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2019 Interdisciplinary Contest in Modeling (ICM) Summary Sheet

Assessment of ecological services

Summary

Traditionally, the economic theories have not considered the impact of ecosystem services. In order to implement the concept of sustainable development and change the status quo of ecosystem destruction caused by human abuse of land, an ecological service evaluation model is required to establish for determining the real and comprehensive valuation of the projects.

Firstly, we give a set of indicators to analyze the true economic costs of land-use projects when ecosystem services are considered, including the natural resource depletion (NRD), preventive cost (PC) and repair cost (RC). By these indicators, we analyze the definition of environmental costs and the total cost of environmental pollution and ecological damage.

Secondly, in order to make the cost-benefit analysis of land use development projects for different scales, we give two instances: a rural community-based and south-to-north water transfer center project in China. For the community-based project, we extract the main data from the collected data in the land use development area, use the transfer network based on the GIS map, and dynamically analyze the impact of land change on the environment. For the large national projects, we use the main pollutants based on principal component analysis (PCA). In addition, we combine with the ecological environment assessment model and the cost of environmental degradation.

Thirdly, we use the sensitivity analysis to determine the influencing factors of the model and the dependence of the relevant parameters on the model. By changing the value of the parameters, we analyze the different results of the environmental cost and find our model and methods are stable. The results from the proposed model show that the main influencing factor of the accuracy is the depletion of production materials and the model is effective. Moreover, our model makes proper improves, and the introduction of human science factors is negatively correlated with environmental costs, resulting in new calculation expressions:

Finally, the advantages and disadvantages of the model are described and summarized, for further expanding and improving the proposed model.

Keywords: Ecosystem services; Land use projects; Principal component analysis; Environmental cost.

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1 Introduction

1.1 Background

In recent decades, in order to implement the concept of sustainable development and change the status quo of human ecosystem destruction caused by human abuse of land, the understanding of the ecosystem has been transformed from an inexhaustible unpaid theory to a service theory of paid supply [1]. However, ecosystem services are often in the category of open access and purely public services, which means that they often have no producer property rights, vague rights structures and prohibitive transaction costs. It is difficult for managers to measure the value of ecological services in the form of monetization.

Considering these issues, Richmond et al. adopted the net primary production agency ecosystem service system [2], and Norgaard, elaborated on the ecosystem service value assessment method from an ecological perspective. The ecosystem service value assessment system was established in [3]. Therefore, the ecosystem services can be measured from the use value, non-use value, and they can be subdivided into the value of natural resources, soil, surface water and ecosystem.

1.2 Restatement of the problem

Traditionally, most land-use projects have not considered the impact and changes of ecosystem services. The economic costs to mitigate negative results of land use changes: polluted rivers, poor air quality, hazardous waste sites, poorly treated waste water, climate changes, etc., are often not included in the plan. To understand the true economic costs of land-use projects, our team was hired to create an eco-service evaluation model when considering ecosystem services. We need to answer the following two questions:

- (1) Is it possible to put a value on the environmental cost of land use development projects?
- (2) How would environmental degradation be accounted for in these project costs by the mathematic model?

1.3 Overview of our work

1. First, we make an analysis of the real economic cost of the land use project, namely, the environmental cost, when considering ecosystem services. Then, we consider this issue by three indicators, called natural resource depletion (NRD), preventive cost (PC) and repair cost (RC). Furthermore, we use the corresponding secondary and tertiary indicators.
2. To show the efficiency of the proposed model, we explore the small-scale community project and the South-to-North Water Transfer Middle Line Project (a large- scale national project), and make the cost-benefit analysis of the project separately.

3. Combining the local sensitivity analysis with the global sensitivity analysis, the validity of the model is testified .
4. In order to help project planners for determining the location of the minimum environmental cost, we select the land use development project area and use numerical simulation.
5. Finally, the extra factors related the times are added to the proposed model for illustrating the change over time.

2 General Assumptions and Justifications

To simplify the considered problems, we make the following basic assumptions, which are properly justified.

- The data collected is more authentic and reliable, and there will be no critical data errors.
- Sudden changes in the ecological environment are ignored in the calculation of environmental costs.
- Annual resource rents remain constant at the comparable price levels.
- Each sub-indicator only plays a role in the range of indicators set, ignoring the effect on other indicators.
- Explosive changes are ignored in the predictions of more than a decade.

3 Variable Description

Table 1: Symbol TableÍCVariables

Symbol	Description
NRD	Natural resource depletion
RC	Repair cost
PC	Protective cost
$C_{NRD_{ij}}$	The NRD for the j-th second class indicator of the i-th first class indicator
$C_{RC_{ij}}$	The RC for the j-th second class indicator of the i-th first class indicator
$C_{PC_{ij}}$	The PC for the j-th second class indicator of the i-th first class indicator
ESA	Metrics for ecological service assessment
e_i	The i-th index entropy
p_{ij}	The weight of the j-th index and the i-th evaluation index
v_j	The comprehensive evaluation value under the j-th index

4 Ecological Service Valuation Model

According to the information provided in the literatures [4-6], there are three types of main costs for exploring land development and utilization when the ecological services were considered: natural resource depletion, pollution remediation and protective expenditure. In this section, we follows their ideas and set up an unique mathematic model to evaluate the ecological services. Now, we explain three indictors mentioned above.

- **Natural resource depletion** is a material environmental resource that calculates how much value is consumed by humans.
- **Reparative expenditure** refers to the environmental protection expenditure, which is the costs to prevent the environmental damage, or incurred in repairing the damaged environment.
- **Protective expenditure**

  a. refers to the cost of education to eliminate the negative impact of land development and utilization;

  b. refers to the expenses incurred in measuring pollution, collecting data, and implementing relevant policies in order to manage environmental quality.

4.1 How to assess the costs?

Assessing the costs is of great importance for setting up the model and understanding the ecosystem services. Here, we give some principles for determining indicators and show their ranges, according to the theoretical and practical properties.

4.1.1 Principles for determining indicators

- **The principle of market price.** Environmental assets with market prices are preferred for inclusion in the accounting range. There are no direct market prices but there are indirect market prices and important ones are also optional. There is no price basis for non-selection.
- **Comparability principle.** The results of the calculations should be comparable for comparison, including horizontal comparison and vertical comparison. To ensure comparability, the scope and method of environmental value accounting should be as consistent as possible for different regions
- **The principle of implement.** Environmental accounting must be implementable. In addition to price factors, physical quantity data is also essential. For environmental assets that lack physical quantity data, they can only be temporarily not accounted for.

4.1.2 Determine the accounting range of the indicator

According to the literature [5], the ecological service consists of five parts. For Life-fulfilling services and Preservation of options, we do not include them in the model due to the lack of data and uncertainty.

According to the three principles mentioned above, we have natural resource depletion and protective expenditure based on the physical quantity data available in the China Environmental Statistics Yearbook and the specific classification of China's physical quantity. The classification of environmental awareness was divided into three parts. Moreover, we use eight secondary influencing factors for further explaining the indicators in detail.

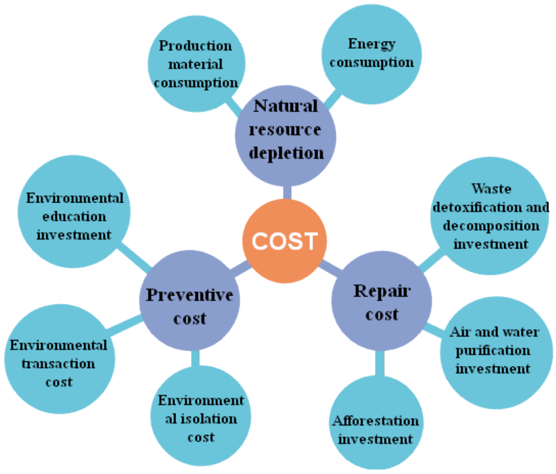


Figure 1: All the indicators for exploring the costs.

4.2 Natural resource depletion

4.2.1 Potential indicators for natural resource depletion

From the environmental theme of environmental protection [6], natural resource depletion contains many topics, such as forest resources, crop resources, aquatic resources, animal resources, metal minerals and non-metallic minerals. We divide these topics into two categories: production materials and energy consumption. And we show this relationship in Figure 2.

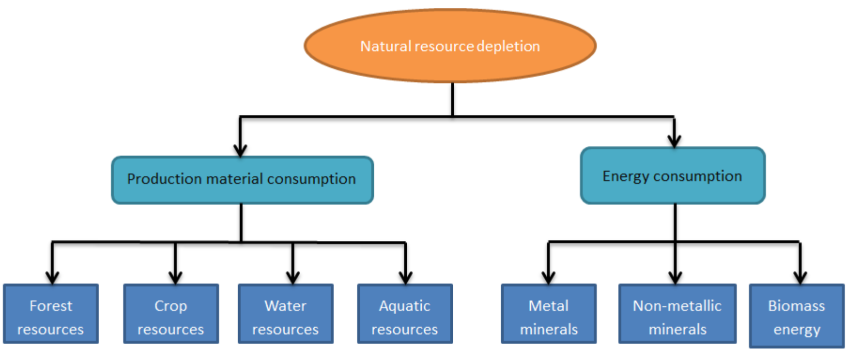


Figure 2: Two categories of Natural Resource Depletion

- **The depletion of production materials** is a component that focuses on understanding the value of commodity production in ecosystem services, mainly in forest resources, crop resources, aquatic resources and animal resources, which are the products of ecosystem cycles. When a new land development project is introduced, the production losses caused by the original ecosystem damage are equivalent to the sum of the four parts of the resource losses.

  - **Forest resource.** According to the literature [7], the value in forest resource is the discounted value of the mature forest price after deducting the cost during the forest growth period. According to the standing value method, the direct application of the net present value is more complicated, so it is simplified to

$$C_{NRD_{11}}=A \times p \times Q, \tag{4.1}$$

  where A is the forest area (unit: hectare), p is the average standing price per cubic meter (equivalent to the price of the log minus the cost of cutting), and Q is the level of forest stock (unit: cubic meter hectare).

  - **Crop resource.** For crop resource, market prices can be obtained and valued by the market price method. The calculation formula is as follows:

$$C_{NRD_{12}}=\sum_{i=1}^{n} P_i Q_i, \tag{4.2}$$

  where P_i represents the price, Q_i represents the crop yield, and i represents the type of crop.

  - **Water resource.** The water has been in a state of constant circulation. In the physical quantity data, the surface water and groundwater will be repeated, and the water has different quality. In theory, the price of water should also be different due to its quality. We use the possession method to estimate water resources. The formula for calculating the value of surface water resources reads as:

$$C_s = \sum_{t=1}^{n_1} \frac{R_s}{(1+r)^t} = \sum_{t=1}^{n_1} \frac{P_s Q_s}{(1+r)^t}, \tag{4.3}$$

  where R_s is the surface water resource rent; P_s is the surface water resource fee, which represents the unit resource rent; Q_s is the total surface water; r is the discount rate; n_1 is the current total surface water useful life.

  Similarly, we can get the formula for calculating the value of groundwater resources as follows:

$$C_g = \sum_{t=1}^{n_2} \frac{R_g}{(1+r)^t} = \sum_{t=1}^{n_1} \frac{P_g \cdot Q_g}{(1+r)^t}. \tag{4.4}$$

  By summarizing the value of surface water and groundwater, we can calculate the total value of water resources, expressed as $C_{NRD_{13}} = C_s + C_g$;

  - **Aquatic resource.** Fish cultured by water-producing institutions are assets of production that are privately owned and can be traded on the market. In most cases, it is easy to obtain the market price of fish, and the market price method can be used to estimate the fish value:

$$C_{NRD_{14}} = \sum_{i=1}^{n} p_i Q_i + \sum_{j=1}^{m} p_j Q_i, \tag{4.5}$$

where p represents the price; Q represents the amount of aquaculture; i indicates the type of aquaculture produced and j indicates the type of fish caught.

- **Energy consumption reduction.** Energy is the original commodity of ecosystem services. By accounting for metal minerals, non-metallic mines and biomass energy, we can assess the value of the energy depletion portion of ecosystems after land development. The following formula can be obtained by using the price-adjusted net present value method.

$$C_{NRD_{2i}} = \sum_{i=1}^{n} R\left(\frac{1+\mathrm{i}}{1+r}\right)^t = R \times \frac{(1+\mathrm{i})}{(r-i)} \times \left(1 - \left(\frac{1+i}{1+r}\right)^n\right), \tag{4.6}$$

where R is the resource rent; i is the price growth rate of the resource; r is the discount rate; n is the resource life.

4.2.2 The NRD accounting system

Based on the analysis of natural resource depletion above, we developed a method, called Natural Resource Loss (NRD), to assess the cost of ecological services at the natural loss level. The indicator includes two primary indicators and seven secondary indicators. We show the metrics for NRD in Table 2.

Table 2: The indicators used in the natural resource depletion.

	Indicators	Notation	Indicators	Notation	Target
NRD	Production material consumption	NDR_1	Forest resources	NDR_{11}	↓
			Crop resources	NDR_{11}	↓
			Water resources	NDR_{12}	↓
			Aquatic resources	NDR_{13}	↓
	Energy consumption	NDR_2	Metal minerals	NDR_{21}	↓
			Non-metallic minerals	NDR_{22}	↓
			Biomass energy	NDR_{23}	↓

Explanation: the smaller the seven indicators listed in the above table, the more natural resource consumption and the corresponding calculated environmental expenditure costs. Since the cost proportion of each factor is different, in order to reduce the error caused by calculation, we add the correction coefficient and get the accounting formula of NRD as $C_{NRD} = \alpha_1 \cdot C_{NRD_1} + \alpha_2 \cdot C_{NRD_2} + \alpha_3 \cdot C_{NRD_3}$.

4.3 Repair cost

4.3.1 Potential indicators for repair cost

In this section, we analyze the evaluation indicators of repair expenditure using multi-criteria analysis [5]. In addition, we show the Amazon agricultural development case in evaluating sustainability options. The repair expenditure consists of three components, (a) detoxification and decomposition of waste; (b) investment in air and water purification, and (c) investment in afforestation. In order to better describe the components of the repair expenditure.

- **Contamination composition.** During the land development process, various pollution is produced, such as: air, water and solid pollution. Pollution will cause degradation of environmental quality. In order to improve the environmental quality, it is necessary to take many effective measures. According to reference [7], we use more convincing and virtual governance costs to estimate the value of environmental degradation.

  1. When the environment quality is degraded, the degraded value becomes a component of the product value. This value is non-productive, and should be deducted.

  2. The actual treatment cost paid makes the environment improve. Deducted from it, there is still a part of the unrecovered environment.The value needs to be deducted.

  3. The part of the unrecovered environment is the cost of its full recovery, that is, virtual governance Cost, so virtual governance costs can be used entirely to represent the value of environmental degradation.

By the analysis above, we decided to use the governance cost coefficient method to carry out cost assessment on the interpretation of waste affecting repair expenditure. The idea is to introduce the concept of treatment facility benefits, to calculate the treatment cost coefficient of each pollutant, and to apportion the treatment costs among various pollutants, so that the unit treatment cost of various pollutants can be estimated. The calculation steps are as follows:

Step 1. Calculate the treatment benefit of the i pollutant in a treatment facility

$$\eta_i = \frac{I_i - E_i}{S_i} \cdot \frac{E_i}{I_i}, \tag{4.7}$$

where η_i represents the treatment benefit of the i contaminant, E_i represents the export concentration of the i contaminant, and I_i represents the import concentration of the i-th contaminant, $\frac{E_i}{I_i}$ indicates the difficulty of the treatment of the i-th contaminant, and S_i represents the maximum allowable emission concentration of the i contaminant.

Step 2. Calculate the cost of treatment of the i-th pollutant

So as to share the total governance cost. The formula is:

$$\gamma_i = \frac{\eta_i}{\sum\limits_{i}^{n} \eta_i}. \tag{4.8}$$

Among them, M is the total amount of residue, i is the category of pollutants, and C is the total cost of treatment.

Step3 Calculates the unit governance cost of the i-th pollutant

The formula is:

$$\overline{C_i} = \frac{C_i \cdot \gamma_i}{M_i} = C/S_i \cdot M \cdot \sum_{\text{i=1}}^{n} \frac{I_i - E_i}{S_i}. \tag{4.9}$$

Among them, M is the total amount of residue, i is the category of pollutants, and C is the total cost of treatment.

Step 4. Calculates the total cost

$$C_p = C + \overline{C} = C + \sum_{i=1}^{n} \overline{C}_i, \tag{4.10}$$

where C is the total cost of pollution control, and $\overline{C}$ is the cost of virtual pollution control.

- **Afforestation.** In order to repair existing pollution, reduce the probability of bad weather, and improve biodiversity, afforestation is a long-term strategy. The cost is equal to the input labor plus the value of the trees.

4.3.2 The RC accounting system

Based on the above analysis of the impact of maintenance spending, we develop a method called Rehabilitation Cost (RC) to assess the cost of ecological services at the natural loss level. The indicator includes three primary indicators and five secondary indicators. We show the metrics for RC in the table 3.

Table 3: The indicators used in the Repair cost

	Indicators	Notation	Indicators	Notation	Target
RC	Waste detoxification and decomposition investment	RC_1	Solid waste pollution	RC_{11}	↑
	Air and water purification investment	RC_2	Air pollution	RC_{21}	↑
			Water pollution	RC_{22}	↑
	Afforestation investment	RC_3	Severe weather occurrence probability	RC_{31}	↑
			Biodiversity	RC_{32}	↓

Explanation: the larger the five indicators listed in the above table, the more the repair expenditure and the corresponding calculated environmental expenditure costs. Since the cost proportion of each factor is different, for reducing the error caused by calculation, we add the correction coefficient, and finally get the accounting formula of RC is $C_{RC} = \alpha_1 \cdot C_{RC_1} + \alpha_2 \cdot C_{RC_2} + \alpha_3 \cdot C_{RC_3}$.

4.4 Preventive cost

4.4.1 Potential indicators for preventive cost

In this section, we will discuss preventive spending, the cost used to prevent land development and utilization. From the analysis of environmental climate change caused by the Bangladesh land development strategy in [6], we summarize three components for the preventive expenditure: environmental education investment, environmental affairs costs and environmental isolation costs.

- **Environmental education investment** refers to investing capital to cultivate specialized environmental protection personnel or raise people's awareness of environmental protection.
- **The cost of environmental affairs** refers to a series of protective measures taken to prevent pollution, such as the government formulating environmental protection policies and recruiting relevant personnel to implement pollution monitoring.

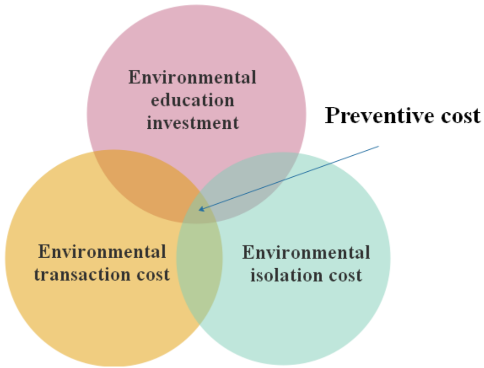


Figure 3: Components of Preventive Cost

- **Environmental isolation costs.** Large-scale projects such as factories and nuclear power plants have great potential damage to the environment. The most direct way to protect life and reduce the impact of environmental pollution is to isolate pollution sources and evacuate nearby residents.

4.4.2 PC accounting system

Based on the above analysis of preventive expenditure indicators, we developed a measure called preventive expenditure (PC) to assess the cost of ecological services at the level of preventive expenditures. The indicator includes three primary indicators and six secondary indicators. We show the metrics for the PC in the table (4).

Table 4: The indicators used in the Preventive cost

	Indicators	Notation	Indicators	Notation	Target
PC	Environmental education investment	PC_1	Educational investment	PC_{11}	↑
			Publicity investment	PC_{12}	↑
	Environmental transaction cost	PC_2	Formulate policies	PC_{21}	↑
			Measuring pollution	PC_{22}	↑
	Environmental isolation cost	PC_3	Pollution source isolation	PC_{31}	↑
			Evacuation personnel	PC_{32}	↑

Explanation: the larger the six indicators listed in the above table, the more natural resource consumption, and the corresponding calculated environmental costs. Since the cost proportion of each factor is different, in order to reduce the error caused by calculation, we add the correction coefficient, and finally get the accounting formula of RC is $C_{PC} = \alpha_1 \cdot C_{PC_1} + \alpha_2 \cdot C_{PC_2} + \alpha_3 \cdot C_{PC_3}$.

4.5 Evaluation of environmental degradation cost

All in all, we built an evaluation system based on the NRD, RC and PC, which integrate the introduced factors. The cost can be summarized by the equation:

$$Cost = NRD + RC + PC. \tag{4.11}$$

5 Performing a Cost Benefit Analysis

5.1 For small community-based project

In this section, we conducted a case of the environmental costs, including a small community project and a large country project. For a small community project, the data to obtain is a challenge, since the missing or ambiguous data sets cannot be used. By the ways from [7], we get the desired data with remote sensing techniques such as GIS.

5.1.1 Area selection

With the aids of Google Earth, we can obtain the map of the different communities in the city of China and selected a few of them for case analysis.

(a) Year 2010. (b) Year 2017.

Figure 4: Comparison of map between 2010 and 2017 for the city of China.

The above pictures show two satellite maps obtained. Based on these data, we established a time-space ecological environment service evaluation model.

5.1.2 Eco-environmental service evaluation model based on spatio-temporal pattern analysis

The areas of different colors in the figure have different ecological service values.

- The green and blue areas are ecological resource areas, such as forest land, and water sources can provide certain ecological resources;
- The construction land is an ecological demand zone, such as houses and roads, which does not contribute to ecological services;
- The yellow area is an unused land and can be developed as a forest land or a construction land.

With the help of the GIS toolbox in Matlab, combined with the above two division rules, we clarify the research object to be the spatial and temporal changes of the ecological resource area, then make a land use transfer network of the study area, which can visually and concretely indicate the mutual conversion between land use types. The situation helps us to reveal the direction of migration and spatial evolution of land use types over a period of time.

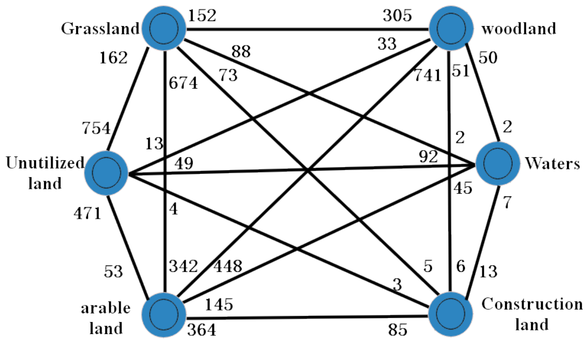


Figure 5: Land use transfer network

Through the land use transfer network shown in Figure 5, we can intuitively find that the grassland in the region is the most transferred to the construction land (increased cost); the second unused land is mainly converted to grassland and forest land (cost reduction). According to the formula, we can get the environmental degradation cost of the region,

$$\begin{aligned} Cost &= C_{NDR_{11}} + C_{NDR_{12}} \\ &= \sum_{i=1}^{n} A_i p_i Q_i. \end{aligned} \tag{5.1}$$

5.2 For "South-to-North Water Transfer" projection

5.2.1 Project overview

"South-to-North Water Transfer Project" is a strategic project in China. The total length of the main canal is 1,273 km, and the annual water transfer scale is 13 billion m^3. The goal is to solve the problem of water shortage in more than 20 large and medium-sized cities along Beijing, Tianjin, Shijiazhuang and Zhengzhou, and to take into account the ecological environment along the line and agricultural water. The engineering route is shown in the figure below.

Figure 6: The midline project of "South-to-North Water Transfer".

We select the city of wuhan in the middle and lower reaches of the han river on the middle route of "south-to-north water diversion project" as the research object, and analyze the environmental cost in the city of wuhan for considering ecological services.

5.2.2 Data Preprocessing

(1). Data collection

Based on the evaluation indicators in the previous ecological service evaluation model, we introduce a series of chemical indicators in various regions of Wuhan from 2007 to 2018 from the China Environmental Monitoring Center. By the data obtained, such as DO, COD, NH_3-, dissolved oxygen, phosphorus content, nitrite nitrogen, etc., and from the literatures [7-9], we collect measurement data of Wuhan at other time points.

(2). Data padding

The availability of data is an important issue. By using unreliable or untrue data, it will not provide an effective assessment. Therefore, the continuity and authenticity of the research data must be ensured. However, not all data can be collected, and in particular, the data provided in the literature is severely fragmented.

In order to improve this situation, four methods have been proposed to improve the data, as shown below.

- If the data value of the indicator is smooth, it can be replaced with the previous data;
- If the previous and subsequent data are available, the average value can be considered as missing;
- If the two groups of data are similar, the missing data in one group can be replaced with the value in the same position in the other group;
- Interpolation method is used for data fitting.

5.2.3 Calculating the environmental degradation cost of "South-to-North Water Transfer"

Step 1. Calculating the cost of natural resource loss

Combined with the data of natural resources (forest area, aquatic resources and crop area) in the vicinity of Hanjiang River in Wuhan in the past 15 years, we have made a map of their changes based on the above data processing method.

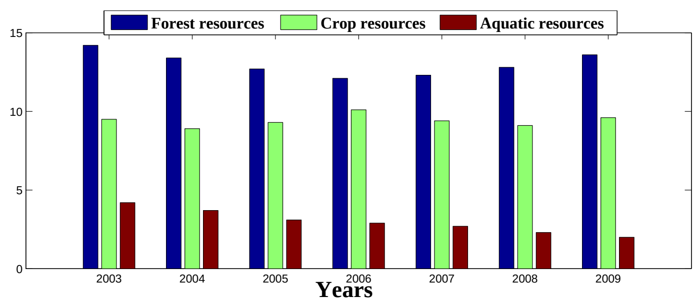


Figure 7: Natural resource changes

From Figure 7, we may observe that

- The early stage of forestland resource area has obvious shrinkage due to the influence of "South-to-North Water Transfer". However, the area of forest land has been increasing year by year and is not included in the calculation.
- Crop resources have a slight fluctuation in area for some reasons, and then it is not included in the calculation.
- Due to the development of "South-to-North Water Transfer", aquatic resources from the river ecosystem is decreasing.

Step 2. Calculating maintenance costs by combining fuzzy principal component analysis

Calculating maintenance costs by combining fuzzy principal component analysis, we collect the chemical solubility of 11 groups of pollutants (including 5 groups of air pollutants, 3 groups of water pollutants and 3 groups of land pollutants). If the maintenance cost of each pollutant is calculated, the cost will be very huge.

Therefore, we decide to use principal component analysis to perform principal component on these 11 groups of pollutants and select substances that have a major impact on the cost of calculation. The specific steps are as follows.

(1) Calculate the comparative treatment cost of various pollutants

We use the literature [10] to calculate the cost of treatment of each pollutant unit in Zhejiang Province as $\overline{C}_i$, and calculate the comparative treatment cost of each pollutant by the following formula.

$$C_{compared} = \overline{C} \cdot (I_i - S_i). \tag{5.2}$$

(2) Data standardization

Since the units of these 11 indicators are different, the data cannot be directly compared. In order to normalize the data, all data is converted to a number between 0 and 1. Contaminants are cost-type indicators that can be standardized by the following formula.

$$x_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}}, i = 1, 2, ..., 15; j = 1, 2, ..., 11, \tag{5.3}$$

where x_{ij} is the j-th indicator of $i$year; x_{max} is the maximum of the indicator x_{ij}; x_{min} is the indicator the minimum value of x_{ij}.

(3) Validity test of data

Since the data obtained are standardized, we directly perform a KMO test on the data, and the test results are shown in Table 5.

Table 5: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.913
Bartlett's Test of	Approx. Chi-Square	1116.051
Sphericity	df	62
	Sig.	0.011

As shown above, the KMO value is 0.913, much higher than 0.5, which indicates that there are many common factors between the indicators. Thus, the method is very suitable for fuzzy principal component analysis.

(4) Fuzzy principal component analysis

Fuzzy principal component analysis is performed on the obtained variables to obtain the global eigenvalue and the contribution rate of each principal component variance (the first principal component contribution rate is 69.875%, and the second principal component contribution rate is 19.947%, which adds up to 89.822%.) and the rotation component matrix, the results are shown in Table 6.

Table 6: Component Matrixa

	Component	
	1	2
SO_2	0.898	0.425
NO_2	0.377	0.805
CO	0.997	0.022
O_3	0.617	-0.204
$PM_{2.5}$	0.926	-0.34
benzene	0.551	0.738
Ethyleneglycol	0.997	0.057
Dichloroethane	0.728	-0.62
Hg	0.973	0.294
Cd	0.929	0.335
Cr	0.953	-0.277

Extraction Method: Principal Component Analysis.

The rotational component of the first principal component in the table is the highest of the 11 indicators, so we consider these three(CO,Hg,Ethyleneglycol) as the main impact indicators.

Step 3. Calculating the cost of prevention

The prevention cost of the"South-to-North Water Transfer Project" mainly comes from the monitoring of the water source along the way and the surrounding geology. Since the government has not disclosed this item, the total cost of our final calculation is

$$Cost = C_{NRD} + C_{RC} + C_{PC}. \tag{5.4}$$

5.3 Project benefit analysis

The project benefit is the benefit of land acquisition development that causes certain damage to the ecosystem service system and leads to environmental degradation, including the investment in the ecosystem service system by preventive cost and remediation cost. The benefit can be divided into two parts: main resource efficiency and environmental benefit.

- **Resource benefit estimate**

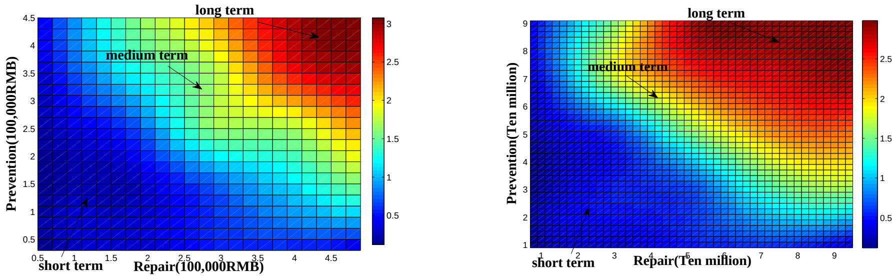
$$C_Z = \sum (Q_i \times k_i) + Q/A_S \times B_S. \tag{5.5}$$

- **Environmental benefit estimate**

$$\begin{aligned} C_h &= C_{h1} + C_{h2} + C_{h3} - C_{h4}, \\ C_{h1} &= Q/A_S \times B_S + Q \times K_S, \\ C_{h2} &= \sum_i^n Q_i \times k_i \times H_i, \\ C_{h3} &= \sum_i^n Q_i \times k_i \times (T_a + T_w + T_g + T_S), \end{aligned} \tag{5.6}$$

where C_{h4} is a constant.

Substituting the data obtained in the previous section into the above formula, we plot the figures of the project benefit results in Figure 8.



(a) Small projects (b) Large projects

Figure 8: Project Benefits Results Map

6 Sensitivity analysis

6.1 Basic issue

Based on the ecological service evaluation model, we firstly select the six indicators, such as production material consumption reduction (NRD_1) and energy consumption reduction (NRD_2) as the variables for local sensitivity analysis (normally, the proportion of preventive cost in environmental cost is relatively small, resulting in the changes in preventive costs (PC_1, PC_2, PC_3) are small, and the eco-service model is considered to be insensitive to preventive cost. To simplify the analysis, the environmental education investment PC_1, environmental transaction costs and environmental isolation costs are accumulated, and preventive expenditure is used. PC indicates). Only one parameter value is changed during analysis, other parameters remain unchanged.

The sensitivity of the model is measured by calculating the amount of change in the model output value when the parameter changes. When calculating, the parameters are slightly disturbed, such as $\pm 5\%$ change, and the response fluctuation caused by the model output to a single input is the sensitivity index.

In the local sensitivity analysis, we use the finite difference method to calculate the sensitivity of each index. The calculation formula is as follows:

$$\frac{\partial y}{\partial x_i} = \frac{y(x^i) - y(x)}{\Delta x_i} + 0(\Delta x) \approx \frac{y(x^i) - y(x)}{\Delta x_i}. \tag{6.1}$$

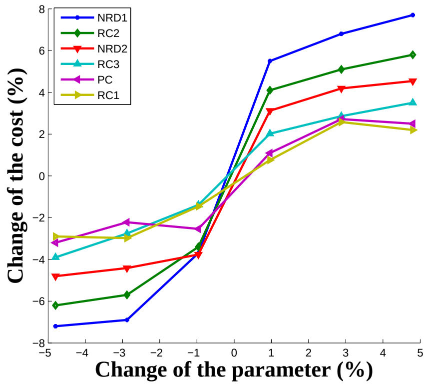


Figure 9: Natural resource changes

6.2 Sensitivity analysis result

- According to the calculation of the range of flow velocity variation, it can be determined that the production material consumption reduction (NRD_1) has the most obvious impact on the model, followed by air and water purification investment (RC_2), energy consumption reduction (NRD_2), and climate change mitigation investment (RC_3), preventive cost (PC), waste decomposition investment (RC_1), when the production material consumption fluctuates by ±5%, the environmental cost fluctuates by about +7.9% and -7.6%, respectively. The waste decomposition investment fluctuates by ±5%, the environmental cost fluctuates by approximately +2.0% and -2.5%, respectively.
- The six parameters are approximately linear with the calculated flow rate and are proportional to changes in environmental costs.
- The fluctuations of the selected parameters are more obvious for the change of the output value of the model (the fluctuation is greater than ±2.0%), which indicates that the indicators selected by the model have good representativeness and the model has good sensitivity and validity.

7 Implications on Planners and Managers

From the title, we can understand the impact of our ecological service model on land use project planners and managers when considering the ecological environment. It indicates that project technicians and managers need to analyze and evaluate the environmental impacts after the implementation of land use planning, and propose countermeasures and measures to prevent or mitigate adverse environmental impacts.

Therefore, we choose 10 square kilometers of land use development area for simulation. However, the data of this development area is more complicated, it needs to simplify the data screening and delete the useless data. Therefore, we use the entropy weight method to process the data. The smaller the information entropy is, the lower the disorder degree of the information is. The greater the utility value of the information is, the larger the weight of the index is. On the contrary, the larger the information entropy is, the higher the disorder of the information is, and the more the utility value of the information is. Small, the weight of the indicator is also smaller. Specific steps are as follows.

Step1. Standardize the data of each indicator.

$$x_i = \frac{s_i - s_{\min}}{s_{\max} - s_{\min}}. \tag{7.1}$$

Step2. Calculate the entropy value of each indicator.

$$e_i = -k \sum p_{ij} \ln(p_{ij}), \tag{7.2}$$
$$k = 1/\ln(n), \tag{7.3}$$
$$p_{ij} = \frac{x_{ij}}{\sum\limits_{i=1}^{m} x_{ij}} = \frac{1}{n}. \tag{7.4}$$

where e_i value range between $[0, 1]$.

Step3. Calculate the difference coefficient between the indicators.

The smaller the entropy value, the larger the coefficient of variation between indicators, the more important the indicator is. Its formula is $g_i = 1 - e_i$.

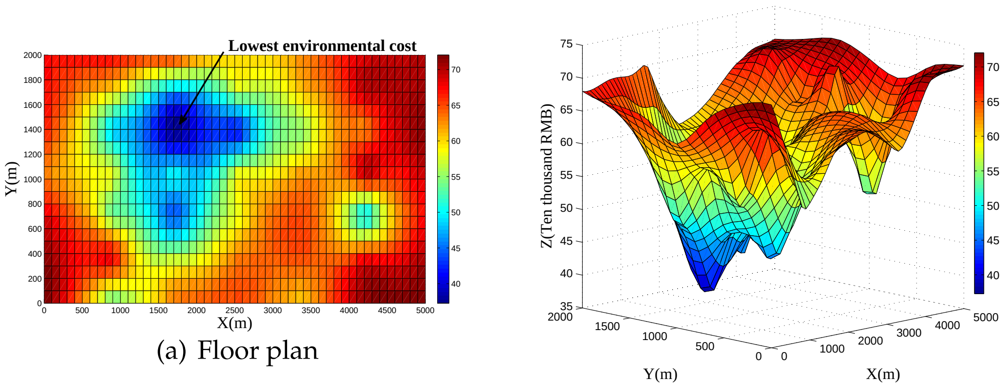
Step4. Define the weight value

$$w_i = g_i / \sum_{i=1}^{m} g_i. \tag{7.5}$$

Step5. Calculate the comprehensive evaluation value

$$v_j = \sum_{i=1}^{m} w_i p_{ij} + \sum_{k=1}^{m} w_k (1 - p_{ij}). \tag{7.6}$$

Finally, the indicator data of the filtered development zone is substituted into the model to obtain the final environmental cost distribution map as in Figure 10.



(a) Floor plan (b) 3D map

Figure 10: Environmental cost distribution map

It can be seen from the figure that the environmental cost of the land use development project is about RMB 350,000, and the location is in the surrounding area of coordinates (1700, 1400). Thus, It helps the project designer's management personnel locate the land development project and the economic cost of the project save.

8 Model Changes Over Time

Over time, science and technology innovation, national environmental protection policies, and national land use development policies are all changing. It also affects our model in a subtle way. Based on this, the model adds human science indicators on the basis of the original, so as to improve the evaluation of the environmental cost of the model over time. Here are the changes that have occurred with the model over time:

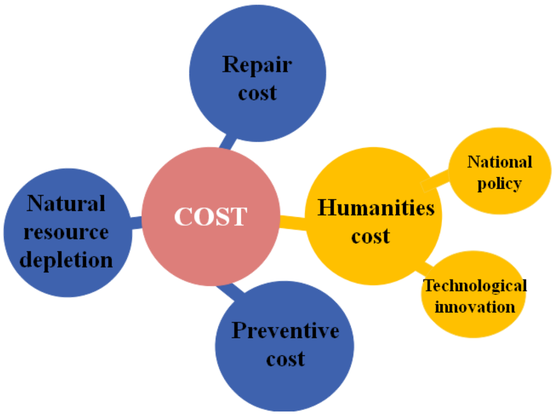


Figure 11: Model after the change

Due to the development of the times, the advancement of science and technology, the further improvement of relevant policies and other human science factors contribute to the ecosystem service system. The relationship between human science factors and environmental costs is as follows.

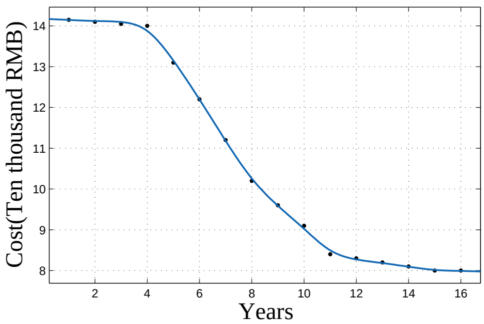


Figure 12: Relationship between human science factors and environmental costs

As can be seen from the figure, the two show a negative correlation trend. As the humanities factor plays a role, the corresponding environmental costs are gradually reduced. Thus, the calculation formula for the final environmental cost can be changed.

9 Strengths and Weakness

9.1 Strengths

- The establishment of the model starts from the definition of environmental cost, and constitutes an ecological service evaluation model for the three parts of natural resource depletion, remediation expenditure and preventive expenditure. Comprehensive methods such as grey correlation analysis and principal component analysis are used. Moreover, the algorithm is simple and easy to learn. The model is based on rigorous mathematical derivation, the solution process is strict, the result is highly reliable, and the persuasive power is strong.
- Through the sensitivity test in the model validity analysis, the model has relative rationality and good generalization.

9.2 Weakness

- Data Deviation: The data we collect comes from multiple websites, and differences in statistical standards may lead to biased conclusions. More importantly, the lack of more metrics of data may lead to errors in the evaluation model.
- Subjectivity: Some subjective methods are used in the model, and some indicators are based on our own experience and intuition. And because some conditions are simplified, there is a gap with the actual, thus affecting the accuracy of the results.

10 Conclusion

In this paper, we use three components, natural resource depletion, preventive cost and repair cost for considering the true economic cost of land use projects in ecosystem services. To analyze and model the effectiveness of the model, we give the sensitivity analysis to obtain the main impact factor of the model accuracy and the results show the model is effective.

In addition, we extract the data from the collected complex data by the entropy weight method, and substitute the model to obtain the environmental cost distribution map in the whole region. Finally, as time goes by, our model makes appropriate changes, and the introduction of human science factors is negatively correlated with environmental costs, resulting in new calculation expressions.

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