem value has not changed much, we believe that the economic value of the annual natural grain output of farmland with a national average yield in the adjacent years has not changed much. To measure the environmental cost of land development, we can only use the economic value of the

annual natural grain output of farmland with a national average yield in one year to calculate the ecosystem service value coefficient and thus making the solving process simple.

Solution B. However, when unexpected events occur in a short period of time, such as a financial crisis, our assumption of a stable national economy will not hold, and the economic value of the annual natural grain output of farmland with a national average output in adjacent years may change greatly. We must calculate the economic value of the annual natural grain output of farmland with a national average output in each year separately when calculating the environmental cost, so that there will be no large error of the results.

Solution C. For the evaluation of long-term ecosystem value and the calculation of environmental cost, the definition of long-term is that the land development time is more than one year. Although under our assumption, the proportion of biomass in each ecosystem has not changed much in a period of time, there are still some differences. The accumulation of these differences over time leads to some non-negligible changes in the proportion of biomass in two years if the time span is large, while biomass is related to the calculation of the basic equivalent value table , which result in large differences in the basic equivalent value table . The calculation can no longer be based on the same scale, so when calculating large-scale national land development projects with large time span, as described in section 4.2, we divide them into several small projects with short time period to simplify the solution.[3]

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