

# Assessment of Environmental Degradation Costs: A Case Study of Beijing and Tianze Agricultural Parks

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**Abstract.** Nowadays, the community of human destiny has gradually become the consensus of people. The pursuit of economic benefits and the neglect of ecological benefits will bring serious consequences. Therefore, predicting the cost of environmental degradation for managers is an urgent problem we need to solve.

We establish a mathematical model to predict the cost of environmental degradation. And we ignore some insignificant factors and choose seven factors as indicators in our model under the consideration of actuality. To make the model more intuitive, we transform environmental degradation costs into ecosystem services values and calculate the value of each service in the ecosystem separately. At the same time, we use Analytic Hierarchy Process to calculate the weight of each service according to the judgment matrix. Then we introduce a concept in economics " Weighted Average Cost of Capital (WACC) ". Hence, we can derive the final cost of environmental degradation. Next, we take Beijing's construction as an example of a large national project and Tianze agricultural park as an example of a small community-based project to estimate their respective degradation costs.

As for the effectiveness analysis, we use polynomial 7-th approximation to fit curve and prove its effectiveness successfully. According to the data we get from fitting curve, we analyze the ideal environment level of 2020. The result shows that land use projects exist many shortcomings and we give land use project planners and managers some advice to help them reach the ideal environment level in 2020.

Since ecosystem service valuation is pretty complex and some indicators are influenced by humanity factor, we cannot ensure the accuracy of our calculation. We improve our model and add fuzzy mathematic method into AHP. By using Fuzzy Analytic Hierarchy Process, we can let the weight change automatically over time. Therefore, we success in improving our model and adding time factor into our improved model.

Finally, we analyze our works and then discuss strengths and weaknesses of our model.

## 1. Introduction

We gradually realize that our environment has degraded, and that we have lost the function that environment brings to us and the world—ecosystem services. Ecosystem services are the many and varied benefits that humans freely gain from the natural environment and from properly-functioning ecosystems.

People tend to ignore that land use projects may cause environmental degradation and limit or remove ecosystem services. Especially in small-scale land use projects, these impacts easily seem negligible. However, the accumulation of these small projects must be the negative impact on



ecosystem and lead to environmental degradation. If we take these ecosystem service functions into consideration of economic costs, we can reduce the negative impact on the biosphere caused by land use. First of all, our task is to establish an ecological services valuation model to account for environmental degradation costs into land use development projects. Then we can use this model to calculate the true economic cost of land use projects. Next, we need to perform a cost benefit analysis of land use projects of varying sizes through our model. Thirdly, we need to evaluate the effectiveness of our model. Finally, we add time parameters to the model to predict future land use project costs and use it to suggest land use project planners and managers.

In fact, the concept of ecosystem services is not a new one nowadays. As early as 1974, Holdren and Ehrlich proposed it. However, until 1997, Costanza estimated the value of ecosystem services which really arouse the world's attention to this topic [1]. In 2005, the concept of ecosystem services gained broader attention when the United Nations published its Millennium Ecosystem Assessment (MEA). On the basis that Costanza has defined the connotation of ecosystem service functions, researchers in different countries have proposed various methods for the value of ecosystem services, including the equivalent method, market value method and shadow price method. On the other hand, different researchers have various classifications of ecosystem service functions. Hence, we make categories of ecosystem service ourselves according to one of numerous papers [2], simplifying and modifying as we need. Then we integrate several methods for the value of ecosystem services above in our model to estimate ecosystem services value.

## 2. Analysis

Natural environmental resources such as the atmosphere, water and land are non-exclusive resources that have long been used freely by people [3]. In the past, environmental values have not received enough attention. Nowadays, with the development of society, we have gradually realized the importance of the value of ecosystem services. We have begun to demand a corresponding price for some projects that consume natural resources. For this purpose, we establish a model for quantifying the cost of environmental degradation.

The value of ecological services is a relatively abstract concept and is hard to quantify. When we define this concept and refer to the methods used in the World Bank report [4] and other articles, we decide to use economic methods such as environmental cost value to quantify.

The cost of environmental degradation is measured by estimating the value of the original ecosystem and the possible consequences of development. First, we divide ecosystem services into three types. Among the three types, we ignore the services with less economic value and consider the specific seven services. Secondly, we introduce the concept of "Weighted Average Cost of Capital" to further refine our ecological environment value. Furthermore, instead of simply using the analytic hierarchy process, we use the fuzzy analytic hierarchy process to obtain the proportion of these four types in the evaluation of ecosystem service value. At the same time, through methods like the shadow price method and market assessment method, we quantify the value of these specific services and combine them with their respective weights to arrive at the final environmental degradation cost calculation formula. With the WACC formula, we can calculate the cost of environment degradation.

## 3. Assumptions and Justifications

- The ecological environment value can be quantified, and we use this to estimate the cost of environmental degradation.
- We assume that the functions of the ecosystem have three broad categories, and the three categories can be subdivided into seven indicators.
- We assume that each ecosystem could produce their own products. They are independent of each other and do not affect each other.
- To simplify the calculation, we assume that the land's ability to dispose of waste is the ability to digest nitrogen and phosphorus in the land. At the same time, we consider that the value of water conservation in the land is the cost of storing water.

- We believe that the various functions of the soil can be transformed by methods such as market value method and shadow price method because they are abstract.
- We assume that the relevant data in the model will not change in the short term, which means that the price and other indicators are sticky.
- We assume that the value of the main elements of the main nutrient is approximately equal to the soil nutrient value in the ecosystem for the convenience of calculation.
- We ignore some parts of ecosystem services value because of their negligible influence on the final result.

#### 4. Notations

<i>Symbols</i>	<i>Definition</i>	<i>Unit</i>
$E$	The ecosystem services value	yuan
$A_i$	The indicator of the i-type of ecosystem services	
$B_j$	The indicator of specific services j	
$\beta_{A_i}$	The weight of $A_i$	
$\beta_{B_j}$	The weight of $B_j$	
$E_j$	The value of services j	yuan
$W_c$	The amount of water conservation	t
$P_w$	The cost of storing unit water	yuan/t
$S_p$	The area of the plant of the project	hm <sup>2</sup>
$P_c$	The price of carbon	yuan/t
$P_o$	The price of oxygen	yuan/t
$B_n$	The annual net productivity of the plant	t/(hm <sup>2</sup> *age e)
$R_c$	The rate of carbon content of carbon dioxide	
$V_c$	The annual value of plant carbon sequestration	yuan/age
$V_o$	The annual value of plant oxygen release	yuan/age
$S_l$	The area of the cultivated land of the project	hm <sup>2</sup>
$M$	Cultivated land erosion modulus	t/(hm <sup>2</sup> *age e)
$W_l$	The reduction amount of cultivated land soil erosion	t
$T_l$	The average thickness of the land tillage layer	m
$W_a$	The reduction area of land resource	hm <sup>2</sup>
$I$	The annual average income of cultivated land	yuan/hm <sup>2</sup>
$V_e$	The value of cultivated land reduction soil erosion	yuan
$V_s$	The value of reduce siltation	yuan
$R_N$	The nitrogen content in unit erosion	g/kg
$R_P$	The phosphorus content in unit erosion	g/kg
$R_K$	The potassium content in unit erosion	g/kg
$P_N$	The market price of nitrogen	yuan/kg
$P_P$	The market price of phosphorus	yuan/kg
$P_K$	The market price of potassium	yuan/kg
$V_f$	The fixed fertility value	yuan
$R_m$	The organic matter content in unit erosion	g/kg
$P_f$	The average price of fuel wood	yuan/kg
$V_m$	The value of organic matter	yuan
$S_r$	The area with cultural research ecosystem value	hm <sup>2</sup>
$P_r$	The cultural research value per unit area	yuan/hm <sup>2</sup>
$H$	The total tourism revenue in the project area	yuan

$R_t$	The proportion of ecological attractions to the total number of tourist attractions	
$V_n$	The functional value of nutrient cycling in cultivated land	yuan
$V_b$	The value of the biobank involved in the circulation of nutrients	yuan

**5. The Basic Model of Ecosystem Service valuation**

In our model, the value of ecological services is divided into three categories: regulation service, cultural service, and support service. These three types are divided into air quality regulation value, erosion regulation and soil formation value, culture and research value, recreation and ecotourism value, nutrient cycling value, land consumption of manure value and water conservation. We calculate the value of each of these seven categories separately [5], and then calculate the final value based on the weight. Finally, we can arrive at the cost of land degradation.

Goal	Criteria	Indicator
Ecosystem Service Valuation $E$	Regulating Services $A_1$	Air quality regulation $B_1$
		Erosion regulation and soil formation $B_2$
	Cultural Services $A_2$	Culture and research $B_3$
		Recreation and ecotourism $B_4$
	Supporting Services $A_3$	Nutrient cycling $B_5$
		Land consumption of manure $B_6$
		Water conservation $B_7$

**Figure 1.** Hierarchy structure.

According to our classification, we make a hierarchy structure above (Figure 1).

First of all, we use Analytic Hierarchy Process (AHP) method to calculate the weight of each indicator.

*5.1. The process of AHP*

Analytical Hierarchy Process is a methodology developed by Saaty<sup>[6]</sup> which can be used in any situation with many integrating, interrelating and interdependent factors. By using this method, we can give each valuation a weight.

The AHP algorithm has four major steps:

*5.1.1. Establish hierarchical structure model*

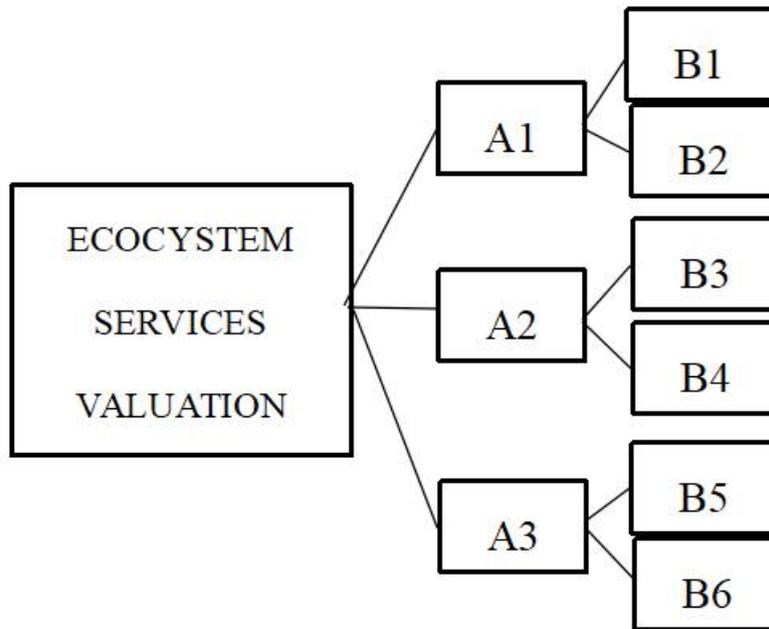


Figure 2. Hierarchy structure.

5.1.2. Construct judgement matrix

Since the hierarchy structure is established, we decision-maker should derive “1-9” ratio-scale [6] priorities reflecting the relative importance of objectives via pairwise comparisons with respect to the goal of the problem. Following this rule, we decision-makers can derive ratio-scale which reflects the priority of each ecosystem service valuation.

By comparing the effect of indexes and add our judgement from data we have into consideration, we construct the pairwise comparison matrix  $E-B_i$  and  $B_i-C_j$ .

where  $i=1,2,3,4$  and  $j=1,2, \dots, 8$

While choosing the definition of scales, we employ the research result of Satty[6].

In psychology, the more gradients of scale, the more difficulties we will meet while judging. Finally, we choose “1-9” ratio-scale chart.

Intensity of importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values

Chart 1: Ratio-scale chart of AHP

5.1.3. Hierarchical sorting and consistency testing

As we all know, N-th order positive reciprocal matrix A is uniform matrix if and only if the largest eigenvalue  $\lambda_{max}$  is equal to n, else the largest eigenvalue  $\lambda_{max}$  is greater than n. Therefore, we can utilize the  $\lambda_{max}$  to test the consistency of each judgement matrix.

Firstly, calculate the coincidence indicator CI:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

Secondly, find out the corresponding mean random consistency index RI from the following chart given by Saaty [6].

<i>n</i>	1	2	3	4	5	6	7	8	9
<i>RI</i>	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Chart 2: The value of *RI*

Thirdly, run out the consistency ratio CR

$$CR = \frac{CI}{RI} \quad (2)$$

If  $CR < 0.10$ , we can consider the consistency is acceptable, else we should go back to Step2 and reconstruct the judgement matrix.

#### 5.1.4. Calculate the weight of each indicator

As to each judgement matrix, find out the eigenvector corresponding to the maximum eigenvalue  $\lambda_{\max}$  and standardize it. Then we have the weight of each indicator.

### 5.2. The seven kinds ecosystem services value

#### 5.2.1. The air quality regulation value

In this paper, two indicators of carbon fixation and oxygen release are used to reflect this function.

Carbon sequestration value  $V_c$ :

$$V_c = 1.63 \times S_p \times P_c \times R_c \times B_r \quad (3)$$

$V_c$  is the annual value of plant carbon sequestration;  $S_p$  is the area of the plant of the project( $\text{hm}^2$ );  $P_c$  represents the price of carbon(yuan/t);  $R_c$  represents the rate of carbon content of carbon dioxide;  $B_n$  is the rate of carbon content of carbon dioxide( $\text{t}/(\text{hm}^2 \cdot \text{age})$ ).

Oxygen release value  $V_o$ :

$$V_o = 1.19 \times S_p \times P_o \times R_c \times B_n \quad (4)$$

$V_o$  is the annual value of plant oxygen release;  $P_o$  represents the price of oxygen(yuan/t).

Therefore, the air quality regulation value  $E_1$ :

$$E_1 = V_c + V_o \quad (5)$$

#### 5.2.2. The erosion regulation and soil formation value

The soil-fixing and fertilizing functions of the land have three aspects: maintaining soil fertility, reducing sedimentation in rivers and lakes, and fixing fertility (fertilizer and organic fertilizer). We use the alternative market method<sup>[5]</sup> and shadow engineering method<sup>[5]</sup> to calculate the value of these three aspects of land development. And the following is the equation.

$$E_2 = V_e + V_s + V_f + V_m \quad (6)$$

where

- $E_2$  represents the value of erosion regulation and soil formation;
- $V_e$  represents the value of cultivated land reduction soil erosion;
- $V_s$  represents the value of reduce siltation;
- $V_f$  represents the fixed fertility value;
- $V_m$  represents the value of organic matter.

The formula for calculating the total amount of soil erosion in cultivated land is

$$W_1 = S_1 \times M \quad (7)$$

The area  $W_a$  of farmland to reduce the loss of land resources is obtained by the total reduction amount of cultivated land soil erosion divided by the average thickness of the cultivated layer of the land.

$$W_a = \frac{W_1}{T_1} \quad (8)$$

where

- $S_1$  represents the area of the cultivated land of the project;
- $M$  represents cultivated land erosion modulus;
- $W_a$  represents the reduction area of land resource(hm<sup>2</sup>);
- $W_1$  represents the reduction amount of cultivated land soil erosion(t);
- $T_1$  represents the average thickness of the land tillage layer(m).

The annual average income of cultivated land is used as the opportunity cost of reducing the abandoned land to calculate the value of the total amount of soil erosion.  $V_e$  is the value of reducing the total amount of soil erosion in cultivated land.  $I$  is the annual average income of cultivated land. The value of land erosion can be obtained by substituting above numbers.

$$V_e = W_a \times I \quad (9)$$

The value of reducing siltation

According to the laws of sediment movement in China's main river basins, 24% of the sediments lost by soil erosion redeposited in reservoirs, rivers and lakes. This part of the sediment directly causes the decrease of water storage of reservoirs, rivers and lakes, which increase the opportunities for drought and flood disasters, and another 33% have been stranded and 37% have entered the sea [7]. This paper only considers the siltation of 24% of reservoirs and rivers and lakes, which is the annual economic value of sedimentation. According to the shadow engineering method, we calculate the value of reducing sedimentation in rivers and lakes:

$$V_s = W_1 \times 24\% \times P_w \quad (10)$$

The value of fixed fertility

The value of fixed fertility is mainly calculated based on the value of soil fertility in reducing soil loss. Among them, the value of organic matter loss is determined by the cost of fuel wood that can be increased by cultivated land.

$$V_m = \sum (R_j \times P_j) \times W_1 \quad (11)$$

$$V_m = W_1 \times R_m \times P_f \quad (12)$$

where

- $R_j$  is the content of the j-th nutrient element in the unit erosion (g/kg);
- $P_j$  is the market price of the j-th nutrient element (yuan/kg);
- $R_m$  is the organic matter content in unit erosion;
- $P_f$  is the average price of fuel wood.

### 5.2.3. The value of cultural and research

The value of cultural research functions of various ecosystems mainly includes related basic scientific research, teaching internships, and cultural propaganda. To accurately calculate the value of cultural research functions often requires data such as relevant research investment and actual research costs, only the general value can be referred to since the relevant information cannot be obtained at present.

$$E_3 = S_r \times P_r \quad (13)$$

where

- $S_r$  represents the area with cultural research ecosystem value;
- $P_r$  represents the cultural research value per unit area.

### 5.2.4. The value of recreation and ecotourism

The value of leisure and entertainment can be calculated according to the proportion of ecotourism in the value of tourism.

$$E_4 = H \times R_t \quad (14)$$

where

- $H$  represents the total tourism revenue in the project area;
- $R_t$  represents the proportion of ecological attractions to the total number of tourist attractions.

### 5.2.5. The nutrient cycling value[5]

The nutrient cycling of ecosystems is mainly carried out between biobanks, litter banks and soil banks. Our model only considers soil banks and biobanks. In this paper, only the relatively high levels of nitrogen, phosphorus and potassium are considered for the nutrients in the biobanks and soil banks involved in the evaluation.

$$E_5 = V_n + V_b \quad (15)$$

$$V_n = \sum_1^m NPP_J (C_{nj} P_n + C_{pj} P_p + C_{kj} P_k) V_n = \sum_1^m NPP \quad (16)$$

$$V = \sum_1^m M_J (S_{nj} P_n f_n + S_{pj} P_p f_p + S_{kj} P_k f_k) V \quad (17)$$

$E_5$  is the functional value of the nutrient circulation of the land;  $V_n$  is the value of the bio-library involved in the circulation of nutrient elements;  $C_{nj}$  is the percentage of nitrogen in the biomass of the j-type agricultural products.  $C_{pj}$  is the percentage of phosphorus in the biomass of the j-type agricultural products;  $C_{kj}$  is the percentage of potassium in the biomass of the j-type agricultural products;  $P_n$ ,  $P_p$  and  $P_k$  correspond to the market price of nitrogen, phosphorus and potassium respectively.  $V_b$  is the value of nutrient cycling in the soil bank.  $M_J$  is the total soil pool of the j-type agricultural products;  $S_{nj}$  is the percentage of nitrogen in the soil bank of the j-type agricultural products;  $S_{pj}$  is the percentage of phosphorus in the soil bank of the j-type agricultural products;  $S_{kj}$  is the j-th percentage of potassium in the soil bank of agricultural products.

### 5.2.6. The value of land consumption of manure.

The land consumption of livestock manure can reduce the pollution of livestock and poultry manure. Our model mainly considers the ability of land to absorb nitrogen and phosphorus. We determine the calculation method for arable land consumption waste:

$$E_6 = S_1 \times (\sum V_j \times P_j) \quad (18)$$

$V_j$  is the amount of nitrogen and phosphorus in the year of cultivation.  $P_j$  is the price of j fertilizer, and  $S_1$  is the area of cultivated land.

### 5.2.7. The value of land conservation water source

$$E_7 = W_c \times P_w \quad (19)$$

where

- $E_7$  is the value of water conservation.
- $W_c$  is the conservation water source.
- $P_w$  is cost of storing unit water.

## 5.3. Calculation of the cost of Environmental Degradation

We combine the cost of environmental degradation and economic method WACC together, by defining parameters in this method we can transform this cost into economic category, so that we success to quantify this cost.

$$W_i = \beta_{B_i} \quad (20)$$

$$K_i = E_i \quad (21)$$

$$WACC = \sum_{i=1}^n W_i \times K_i \quad (22)$$

## 6. Application of models in land use projects

### 6.1. Calculate the weights

Following the process of AHP, we consider different degrees of indicators and get these judgement matrixes.

① Judgement Matrix E~A:

$$E \sim A = \begin{pmatrix} 1 & 5 & 3 \\ \frac{1}{5} & 1 & \frac{1}{3} \\ \frac{1}{3} & 3 & 1 \end{pmatrix}$$

	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	βA
A <sub>1</sub>	1	5	3	0.6370
A <sub>2</sub>	$\frac{1}{5}$	1	$\frac{1}{3}$	0.1047
A <sub>3</sub>	$\frac{1}{3}$	3	1	0.2583

CI=0.0193; CR=0.0332<0.1000

So, matrix E~A through the consistency examination.

② Judgement Matrix A1~B:

$$A_1 \sim B = \begin{pmatrix} 1 & 3 \\ \frac{1}{3} & 1 \end{pmatrix}$$

	B <sub>1</sub>	B <sub>2</sub>	βB
B <sub>1</sub>	1	3	0.7500
B <sub>2</sub>	$\frac{1}{3}$	1	0.2500

CI=0; CR=0<0.1000

So, matrix E~A through the consistency examination.

③ Judgement Matrix A2~B:

$$A_1 \sim B = \begin{pmatrix} 1 & \frac{1}{7} \\ 7 & 1 \end{pmatrix}$$

	B <sub>3</sub>	B <sub>4</sub>	βB
B <sub>3</sub>	1	$\frac{1}{7}$	0.1250
B <sub>4</sub>	7	1	0.8750

CI=0; CR=0<0.1000

So, matrix E~A through the consistency examination.

④ Judgement Matrix A3~B:

$$A_3 \sim B = \begin{pmatrix} 1 & 2 & \frac{1}{5} \\ \frac{1}{2} & 1 & \frac{1}{7} \\ 5 & 7 & 1 \end{pmatrix}$$

	B <sub>5</sub>	B <sub>6</sub>	B <sub>7</sub>	βB
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B <sub>5</sub>	1	2	$\frac{1}{5}$	0.1666
B <sub>6</sub>	$\frac{1}{2}$	1	$\frac{1}{7}$	0.0938
B <sub>7</sub>	5	7	1	0.7396

$$CI=0.0193; CR=0.0332<0.1000$$

So, matrix E~A through the consistency examination.

After calculating all the weights, we can get the total sequencing:

**Table 1.** Total sequencing.

	<i>A1</i> <b>0.6370</b>	<i>A2</i> <b>0.1047</b>	<i>A3</i> <b>0.2583</b>	<i>Sequencing</i>
<b>B1</b>	0.7500	0	0	<b>0.4778</b>
<b>B2</b>	0.2500	0	0	<b>0.1593</b>
<b>B3</b>	0	0.1250	0	<b>0.0131</b>
<b>B4</b>	0	0.8750	0	<b>0.0916</b>
<b>B5</b>	0	0	0.1666	<b>0.0430</b>
<b>B6</b>	0	0	0.0938	<b>0.0242</b>
<b>B7</b>	0	0	0.7396	<b>0.1910</b>

$$CR = \frac{0.0193 \times 0.2583}{0.5800 \times 0.2583} = 0.0333 < 0.1000$$

6.2. Application in small community-based projects

Using the basic model we establish above, we take “Tian-ze agricultural park construction project”<sup>[8]</sup> as an example. By combining the data<sup>[8]</sup> and WACC together, we finally work out the cost of this project.

**Table 2.** The data of the small project.

<b>Indicator</b>	<b>Amount</b>
C(t)	377561.72
O(t)	275643.22
Soil Erosion Modulus (t/(km <sup>2</sup> a <sup>1</sup> ))	1940
Reduction in Soil Erosion(t)	9113.78
Soil Water Storage(m <sup>3</sup> )	12492.18
Area(m <sup>3</sup> )	15188.93
Soil Fertility (yuan)	33800

$$WCAA(S. project) = 2.3721 \times 10^7 \text{ yuan}$$

6.3. Application in large national projects

Similarly, we take “Beijing urban and rural planning standardized land use project”<sup>[5]</sup> as an example. Finally, we work out the cost of this project.

**Table 3.** The data of the large project.

<b>Indicator</b>	<b>Amount</b>
Soil turnover of <i>N</i>	0.08
Soil turnover of <i>P</i>	0.01
Soil turnover of <i>K</i>	0.01

Average content of elements in biological library- <i>N</i>	3.09%
Average content of elements in biological library- <i>P</i>	0.74%
Average content of elements in biological library- <i>K</i>	3.28%
The cost of the reservoir (yuan/m <sup>3</sup> )	6.48
Mean soil density(g/cm <sup>3</sup> )	1.3
Mean soil thickness(m)	0.5
Average land income(yuan/hm <sup>2</sup> )	32000
Annual consumption of <i>N</i> (kg/hm <sup>2</sup> )	60
Annual consumption of <i>P</i> (kg/hm <sup>2</sup> )	12
Price of <i>N</i> (yuan/t)	3152
Price of <i>P</i> (yuan/t)	8823
Price of <i>K</i> (yuan/t)	3455
Price of Oxygen (yuan/t)	1000
Price of Carbon (yuan/t)	1200
The carbon content of carbon dioxide	27.27%
Scientific research value of unit area of wetland(yuan/(a×hm <sup>2</sup> ))	382

$$WCAA(L. project) = 7.6913 \times 10^9 \text{ yuan}$$

## 7. The effectiveness of the model

As the ecosystem service valuation is hard to quantize, we apply AHP method into our model and it is used to measure the importance between these indicators and allocate weights of each one. However, AHP is a method with too many humanity factors, that is to say, it has poor objectivity. Comparing to linear addition method, giving each indicator a weight is more important. Because each indicator plays different role in different ecosystem, while using AHP we judge each importance according to data we get from specific projects so that we can reduce some error led by subjectivity.

### 7.1. Polynomial 7-th Approximation

To test the effectiveness, we decide to apply our model to China Environment Data from 2000-2015. After working out all the valuation, we get a set of data and we fit curve through tendency of increase and decrease these data. Using the curve we have, we calculate the data of 2016 and compare it to valuation we calculate by real data.

We get a scatter plot of Data, and then we use polynomial approximation to fit the curve. Finally, we get the plot of Fitted Curve.

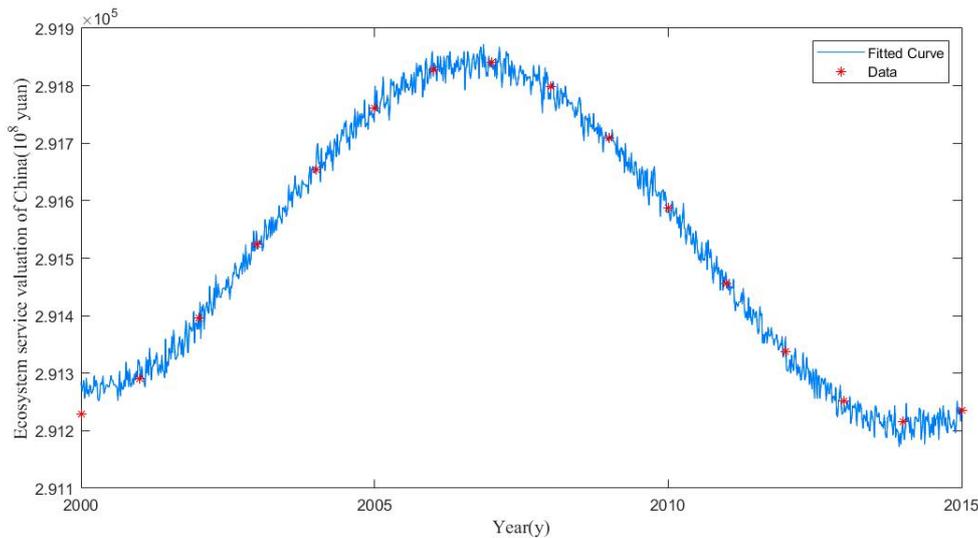


Figure 5. The plot of fitted curve.

7.2. The feasibility of curve fitting

By using Polynomial 7-th Approximation, we get the curve above. The Adjusted R-square of this approximation is 0.9872, which is highly approach to 1. Hence, we can think this curve is relatively scientific.

7.3. The effectiveness examination

According to the data we get from China Statistical Yearbook 2016, we calculate the data of 2016. Then we go back to the fitted curve we get and compare the data of 2016 on this curve to the data we calculate.

Fitted data	2.913
Real data	2.9128957

We can see that the data we fitted is highly approach to the real data. Hence, the model is effective and scientific.

8. Implications on land use project planners and managers

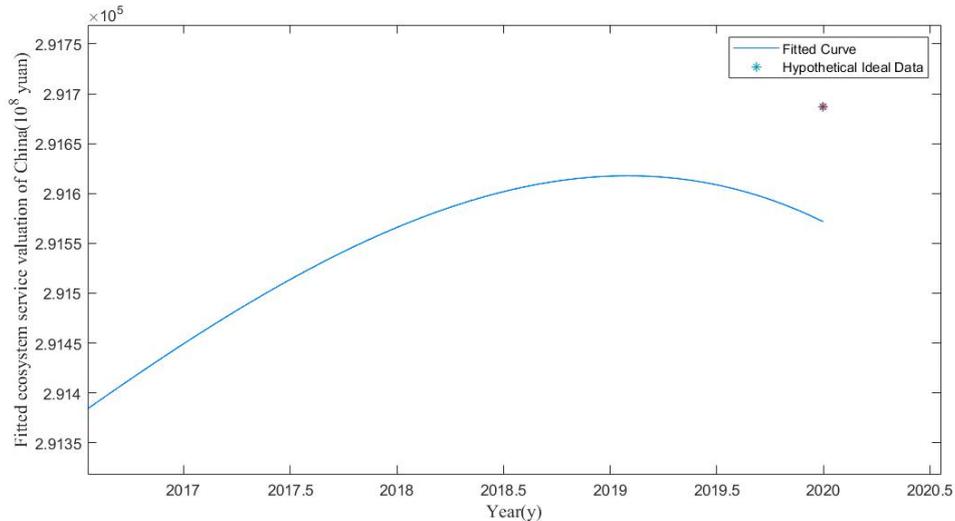
For project planners and managers, the cost of environmental degradation is a non-negligible project when calculating costs. In our model, we could calculate the value weights which are contained in each part of the ecosystem. Although it includes subjective factors, it can adjust the proportion of factors with environmental changes, so this is also an advantage for measuring value.

We analyze the data we calculate while testing the effectiveness of model, and we find that the ecosystem service valuation of China shows a letter “U” tendency. In the plot, the valuation arrives the maximum in 2007-2008 when the whole country was preparing the Olympics. After that, land development is dominant. The most significant change is the valuation decreased over time.

For land use project planners and managers, they should realize that the rapid urbanization has seriously endangered the ecological quality of ecosystem. Especially for land plan bureau in government, it should pursue new ecological projects and consider the cost of environment degradation when developing land. It is necessary to aware that we should not only consider the current profits, but also consider the long-term profits according to the development purpose.

Take data from the 13th five-year plan - statistics of major indicators of resources and environment into our consideration and apply our model. We work out the hypothetical ecosystem service valuation of 2020.

Hypothetical ideal data	2.91687
Fitted data	2.91572



**Figure 6.** The fitted curve from 2016 to 2020.

From this figure, we can know that if land use planners and managers use the old way, the indicators of 2020 cannot be reached. It’s high time that they should devote greater effort to optimize their land use projects.

**9. The improved model about time factor**

The ecological environment will change with natural factors such as storms, mudslides and other unpredictable factors over time. It is important to note that our model is applicable in the short term under the assumption we design. But in the long run, we should properly modify the weight according to changes in the environment. At the same time, the market value of many elements will change with time. In a certain period of time, we need to recalculate the ecological environment value to estimate the corresponding environmental degradation cost. But the basic framework of the calculation remains the same.

As time going by, the ecosystem will change. The weight of each indicator we calculate before will not be applicative. Hence, we should reconstruct the judgement matrix. While in this improved model, we combine fuzzy mathematical method and AHP together, which we call “FAHP”. It has a new type of ratio-scale chart.

For fuzzy judgement matrix R, we can let

$$\begin{aligned}
 r_{ij}(\alpha) &= \log_{\alpha} a_{ij} + 0.5 \\
 0 &\leq r_{ij}(\alpha) \leq 1
 \end{aligned}
 \tag{23}$$

Intensity of importance	Definition
0.5	Equal importance
$\log_{\alpha} 3 + 0.5$	Weak importance
$\log_{\alpha} 5 + 0.5$	Strong importance
$\log_{\alpha} 7 + 0.5$	Demonstrated importance
$\log_{\alpha} 9 + 0.5$	Absolute importance
$\log_{\alpha} i + 0.5, i=2,4,6,8$	Intermediate values

Chart 3: Ratio-scale chart of FAHP

According to the research of Xu Yang etc. [10], we can define the parameter  $\alpha$  as a bridge of time and ratio-scale.

$$\alpha = 81 \times \psi$$

$$\psi = \left[ \frac{year}{10} \right] \quad (24)$$

With time going by, the improved model can change weight of each indicator. This is what parameter  $\alpha$  in this model.

## 10. Strengths and Weaknesses

### 10.1. Strengths

- Using the fuzzy analytic hierarchy process to derive the proportion of each value component in the ecosystem, which could give the planners and managers a more direct value assessment.
- Water resources, land resources, the atmosphere, etc. considered into the model, the deviation between the ecological environment value estimation and the actual value is acceptable. It means that our model could be used to predict the true economic cost of environmental degradation.
- Using a variety of analytical calculation methods such as analytic hierarchy process, shadow price method, market value method to convert the abstract ecological value cost into economic cost.
- After testing, the model used is applicable to both large projects and small projects. The model is effective.

### 10.2. Weaknesses

- The analytic hierarchy process is subjective, and the actual weight may be slightly different from the calculation.
- The calculation method will have errors, so the calculated value may be not so accurate.
- The weights are averaged, so the weights in the model and the exact values corresponding to each year may be biased.
- The subtle effects generated in small projects are not taken into account in the model. When multiple small projects are combined, the combination of these subtle effects has a large impact, which could not be calculated in our model.

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### Appendix

Indicators	2015	2020
Cultivated land ownership (100 million mu)	18.6 5	18.65
New construction land scale (ten thousand mu)	-	-
Water consumption per ten thousand yuan of GDP decreased (%)	-	-
Energy consumption per unit of GDP reduced (%)	-	-
Proportion of non-fossil energy in primary energy consumption (%)	12	15
Carbon dioxide emissions per unit of GDP reduced (%)	-	-
Forest development	21.6 6	23.04
	151	165
Air quality	76.7	>80
	-	-
Surface water quality	66	>70
	9.7	<5

**Chart 1.** Statistics of major resources and environment indicators in China's 13th five-year plan.

Year	Hectares
2000	65336.2
2001	65331.6
2002	65660.7
2003	65706.1
2004	65701.9
2005	65704.7
2006	65718.8
2007	65702.1
2008	65687.6
2009	64777.5
2010	64728.0
2011	64686.5
2012	64646.6
2013	64616.8
2014	64574.1
2015	64545.7
2016	64512.7

**Chart 2.** Statistics of land use in China over the years (2000-2016).

Year	Total water resources (billion cubic meters)	Rainfall (billion cubic metres)
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2000	27701	60092
2001	26868	58122
2002	28261	62610
2003	27460	60416
2004	24130	56876
2005	28053	61010
2006	25330	57840
2007	25255	57763
2008	27434	62000
2009	24180	55959
2010	30906	65850
2011	23257	55133
2012	29529	65150
2013	27958	62674
2014	27267	62602
2015	27963	62569
2016	32466	68672

**Chart 3.** Statistics of water environment in China over the years (2000-2016).

Year	Total industrial emissions (billion cubic metres)	Total nox emission (tons)
2000	138145	1995.1
2001	160863	1947.2
2002	175257	1926.6
2003	198906	2158.5
2004	237696	2254.9
2005	268988	2549.4
2006	330990	2588.8
2007	388169	2468.1
2008	403866	2321.2
2009	436064	2214.4
2010	519168	2185.1
2011	674509	2217.9
2012	635519	2117.6
2013	669361	2043.9
2014	694190	1974.4
2015	685190	1859.1

**Chart 4.** Statistics on China's annual exhaust emission and treatment (2000-2015).

Year	Total investment in environmental pollution control
2001	1166.7
2002	1456.5
2003	1750.1
2004	2057.5
2005	2565.2
2006	2779.5
2007	3668.8
2008	4937.0
2009	5258.4
2010	7612.2
2011	7114.0
2012	8253.5
2013	9037.2
2014	9575.5
2015	8806.4
2016	9219.8

**Chart 5.** Statistics on China's annual exhaust emission and treatment (2000-2015).