

Pollution Cost Evaluation Model Based on Entropy Weight Method

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Abstract: We assume that small-scale land use projects are not have a huge impact on the original ecosystem, and the value of local ecosystem services remains basi-cally not changed, while large-scale land use projects include both. First, in order to calculate the cost of pollution caused by specific projects, based on the classification method of The Millennium Ecosystem Assessment (MA), we introduce six kinds of pollution as our research target and calculate the pollution cost by our model of Pollution Cost of Project(MPCP). Furthermore, using entropy weight method(EWM), we propose an index of cost-effective to judge whether this project is cost-effective. Second, in order to calculate the cost of changes in ecosystem services, we introduce nine kinds of ecosystem service and six kinds of ecosystem as our re-search target. Moreover, according to Constanza and Xie Gaodi's research, we use value equivalents method to estimate the value of different ecosystem by our model of cost of ecosystem services changes(CESC). Then, the cost of large-scale project can also be obtained.

1. Introduction

Ecosystem services are the many and varied benefits that humans freely gain from the natural environment and from properly-functioning ecosystems[1]. Eco-system services include supporting services, provisioning services, regulating services and cultural services that people perceive to be important.

However, human use of land always has negative influence on the ability of ecosystem services. These often neglected impacts have reduced the ability of the biosphere and ultimately led to ecological degradation. So, if we can assess the environmental cost of land use projects, we can analyze the benefits of the projects more comprehensively and objectively and achieve the goal of sustain-able development.

2. Our work

2.1 Restatement of Problems

We analyse ecological cost in this way: the ecological cost of a land use project is divided into two parts, including the pollution cost during the process of projects, and the cost of changes in ecosystem services.

Considering the difference between small-scale and large-scale land use projects, the calculation of this two should be seperated.

We are required to put forward suggestions for land planning projects based on known data, considering the different impact of pollution factors. Besides, we need to consider the time factor and make an improvement of our model.

2.2 Our Work

We will proceed as follows for the sake of tackling these problems:

State assumptions and make notations. Ignoring some insignificant im-pacts, we will narrow the core of our approaches towards real cost of land use projects. Then we will list some notations which are important for us to clarify our model and determine their definitions.

Establish a cost evaluation model which illustrates the pollution cost during the process of projects, and solve the cost estimation task of specific project.

Establish a cost evaluation model which illustrates cost of the changes in ecosystem services, and solve the cost estimation task when ecosystem changes.

Apply our model to San Francisco to verify feasibility and give the results of our analysis to reflect situations of San Francisco.

The time factor is introduced to further improve the model. Project costs change over time, so we take time factor into consideration to ensure that our model can be applied to projects in real life.

Give the sensitivity analysis and conclusion. We evaluate the reliability of our model by changing some indexes and do the sensitivity analysis. Then, we will discuss the strengths and weaknesses about our model and give our conclusion.

2.3 Assumptions

We assume that the financial situation in our statistical location is stable, there will be no drastic inflation and deflation, so our economic value of per value equivalents will not change dramatically. This assumption is reasonable because it is in line with the national conditions of most countries at present.

We assume that the ecological loss caused by the land use project does not consider the economic expenditure of destroying the original ecosystem, because we only consider the ecological cost, ignoring all the variables that are included in the process of construction. This assumption is reasonable because the theme we are discussing emphasizes that cost is ecological cost.

We assume that there's no large-scale reduction of grain production and sudden change of grain price caused by natural disasters. This assumption is reasonable because grain prices are stable in most countries of the world.

We assume that the cost of environment repairing is equal to the cost of economic loss in process of construction. This assumption is reasonable because it is similar to "the shadow engineering" method and is in line with people's common sense.

2.4 Notations

We list the symbols and notations used in this paper in Table 1.

Table 1. Notations

| Symbols | Definition |
|---------|--|
| L | Pollution Cost of Projects |
| Q | The amount of pollution |
| C | The Cost of Pollution Treatment |
| ESV | Total Economic Value in Different Ecosystems |
| PS | Provisioning Services |
| RS | Regulating Services |
| SS | Supporting Services |
| CS | Cultural Services |

3. The Models

3.1 Model 1: Evaluation Model of Pollution Cost of Project

● Selection of Indicators

The construction of projects always have some impact on the environment. In the process of projects, people often have to bear some costs, including direct costs and indirect costs. At the same time, projects will also bring a small amount of ecological benefits. So, We analyse the indicators of various projects.

We find it is hard to take all factors into consideration, so we choose six main indicators to evaluate the pollution costs in different projects: water pollution, noise pollution, air pollution,

garbage disposal, soil erosion and environment protection. In addition, we choose five main infrastructures as our objects: thermal power plant, airport, university, hospital and entertainment place. We will use these typical objects as example to calculate the pollution cost of them. Six selected indicators of our model are shown below:

Table 2. Evaluation Indicators

| | |
|------------------|------------------------|
| direct cost | indirect cost |
| noise pollution | soil erosion |
| water pollution | environment protection |
| air pollution | |
| garbage disposal | |

● Calculation Models of Indicators

The Cost of Noise Pollution

$$L_n = AP\beta b \quad (1)$$

L_n represents the cost of noise pollution. A represents the coverage area of noise. P represents population density in noise covered areas. β represents labor productivity loss rate. b represents profit per capita create in noise-covered areas.

The Cost of Water Pollution

In the process of city operation, a lot of wastewater is produced. When it comes to calculating the economic loss of water pollution, we assume that the cost of pollution treatment is equal to this economic loss. Our formula of this model is

$$L_w = Q_w C_w \quad (2)$$

L_w represents the cost of water pollution, Q_w represents the total amount of waste water, and C_w represents the cost per ton of waste water treatment.

The Cost of Air Pollution

$$L_a = \sum_{i=1}^k Q_i C_i \quad (3)$$

L_a represents the cost of air pollution. i represents the serial number of various kinds of air pollution, such as $S O_2$ and NO_2 . k represents the number of types of air pollution. Q_i represents the amount of each kind of air pollution. C_i represents the cost of each kind of air pollution treatment.

The Cost of Garbage Disposal

We consider the process of garbage disposal includes the garbage transportation and garbage treatment. Our formula of this model is

$$L_g = Q_t C_t + Q_p C_p \quad (4)$$

L_g represents the cost of soil loss. Q_t represents the amount of garbage need to be transferred. C_t represents the cost of garbage transportation. Q_p represents the amount of garbage need to be processed. C_p represents the cost of garbage procession.

The Cost of Soil Erosion

$$L_s = (G_p - G_n) * C_s \quad (5)$$

L_s represents the cost of environment protection. G_p represents the soil erosion volume caused by human activities. G_n represents the natural soil erosion volume. C_s represents the cost rehabilitating land per unit volume.

The Cost of Environment Protection

In order to show the environmental cost of the project more comprehensively, we take the cost of environment protection in the project into consideration. These include the purchase of environmental protection facilities, the cost of operation of facilities and the wages of environmental protection personnel. Our formula of this model is

$$(X_1', X_2', \dots, X_k') = \begin{pmatrix} x_1'(1) & \dots & x_k'(1) \\ \vdots & \ddots & \vdots \\ x_1'(n) & \dots & x_k'(n) \end{pmatrix}$$

L_p represents the cost of environment protection. j represents the serial number of various aspects of environment protection. C_j represents the cost after consolidation of revenue and expenditure in various respects, which are mainly include water conservation, energy conservation and arable land protection.

Combining the calculation results of the model, small project planners could assess whether this land use project are cost-effective by the ratio of annual income of project to ecological cost of the project. The formula is

$$\lambda = \frac{R}{E} \quad (7)$$

λ represents the ratio which show whether the project is cost-effective. R represents total annual income of the project. E represents the ecological cost of the project. The bigger is, the more cost-effective the project is.

3.2 Model 2: Evaluation Model of Cost When Ecosystem Services Changes

In the process of large-scale land use projects, the ecosystem of the original place may change, and it do cause some losses. In this model, we synthesized the research results of Costanza and Gaodi Xie and estimate the ecosystem service value of large-scale land use projects using value equivalent method. According to different ecosystem service value, we can know how much it costs when we change the ecosystem.

Based on the classification method of The Millennium Ecosystem Assessment (MA)[4] , we choose forest, grassland, farmland, wetland, river and desert as our research target. According to statistics from " American Statistical Yearbook" and United States Department of Agriculture[13] , we can obtain the data of raw mate-rial. Besides, We published 500 questionnaires online and recovered 326. Based on this, we evaluate the value equivalents of different ecosystems. Then, accord-ing to the four types of ecosystem services, we utilize national statistics and get the value equivalents of different ecosystems in the United States.

In the following table, PS, RS, SS, CS represents provisioning services, regu-lating services, supporting services, cultural services respectively. They are the four services that ecosystem provides.

Table 3. Table of Value Equivalent

| first-class | second-class | forest | grassland | farmland | wetland | river | desert |
|-------------|--------------|--------|-----------|----------|---------|-------|--------|
| PS | Food | 0.42 | 0.54 | 1.27 | 0.45 | 0.67 | 0.02 |
| | Material | 3.79 | 0.45 | 0.49 | 0.30 | 0.44 | 0.05 |
| RS | Air | 5.49 | 1.90 | 0.91 | 3.06 | 0.64 | 0.07 |
| | Climate | 5.18 | 1.98 | 2.50 | 17.24 | 2.62 | 0.16 |
| | Hydrology | 5.20 | 1.93 | 0.98 | 17.10 | 23.88 | 0.08 |
| | Waste | 2.18 | 1.68 | 1.76 | 18.32 | 18.90 | 0.33 |
| SS | Soil | 5.11 | 2.85 | 1.87 | 2.53 | 0.52 | 0.21 |
| | Biodiversity | 5.74 | 2.38 | 1.29 | 4.69 | 4.36 | 0.50 |
| CS | Landscape | 2.64 | 1.10 | 0.21 | 5.96 | 5.65 | 0.30 |
| sum | | 35.78 | 14.85 | 11.32 | 69.70 | 57.71 | 1.76 |

Subsequently, based on our value equivalent chart, we try to find a model to converting value equivalent into economic value and calculate the values of different ecosystem. Based on relevant research^[2] , our model formula is shown below and the detailed calculation method is followed.

$$E_{ij} = F_{ij} * V * R_i \quad (8)$$

$$ESV_i = \sum_{j=1}^n E_{ij} M_i \quad (9)$$

i represents the serial number of selected ecosystems. j represents the serial number of ecosystem services. E_{ij} represents the economic value of different services in different ecosystems per unit area (Unit: dollar/hm²). F_{ij} represents the value equivalents of different services in different ecosystems per unit area. V represents the economic value of per value equivalent. R_i represents production correction coefficient in different ecosystems. M_i represents the size of different ecosystems. ESV_i represents the total economic value in different ecosystems.

Considering the economic value of equivalents may change over time, We try to find a reference to keep our values relatively stable as time goes by. So, we build the relationship between economic value and equivalents, using the value of the total grain yield Q this year.

$$V = \frac{PQ}{7M} \quad (10)$$

P represents national average price of grain (Unit: dollar/kg). Q represents total grain yield (Unit: kg). M represents size of the grain area (Unit: hm²). We can also apply our model to different places by using different productivity correction coefficient R_i , and the formula of R_i is

$$R_i = \frac{b_i}{B_i} \quad (11)$$

b_i represents the grain production of local ecosystem. B_i represents average national grain production of an ecosystem. According to Thornthwaite memorial model [3], we can know how to calculate b_i and B_i and the formula is

$$B_i = 3000 [1 - e^{-0.009695(V - 0)}] \quad (12)$$

$$L = 3000 + 25t + 0.05t^3 \quad (13)$$

V represents annual evapotranspiration (Unit: mm). R represents annual precipitation (Unit: mm). L represents average annual evapotranspiration (Unit: mm). t represents average annual temperature (Unit: °C). The calculation method of b_i is similar to that of B_i .

Now, based on the value equivalents table, we can estimate the economic value that different ecosystem holds. So, by calculating the difference of two different ecosystem's economic value, we can get the cost when the ecosystem changes. This logic can be shown by this formula:

$$\Delta ESV = \sum_{j=1}^n (E_{i,j} - E_{i_2,j}) * M_i \quad (14)$$

ESV represents the ecological cost when ecosystem is changed by human activities.

4. Model Test-San Francisco

4.1 Project pollution cost analysis of San Francisco

Based on our model 1, we obtained the pollution cost calculation method for specific land use projects. After that, in order to verify the feasibility of our model and given that our evaluation model is a generalized model whose parameters cannot be determined until the target state is chosen, we test our model on San Francisco. In order to generalize various land use projects as possible, with limited data, we choose University of San Francisco [5], Temple night club [6], San Francisco golf club [7], St. Mary's Medical Center [8], Half-Moon-Bay-Airport [9] as our objects and collect the data of them to do further analysis.

Table 4. Ecological cost of frastructures in San Francisco

| | wastewater | noise | soil erosion | exhaust gas | garbage | protection |
|-------------|------------|--------|-----------------|----------------|---------|------------|
| Club | 1295.5 | 1962.5 | 603 | 729 | 321 | 801 |
| Power Plant | 4731 | 2734.5 | 431 | 2572 | 7508 | 1201 |
| Airport | 16970 | 27400 | 1171 | 3912 | 16624 | 1797 |
| University | 9677 | 7401 | 892 | 932 | 4172 | 933 |
| Hospital | 9300 | 7329 | 239 | 772 | 6229 | 783 |
| Golf Course | 91 | 12 | 0 | 0 | 131 | 12 |

According to the method of judging whether the project is cost-effective in our first model, we calculate the ratio of the above six sites and the result is shown below:

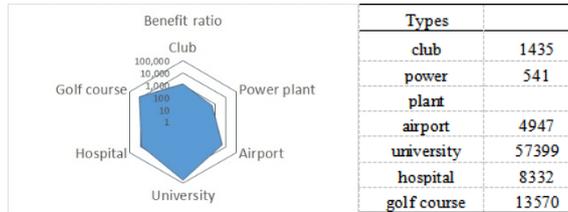


Figure 1: Radar Chart of Benefit Ratio Figure 2: Benefit Ratio

The information above indicates that the construction of universities is the most cost-effective project, while the construction of thermal power plants is the least cost-effective.

4.2 Ecosystem Services Analysis of San Francisco

● Ecosystem Services Value of Non-construction Land

Based on our non-construction land cost model 2 and the table of US ecosystem service value equivalents, we can calculate the economic value of non-construction land in San Francisco.

The economic value of value equivalent V, which represents the average grain price in the United States, can be calculated as 109.172 dollar/hm². In order to make this index more reasonable, we take the average grain price of 2007-2017. The production correction coefficient in different ecosystemsR_i, can be calculated based on U.S. precipitation and annual average temperature data[10] , San Fran-cisco precipitation and annual average temperature data[11] . After our calculation, we can know the production correction coefficient in San Francisco is roughly 0.924.

According to the indexes above, we can obtain the value of ecosystem service in non-construction land and the detailed data is shown below:

Table 5. Table of Economic Value in non-construction land(Unit:dollar/hm²)

| First-class | Second-class | forest | grassland | farmland | wetland | river | desert |
|-------------|--------------|--------|-----------|----------|---------|-------|--------|
| PS | Food | 47 | 61 | 140 | 51 | 75 | 4 |
| | Material | 415 | 51 | 55 | 34 | 50 | 6 |
| RS | Air | 601 | 209 | 101 | 336 | 72 | 9 |
| | Climate | 566 | 218 | 275 | 1884 | 287 | 19 |
| | Hydrology | 569 | 212 | 108 | 1868 | 2609 | 11 |
| | Waste | 240 | 184 | 194 | 2002 | 2064 | 37 |
| SS | Soil | 559 | 312 | 205 | 277 | 58 | 25 |
| | Biodiversity | 628 | 261 | 143 | 514 | 478 | 57 |
| CS | Landscape | 290 | 122 | 25 | 653 | 618 | 34 |
| Sum | | 3915 | 1629 | 1244 | 7618 | 6309 | 201 |

● Ecosystem Services Value of Construction Land

Construction project usually destroys the original ecosystem greatly. There-fore, some of ecosystem services provided by construction land are almost zero. We stipulate that the ecological

value of the ecosystem can be negative, which means that the ecosystem has been destroyed to the extent that is harmful to human beings.

Based on our model 1, we can calculate the economic value of construction land in San Francisco. In order to comprehensively analyze the construction land in San Francisco, we divide the functions of the construction land into seven main categories: Hi-tech area, heavy industry area ,light industry area, residen-tial area, education area, entertainment area and city park. The value of ecosys-tem service in San Francisco construction land is shown below.

Sum up the value of various ecosystem service above, we can obtain the cost of affecting ecosystem services and the total value of ecosystem services.

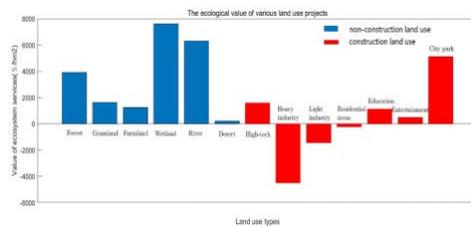


Figure 3: The ecological value of various land use projects

5. Sensitivity Analysis

In model 1, we choose the typical infrastructure to evaluate the ecological cost of urban construction. However, the actual situation of the city is more complex. In order to prevent errors caused by the selection of objects, we use data of other infrastructure to replace some origin data of our model, and observe whether the results have changed significantly.

5.1 Sensitivity of Entropy Weight

According to the results above, we can know noise pollution has the most serious impact on people. To verify this conclusion, we replace the data of golf course by museum and residential area, then we draw a line chart containing three sets of data and make some comparison. The line chart is shown below:

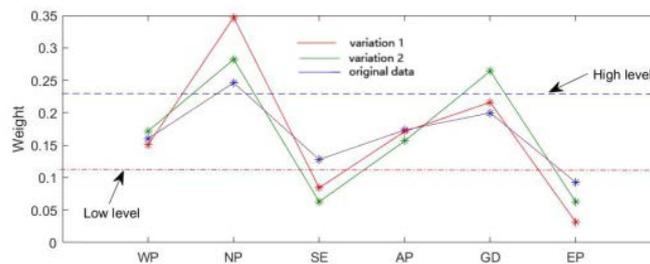


Figure 4: Sensitivity of Model 1

WP, NP, SE, AP, GD, EP represents water pollution, noise pollution, soil ero-sion, air pollution, garbage disposal and environment protection respectively.

According to this chart, we can see the final ecosystem services evaluation system will not change a lot with the selected indicators changed. So we can know that our model is stable.

5.2 Sensitivity of Ecological Cost

Taking San Francisco as an example, we evaluated the ecological costs consid-ering six types of pollution made by projects. In order to evaluate the sensitivity of the ecological cost, we selected two sites and sequentially changed the degree of every kind of pollution by 5%, and observed the change extent of the final ecological cost. The result is shown below:

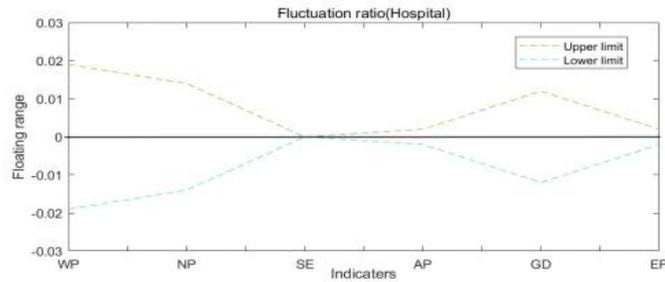


Figure 5: Cost fluctuation of hospital

WP, NP, SE, AP, GD, EP represents water pollution, noise pollution, soil ero-sion, air pollution, garbage disposal and environment protection respectively. According to this chart, we can see the final ecological cost will not change a lot with six selected indicators changed one by one. So we can know that our model is stable.

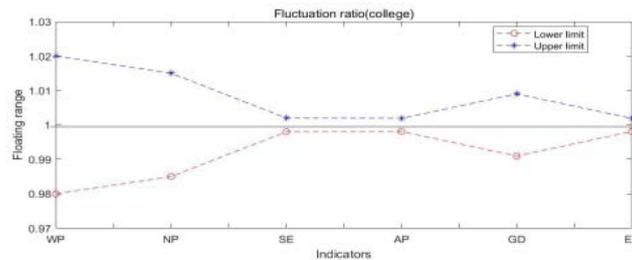


Figure 6: Cost fluctuation of college

6. Strengths and Weaknesses

6.1 Strengths

Usage of expert knowledge our model utilize the research results of ex-perts, and we can get more accurate results for the semi-qualitative and semi-quantitative problem of environmental cost quantification.

Universality and flexibility the value equivalents we utilize to measure the value of ecological services are dynamic and universal, which can inte-grate our calculation into the value system of current economics.

Good Robustness the results of sensitivity analysis are satisfactory, which verifies the stability of our model.

6.2 Weaknesses

Lack of relevant data our model needs a lot of data, the lack of data has some negative impact on the accuracy of our model.

Ignoring of factors our model ignores some minimal pollution factors in calculation, which may affect accuracy of model calculation results.

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