| For office use only | | Team Control Number | For office use only | |
|---|---|---|---|---|
| T1 | ________________ | 1916921 | F1 | ________________ |
| T2 | ________________ | | F2 | ________________ |
| T3 | ________________ | Problem Chosen | F3 | ________________ |
| T4 | ________________ | E | F4 | ________________ |

**2019 MCM/ICM Summary Sheet**

# Environmental Degradation Should Draw Attention


## Abstract

Environmental degradation caused by human activities has a significant impact on ecosystem services. The task of our team is to conduct a cost-benefit analysis for land development projects based on building ecosystem service value model.

In order to solve the foundation of the whole work -- how to establish an appropriate ecosystem service value model, we first consider that ecosystem service function is divided into 4 service categories of supply, regulating, supporting and culture, and further subdivided into 9 kinds of small categories. Then the value of each service function is transformed into the relative value of the total ecosystem service value by the **regression analysis method** and **Entropy Method**. Finally, the value of various ecosystem service functions is calculated recording to the grain price and the ecosystem service value model is established.

On this basis, we consider the loss of ecosystem service value caused by human activities as one of the costs of land development projects in combination with the economic principles. The value weights of various ecosystem service functions are determined through the **Analytic Hierarchy Process (AHP)**, so as to establish the cost-benefit analysis model of land development projects and the evaluation standard of projects economic level.

Connecting with the above two models, we select the Beijing-Shanghai high-speed railway project and a typical residential development project in Xuzhou, China for cost-benefit analysis, their **cost-benefit analysis coefficient** respectively are 0.315 and 0.195. And obtain the corresponding economic rating of the projects.

Through the analysis of these two examples and the design of the model, it can be proved that our model is very effective. Based on this, we make reasonable suggestions to land development project planners and managers.

Finally, we use the collected data to predict the cost of farmland, the area of crops and the disaster area of crops in the next 10 year through **Grey Prediction Model**. Then the **regression equation** between the value of farmland ecosystem service and the above three factors is determined by the regression analysis method. By combining the predicted value with the regression equation, the value of farmland ecosystem service is predicted, and then the dynamic model of ecosystem service value changing with time is established.

At the same time, we do sensitivity analysis and error analysis for various parameters of the value dynamic model, which turns out that our model is superior. Besides, we list the overall strengths and weakness of our models as well as further work.


**Key words**: ecosystem service value model, cost-benefit analysis model, Entropy Method, Analytic Hierarchy Process (AHP), value dynamic model.

# Content

# 1 Introduction

## 1.1 Background

### Ecosystem services and their economic theory

Ecosystem services refers to all benefits acquired by humans from the ecosystem directly and indirectly, including supply services (e.g. provide food and water), regulating services (e.g. control floods and diseases), cultural services (e.g. benefits of spirit and entertainment), and supporting services (e.g. maintenance of nutrient cycling in the living environment of life on earth). From the perspective of economic theory, ecosystem services are equivalent to "natural capital".

There have been many studies in the last few decades aiming at estimating the value of a wide variety of ecosystem services.Through these studies we found that before the formation of the globally recognized pricing method of ecological services, the value of ecological services calculated by the alternative method can basically reflect the benefits people get from the ecosystem.

### The impact of land use change on ecosystem service value

Land use change refers to the change of land cover caused by human's change in land use and management mode.This change not only changes the surface structure, but also affects major ecological processes such as material circulation and energy exchange, and impacts the structure and function of the entire ecosystem, thus affecting ecosystem services and human well-being.[1] Therefore, it is the most direct method to study the change of ecosystem service value based on land use.

## 1.2 Previous Research

All economic activities of human beings are carried out under the support of the ecosystem. In this sense, the value of ecological services should be unlimited. But the impact of human activities on ecosystems is also measurable to some extent.[2] Previous studies have shown that changes in land use caused by human activities will affect the structure and function of the ecosystem, thus leading to influences on the types and intensity of services provided by the ecosystem. Therefore, on the basis of clear connotation of ecosystem service function, it is of great theoretical significance to study the change of ecosystem service value caused by land use change.

So far, researchers in different countries have used different calculation methods to discuss and study the value of ecological services in specific regions, and the results reflect the value of regional ecosystem services to a certain extent. In 1997, American ecologist Costanza[3] proposed a research method based on land use cover area and service unit price to calculate regional ecological service value, which opened a new era of ecological service value assessment accounting and has been widely used in the international scope. The equivalent value, coefficient and regional correction coefficient of China's terrestrial ecosystem services proposed by Chinese scholar Gaodi Xie enrich and develop the evaluation system of the value of ecological services based on land use types. [4]

## 1.3 Our Tasks

In most cases, land-use projects ignore impacts on ecosystem services and their value changes. In fact, the affected ecosystem services should also be included in the cost-benefit analysis of the project. To understand the true economic costs of land use projects in ecosystem services, Our specific tasks are as follows:

- Considering the ecosystem function and its value transformation synthetically, establish the ecosystem service evaluation model.
- According to the principle of economics and its application, establish the cost-benefit analysis model.
- Carry out the cost-benefit analysis of different scale land use and development projects.
- Analyze the impact of the model on land use project planners and managers.
- Consider the situation where the ecological service evaluation model changes over time.

## 1.4 Model Overview

In order to show our modeling process more clearly, we make the mind map as below:

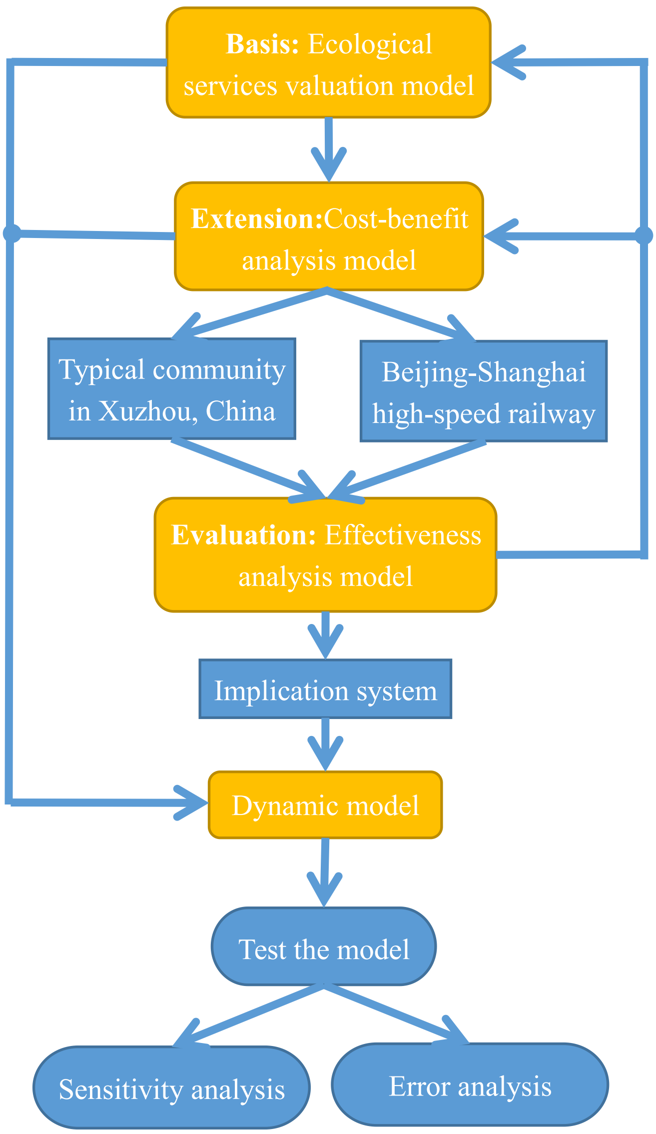


**Figure1**: mind map

# 2 General Assumptions

- **Assume that there are only six ecosystems and nine ecosystem services on global scale (like be mentioned in this article).** Ecosystem types and service functions are subdivided into many types, but only the ones mentioned in this paper have a great impact on the value of ecosystem services and a great possibility to be affected by human activities.
- **After the completion of the project, the ecosystem service function in the project land was neglected.** There may still have some ecosystem service functions after the completion of the project, we will not consider the value of ecosystem service generated by this part.
- **The weights obtained by using the analytic hierarchy process (AHP) are in line with the views of the social subject groups.** The weights obtained by this method are influenced by subjective factors. When the number of empowerment is small, it has greater contingency.
- **During the cost-benefit analysis period, the project does not incur additional losses due to accidents.**
- **When considering the cost effectiveness of project, the price level is assumed to be constant.**

# 3 Symbols Description

| Symbol | Definition | Symbol | Definition |
|---|---|---|---|
| $i$ | Years | $S_{im}$ | The $m^{th}$ area of ecosystem in the $i^{th}$ year |
| $m$ | The type of ecosystem | $V_j$ | The $j^{th}$ ($j$:1~6) total value of ecosystem services over the years |
| $j$ | The type of ecosystem service function | $v_{ij}$ | Total value of the $j^{th}$ ecosystem service functions in the $i^{th}$ year |
| $E_n$ | The value of grain crop per unit area per year | $W$ | A series of weight (Contains absolute weight and relative weight) |
| $CB$ | Cost-benefit analysis coefficient | $E_f$ | Effectiveness judgment factor |

# 4 Ecological Services Valuation Model

Ecosystem service value evaluation is an important basis for ecological environmental protection, ecological function zoning, environmental economic accounting and ecological compensation decision-making.[5~6] We use the method based on the relative factor of value per unit area (hereinafter referred to as the relative factor method) to calculate the value of ecosystem services. Relative factor method is on the basis of differentiating different types of ecosystem service function, construct the relative value equivalent of different types of each ecosystem services function based on quantifiable criteria, and then make an evaluation combined with the distribution area of ecosystem.

This method is intuitive and easy to use, and is applicable to the evaluation of regional ecosystem service value. First, we calculate the relative factors of each ecosystem service value, and then determine the value of each ecosystem service function. Finally we build the model of the total ecosystem service value.

## 4.1 The value of standard relative factor

A standard unit ecosystem service value relative factor (hereinafter refers to as standard relative factor) is the economic value of 1 $hm^2$ national average yield farmland natural grain yield per year. The relative factors of the service value of other ecosystems can be determined by taking this factor as reference and combining with the expert knowledge. Its role is to characterize and quantify the potential contribution of different types of ecosystems to ecological service function. We take the net profit of grain production per unit area of farmland ecosystem as a standard relative factor of ecosystem service value.

## 4.2 Relative Factor Table of Ecosystem Service Function Value

Using millennium ecosystem assessment (MA), the ecosystem services can be divided into 4 major categories: supply services, regulating services, supporting services, and cultural service, and further subdivided into 9 kinds of service functions: food production, gas regulation, tourism, waste treatment, hydrological adjustment, holding soil, raw material production, climate regulation, biodiversity maintaining (table 1).

Use the following calculation procedure to get the relative factor table of ecosystem service value:

(1) Data acquisition

The original data representing the 9 kinds of service functions and 6 kinds of ecosystems are in the appendix.
(2) The least square method was used to determine the regression coefficients, and Non-negative processing is applied to the coefficients to determine the weights of ecosystem service value corresponding to different ecosystems.

Let $S_{im}$ be the $m^{th}$ ( $m$ :1~6) area of ecosystem in the $i^{th}$ ( $i$ :1~8) year,

$$S_{im} = \begin{bmatrix} 1 & s_{11} & \cdots & s_{16} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & s_{81} & \cdots & s_{86} \end{bmatrix} \tag{1}$$

Let $V_j$ be the $j^{th}$ ( $j$ :1~6) total value of ecosystem services over the years,

$$V_j = \begin{bmatrix} v_{1j} & \cdots & v_{ij} & \cdots & v_{8j} \end{bmatrix}^T \tag{2}$$

$$\varepsilon = [\varepsilon_1, \cdots, \varepsilon_8]^T, \quad \beta = [\beta_0, \beta_1, \cdots, \beta_6]^T$$

Select the estimated value $\hat{\beta}_q$ , so when $\beta_q = \hat{\beta}_q$ , $j$ =1,…,6, the sum of the squared errors

$$Q_j = \sum_{i=1}^{8} \varepsilon_i^{\ 2} = \sum_{i=1}^{8} (v_{ij} - \hat{v}_{ij})^2 = \sum_{i=1}^{8} (v_{ij} - \beta_0 - \beta_1 s_{i1} - \cdots - \beta_i s_{i6}) \tag{3}$$

is minimized. And for that, let

$$\frac{\partial Q}{\partial \beta_q} = 0 \text{ , } \ q = 0, 1, 2, \ldots, 8,$$

Get

$$\begin{cases} \dfrac{\partial Q}{\partial \beta_0} = -2\sum_{i=1}^{8} (v_{ij} - \beta_0 - \beta_1 s_{i1} - \cdots - \beta_i s_{i6}) = 0, \\ \dfrac{\partial Q}{\partial \beta_q} = -2\sum_{i=1}^{8} (v_{ij} - \beta_0 - \beta_1 s_{i1} - \cdots - \beta_i s_{i6}) s_{i6} = 0 \end{cases} \tag{4}$$

Made it into the following normal equations:

$$\begin{cases} 8\beta_0 + \sum_{i=1}^{8} s_{i1}\beta_1 + \sum_{i=1}^{8} s_{i2}\beta_2 + \cdots + \sum_{i=1}^{8} s_{i6}\beta_6 = \sum_{i=1}^{8} v_{ij} \\ \sum_{i=1}^{8} s_{i1}\beta_0 + \sum_{i=1}^{8} s_{i1}^{\ 2}\beta_1 + \sum_{i=1}^{8} s_{i1}s_{i2}\beta_2 + \cdots + \sum_{i=1}^{8} s_{i1}s_{i6}\beta_6 = \sum_{i=1}^{8} s_{i1}v_{ij} \\ \vdots \\ \sum_{i=1}^{8} s_{i6}\beta_0 + \sum_{i=1}^{8} s_{i6}s_{i1}\beta_1 + \sum_{i=1}^{8} s_{i6}s_{i2}\beta_2 + \cdots + \sum_{i=1}^{8} s_{i6}^{\ 2}\beta_6 = \sum_{i=1}^{8} s_{i6}v_{ij} \end{cases} \tag{5}$$

The matrix form of the normal system is

$$S_{im}^{\ T} S_{im} \beta = S_{im}^{\ T} V_j \, , \tag{6}$$

When the matrix $S_{im}$ has column full rank, $S_{im}^{\ T} S_{im}$ is invertible square matrix , the solution to the above equation is

$$\hat{\beta}_q = (S_{im}^{\ T} S_{im})^{-1} S_{im}^{\ T} V_j \tag{7}$$

$$\beta = E(\hat{\beta}_q) \tag{8}$$

$\hat{\beta}_q$ is the linear unbiased minimum variance estimation of $\beta$.

The expected value of $\hat{\beta}_q$ is equal to $\beta$.

The smaller the negative value in $\beta$ indicates that the negative correlation between $S_{im}$ and $V_j$ is stronger and the positive correlation is weaker. Then make B non-negative.

(3) Because the values of the six ecosystem service function are different, the entropy method is used to determine the weight of each ecosystem service function value relative to the total ecosystem service value.

**Table 1**: Relative factor table of ecosystem service value

| Ecological Services | Farmland | Forest | Grassland | River/Lake | Wetland | Desert |
|---|---|---|---|---|---|---|
| Food production | 1 | 0.907366497 | 0.86470633 | 0.862903431 | 0.842157386 | 0.919961403 |
| Gas regulation | 1.059333807 | 0.629357917 | 0.759534104 | 0.752567383 | 1.251726045 | 0.938292791 |
| Tourism | 0.84082658 | 1.008023386 | 0.885929277 | 0.866430281 | 0.772232358 | 0.926266698 |
| Waste treatment | 0.311952154 | 0.877854157 | 0.808394606 | 0.994488917 | 1.238184531 | 0.899193277 |
| Hydrological adjustment | 0.877436259 | 0.862505525 | 0.873703575 | 1.12916229 | 0.860613617 | 0.862786755 |
| Holding soil | 0.844645807 | 1.449890499 | 0.797630583 | 0.843475515 | 0.792313385 | 0 |
| Raw material production | 0.39 | 2.98 | 0.36 | 0.35 | 0.24 | 0.04 |
| Climate regulation | 0.97 | 4.07 | 1.56 | 2.06 | 13.55 | 0.13 |
| Biodiversity maintaining | 1.02 | 4.51 | 1.87 | 3.43 | 3.69 | 0.4 |

Note: For raw material production, climate regulation, biodiversity maintaining, we could not obtain the relevant data, their relative factors are quoted from Xie' s Expert Knowledge Based paper[3].

## 4.3 Determination of Ecosystem Service Value

The way to determine relative value： the relative value of the average annual natural grain crop yield per hectare of farmland is defined as 1. Its economic value is equal to 1/7 of the regional average market value of grain crop yield per unit area. Other relative factors of ecosystem services value refer to the contribution of ecosystem services to farmland ecosystem services. Given the price of grain crop, we could convert the relative factor table of ecosystem service value to ecosystem service value table (table 2).

$$E_n = \frac{1}{7}\sum_{k=1}^{n}\frac{O_k}{M}(k=1,\dots,n) \tag{9}$$

$$E_{jm} = e_{jm}E_n \tag{10}$$

$$E = \sum_{a=1}^{n} A_m E_{jm} \tag{11}$$

Where

$E_n$ : Economic value per unit area of farmland ecosystem to provide food production services, ¥/ $km^2$

$k$ : Crop species

$P_k$ : Prices of $k^{th}$ crop, ¥/ $kg$

$O_k$ : The total value of $k^{th}$ grain crop per year, ¥

$M$ : Total area of $n$ grain crops, $km^2$

$E_{jm}$ : Unit price of $j$ ecological service functions of $m$ ecosystem, ¥/ $km^2$

$e_{jm}$ : The relative factors of unit price of ecosystem services provided by the $j$ ecological service functions of $m$ ecosystem relative to the farmland ecosystem

$E$ : Total value of regional ecosystem services

$A_m$ : The area of $m^{th}$ ecosystem

At the research area, formula (9) is firstly used to calculate the economic value of grain crop per unit area of farmland ecosystem. The formula (10) is to calculate the value of each ecological service in each ecosystem. Finally, according to formula (11), the total value of ecological services at the research area is obtained. The formula (10) calculation results are shown in the table 2.

**Table 2**: Ecosystem service value ( ¥/ $(a \cdot km^2)$ )

| Ecological Services Project | Farmland | Forest | Grassland | River/Lake | Wetland | Desert |
|---|---|---|---|---|---|---|
| Food production | 209904.7173 | 190460.508 | 181505.9379 | 181127.5007 | 176772.808 | 193104.2382 |
| Tourism | 176493.4656 | 211588.8639 | 185960.7345 | 181867.8033 | 162095.2149 | 194427.7494 |
| Waste treatment | 65480.22877 | 184265.7287 | 169685.8412 | 208747.9151 | 259900.774 | 188744.9107 |
| Hydrological adjustment | 184178.0098 | 181043.9784 | 183394.502 | 237016.4913 | 180646.858 | 181103.0099 |
| Holding soil | 177295.1394 | 304338.8553 | 167426.422 | 177049.4895 | 166310.3171 | 0 |
| Raw material production | 81862.83976 | 625516.0577 | 75565.69824 | 73466.65107 | 50377.13216 | 8396.188694 |
| Climate regulation | 203607.5758 | 854312.1996 | 327451.359 | 432403.7177 | 2844208.92 | 27287.61325 |
| Biodiversity maintaining | 214102.8117 | 946670.2752 | 392521.8214 | 719973.1805 | 774548.407 | 83961.88694 |

# 5 Cost-benefit Analysis Model

## 5.1 Construction of AHP model

### (1) Establishing hierarchical structure diagram

Firstly, according to the problems to be studied, the overall goal is determined as cost-benefit analysis, and list the relevant influencing factors of the target one by one, and then the internal relations and membership relationships between them are analyzed and layered. Finally, we form a hierarchical structure model. By dividing the three layers into target layer, criterion layer and indicator layer, we construct the following hierarchy diagram.

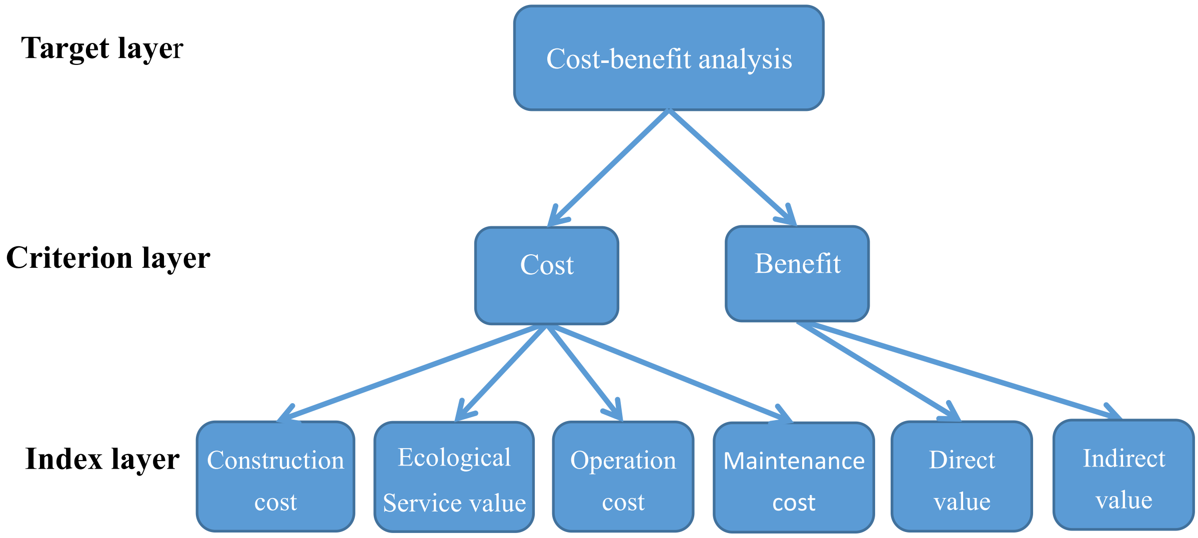


**Figure 2**: hierarchical structure diagram

### (2) Construction of judgment matrix

According to the established hierarchical structure diagram, the elements of each level are compared in pairs through the 1-9 scale method as shown in the table 3, so as to obtain the relative importance of indexes and assign values.

**Table 3**: The value meaning of Scale 1~9 of judgment matrix

| Scale | Meaning |
|---|---|
| 1 | The two comparison factors $i$ and $j$ are equally important |
| 3 | $i$ is slightly more important than $j$ |
| 5 | $i$ is significantly more important than $j$ |
| 7 | $i$ is much more important than $j$ |
| 9 | $i$ is extremely more important than $j$ |
| 2,4,6,8 | The importance is between the two adjacent judgments above |

Note: $a_{ij}$ is the ratio of the importance of factor $i$ relative to factor $j$, $1/a_{ij}$ is the ratio of the importance of factor $j$ relative to factor $i$, For n elements, the judgment matrix $A=(a_{ij})_{n\times n}$ of pairwise comparison is obtained by pairwise comparison of n elements in each level according to the expert evaluation method. As shown in the figure below:

| $A_k$ | $B_1$ | $B_2$ | $B_3$ | $\cdots$ | $B_n$ |
|---|---|---|---|---|---|
| $B_1$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $\cdots$ | $a_{1n}$ |
| $B_2$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | $\cdots$ | $a_{2n}$ |
| $B_3$ | $a_{31}$ | $a_{32}$ | $a_{33}$ | $\cdots$ | $a_{3n}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\ddots$ | $\vdots$ |
| $B_n$ | $a_{n1}$ | $a_{n2}$ | $a_{n3}$ | $\cdots$ | $a_{nn}$ |

The judgment matrix has the following properties:

$$a_{ij}>0;\quad a_{ij}=\frac{1}{a_{ji}}\ (i\neq j);\quad a_{ii}=1\quad (i,j=1,2,3,\cdots,n)$$

## (3) Calculate the relative weight

The specific calculation steps are:

Calculate the product of each row element of the judgment matrix $G_i$:

$$G_i=\prod_{j=1}^{n}a_{ij}\qquad i=1,2,3,\ldots,n$$

Take the $n_{th}$ root of $G_i$:

$$\overline{W_i}=\sqrt[n]{G_i}\qquad i=1,2,3,\ldots,n$$

Normalizing vector $\overline{W}=\left[\overline{W_1},\overline{W_2},\ldots,\overline{W_n}\right]^T$:

$$W_i=\frac{\overline{W_i}}{\sum_{j=1}^{n}\overline{W_j}}\qquad i=1,2,3,\ldots,n$$

Eigenvector $W=(W_1,W_2,W_3,\ldots,W_n)^T$ is the weight vector of $B_i$ relative to $A$

## (4) Consistency Test

① Calculate the maximum characteristic root of judgement matrix $\lambda_{\max}$, the calculation formula is as follows:

$$\lambda_{\max}=\sum_{i=1}^{n}\frac{(AW)_i}{nW_i}\qquad i=1,2,3,\ldots,n$$

② The calculation formula of consistency index $CI$:

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

The smaller the $CI$ value calculated by the above formula is, the better the consistency of the judgment matrix is. If $CI=0$, the judgment matrix is completely consistent. If $CI\neq 0$, the consistency index $CR$ can be introduced to assist the test.

③ The calculation formula of index $CR$:

$$CR=\frac{CI}{RI}$$

$RI$ is the average consistency index, some $CI$ values are shown in the following table.

**Table 4**: $RI$ values

| Order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $RI$ | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.52 | 1.54 |

When $n$ =1,2, $RI = 0$, the formula does not hold, but in general, $CI = 0$, with complete consistency. The formula holds for order $n > 2$.

When $CR = \frac{CI}{RI} < 0.1$, it shows that the matrix satisfies the consistency.

According to the hierarchy model layer, the consistency test of the total ranking should be carried out at the end. The calculation formula is as follows:

$$CR = \frac{\sum B_i CI_i}{\sum B_I RI_i} \qquad i = 1,2,3,\ldots,n$$

Where

$B_i$: The weight of each lower level value.

When $CR < 0.1$, it indicates that the consistency requirement is satisfied.

**Table 5**: Target layer importance judgment matrix

| CB | Cost | Benefit | Weight |
|---|---|---|---|
| Cost | 1 | 1 | 0.5 |
| Benefit | 1 | 1 | 0.5 |

By calculating, $\lambda_{\max}$ =2, n=2, $CI$ =0, $CR$ =0<0.1 Pass the consistency test.

**Table 6**: Cost importance judgment matrix

| Cost | Construction cost | Ecological Service value | Operation cost | Maintenance cost | Weight |
|---|---|---|---|---|---|
| Construction cost | 1 | 5 | 7 | 5 | 0.632291626 |
| Ecological Service value | 1/5 | 1 | 3 | 1 | 0.153001515 |
| Operation cost | 1/7 | 1/3 | 1 | 1/3 | 0.061705344 |
| Maintenance cost | 1/5 | 1 | 3 | 1 | 0.153001515 |

By calculating, $\lambda_{\max}$ =4.0732, n=4, $CI$ =0.0244, $RI$ =0.9, $CR$ =0.027111<0.1 Pass the consistency test.

**Table 7**: Benefit importance judgment matrix

| Benefit | direct | indirect | Weight |
|---|---|---|---|
| direct | 1 | 5 | 0.833333333 |
| indirect | 1/5 | 1 | 0.166666667 |

By calculating, $\lambda_{\max}$ =2, n=2, $CI$ =0, $CR$ =0<0.1 Pass the consistency test.

**Table 8**: Cost-benefit analysis index system weight table

| Target layer | Criterion layer | Weight | Index layer | Relative weight | Absolute weight |
|---|---|---|---|---|---|
| Cost-benefit analysis coefficient | Cost | 0.5 | Construction cost | 0.632291626 | 0.316145813 |
| | | | Ecological Service value | 0.153001515 | 0.076500757 |
| | | | Operation cost | 0.061705344 | 0.030852672 |
| | | | Maintenance cost | 0.153001515 | 0.076500757 |
| | Benefit | 0.5 | Direct value | 0.833333333 | 0.416666667 |
| | | | Indirect value | 0.166666667 | 0.083333333 |

## (5) Standardized processing of cost-benefit data

### ① Dimensionless processing of index

Through the analysis, we divide the cost-benefit index into positive index and negative index. Positive index means that the result is proportional to the index, and increases or decreases at the same time. The opposite is negative. In the evaluation index system of cost-benefit analysis, each index is responsible for the overall target level, but the importance of each index is not comparable, so we introduce dimensionless processing.

- **Dimensionless treatment of positive index**

When $Y_{j\min} < Y_j < Y_{j\max}$; $r_j(y) = \frac{1}{2} + \frac{1}{2}\sin\left[\frac{\pi}{y_{j\max} - y_{j\min}}\left(y_j - \frac{y_{j\max} + y_{j\min}}{2}\right)\right]$

When $Y_j$ is some other value, $r_j(y) = 0$

- **Dimensionless treatment of negative index**

When $Y_{j\min} < Y_j < Y_{j\max}$; $r_j(y) = \frac{1}{2} - \frac{1}{2}\sin\left[\frac{\pi}{y_{j\max} - y_{j\min}}\left(y_j - \frac{y_{j\max} + y_{j\min}}{2}\right)\right]$

When $Y_j$ is some other value, $r_j(y) = 0$

Where

$Y_{j\max}$ :The maximum possible value of the $j^{th}$ term.

$Y_{j\min}$ :The minimum possible value of the $j^{th}$ term.

$r_j$ : The dimensionless value of the $j^{th}$ index.

$Y_j$ : The original value of the $j^{th}$ evaluation index.

② **Normalization processing**

The data after dimensionless processing vary greatly, and the influence of absolute weight on the total cost-benefit analysis coefficient is greatly weakened. In order to avoid this situation, the data after dimensionless processing is normalized.

### (6) Evaluation result calculation and standard determination

$$CB = C \cdot T \tag{12}$$

$C$ : The weight of the index in the index layer relative to the total target

$T$ : The value of the index in the index layer after Standardized processing

Using the linear dimensionless processing method, the cost-benefit analysis index of ecosystem service value are divided into the following five sections, as shown in table 9:

**Table 9**: Cost-benefit index rating table

| Economic level of Cost-benefit index | Coefficient interval | Evaluation level |
|---|---|---|
| Economy needs to be improved | [0, 0.2) | I |
| Certain economy | [0.2, 0.4) | II |
| Better economy | [0.4, 0.6) | III |
| Good economy | [0.6, 0.8) | IV |
| Excellent economy | [0.8, 1.0] | V |

## 5.2 Project analysis

### 5.2.1 Large project－Beijing-Shanghai high-speed railway

The Beijing-Shanghai high-speed railway is a high-speed railway linking Beijing and Shanghai. The project was officially started on April 18, 2008 and officially opened to traffic on June 30, 2011. It is 1318 km long and has a designed maximum speed of 380 km/h.

In order to obtain more reliable cost-benefit analysis result, we select the estimated cost and benefit of Beijing-Shanghai high-speed railway in the next 50 years for analysis.

By consulting relevant materials, we know the total construction cost, annual operation cost, maintenance cost and direct benefit of the Beijing-Shanghai high-speed railway. Based on this criterion, the total operating cost, total maintenance cost and total direct benefit in the next 50 years are estimated (refer to appendix).

We define the indirect benefit algorithm as: the difference between the product of the average ticket price and the passenger flow of the current high-speed train and the product of the average ticket price and the passenger flow of the original ordinary train (both the original passenger flow and the current passenger flow are calculated based on the saturated passenger flow that the Beijing-Shanghai railway system can bear at that time)

According to literature review, the total area of farmland, woodland, grassland and wetland in China accounts for 20.4%, 38.3%, 33.2% and 8.1% of the total area of these four types of land respectively. The total area of farmland, woodland, grassland and wetland occupied by the Beijing-Shanghai high-speed railway in the construction process is determined with this proportion, and then the ecosystem service value loss caused by the construction process of the Beijing-Shanghai high-speed railway is obtained according to the ecosystem services value table.

Based on the dimensionless processing and normalization processing listed above, process the above five costs and benefits. The following cost-benefit analysis table of Beijing-Shanghai high-speed railway is obtained:

**Table 10**: Cost-benefit analysis table of Beijing-Shanghai high-speed railway

| | Construction cost | Ecological Service value | Operation cost | Maintenance cost | Direct value | Indirect value |
|---|---|---|---|---|---|---|
| Cost | 220900000000 | 164862909718.04 | 843950000000.00 | 19770000000 | 1479750000000.00 | 2857500000000.00 |
| Dimensionless processing | 0.8844 | 0.9345 | 0.0589 | 0.999 | 0.201 | 0.6114 |
| Normalization processing | 0.307424917 | 0.3248401 | 0.020474138 | 0.347260845 | 0.247415066 | 0.752584934 |

Using the ecosystem service value model above, we get the cost-benefit analysis coefficient of Beijing-Shanghai high-speed railway is $0.315044036 \in [0.2, 0.4)$. Refer to the Cost-benefit index rating table (table 9) above, the economic level of Beijing-Shanghai high-speed railway cost-benefit index belongs to the $2nd$ evaluation level. It has certain economy.

### 5.2.2 Small project－Typical residential development project

Referring to relevant materials, we select the residential development project in Xuzhou, Jiangsu province, China, Xi Sheng real estate co.,ltd. for cost-benefit analysis.

When considering the project cost, the operation cost mainly includes the elevator operation cost and labor cost (calculated according to the current wage level and electricity cost of Xuzhou);

Maintenance costs mainly include wall maintenance, green maintenance and elevator maintenance (according to the current price level statistics in Xuzhou);

Ecosystem service value costs mainly include the service value loss of farmland, woodland and river/lake caused in the process of project construction.

The direct benefit is the product of the current average housing price of Xuzhou and the total construction area of the community.

The indirect benefits mainly include the increase of consumption level of Xuzhou residents driven by the project and the income of shops along the street (it is estimated that about 30 shops will be built in this community).

Based on the dimensionless processing and normalization processing listed above, process the above five costs and benefits. The following cost-benefit analysis table of typical community is obtained:

**Table 11**: Cost-benefit analysis table of residential development project

| | Construction cost | Ecological Service value | Operation cost | Maintenance cost | Direct value | Indirect value |
|---|---|---|---|---|---|---|
| Cost | 159928400 | 11495286.55 | 59515150 | 72018000 | 1175200000 | 4295163000 |
| Dimensionless processing | 0.095822297 | 0.991870964 | 0.796964812 | 0.71276172 | 0.1302 | 0.9518 |
| Normalization processing | 0.03689134 | 0.381867793 | 0.306829421 | 0.274411446 | 0.120332717 | 0.879667283 |

Using the ecosystem service value model above, we get the cost-benefit analysis coefficient of the residential development project is $0.194779648 \in [0, 0.2)$. Refer to the Cost-benefit index rating table (table 3) above, the economic level of the residential development project cost-benefit index belongs to the $1st$ evaluation level. Its economy needs to be improved.

## 5.3 Effectiveness analysis model

Using control-experiment method to test the validity of our model. Data before and after the elimination of ecosystem service value were divided into control group and experimental group.

The validity coefficient of the model $E_f$ is defined as:

$$E_f = \frac{CB'}{CB} \tag{13}$$

$CB'$: Cost-benefit coefficient excluding ecosystem service value

$CB$: Cost-benefit coefficient including ecosystem service value

When $E_f > 1$, the model is proved to be effective, the opposite is noneffective.

For the large project—Beijing-Shanghai high-speed railway,

$$CB' = 0.381826354,\ CB = 0.315044036,\ E_f = 1.2119777249 > 1$$

This proves that our model is effective in analyzing Beijing-Shanghai high-speed railway project.

For the small project—residential development project in Xuzhou,

$$CB' = 0.207158729\,,\quad CB = 0.194779648\,,\quad E_f = 1.0635542837 > 1$$

This proves that our model is effective in analyzing the project of residential development project in Xuzhou.

Through the analysis of these two examples and the design of the model, it can be proved that our model is very effective.

## 5.4 Recommendations for managers and planners

To the land use project planners, we will advise that they can choose several places as candidates. They can use our cost-benefit analysis model to judge which one is the best choice. Besides, we will suggest that the place chosen as a candidate should deserve fewer ecosystem services value. To the managers, we advise that the project is deserved to be approved whose CB achieves level 5 or level 4. The project whose CB achieves level 3 or level 2 should choose better places. It is better to prohibit the project whose CB achieves level 1.

# 6 Dynamic Model

Assume the relative factor table is constant, according to our ecological services valuation model, what affects our value table is the change of grain price. We apply Grey prediction model and Multiple linear regression model to describe and predict the price change of grain price, and then get the value table change over time.

On the one hand, the change of the second model over time depends on the change of the value table over time in the first model. On the other hand, it relies on how much people pay attention to the cost of ecological services, that is, the scale size in the AHP (Analytic Hierarchy Process).

## 6.1 Grey prediction model

### (1) Establishment of the $GM(1,1)$ model

$GM(1,1)$ means the model is first order differential equation, and it is a gray model with only one variable.

Known the reference data column $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$, once accumulation order (1-AGO)

$$\begin{aligned} x^{(1)} &= (x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)) \\ &= (x^{(0)}(1), x^{(0)}(1) + x^{(0)}(2), \cdots, x^{(0)}(1) + \cdots + x^{(0)}(n)) \end{aligned}$$

Where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$, $k = 1,2,\cdots,n$. The average generation sequence of $x^{(1)}$:

$$z^{(1)} = (z^{(1)}(2), z^{(1)}(3), \cdots, z^{(1)}(n)),$$

Where $z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1)$, $k = 2,3,\cdots,n$

Establish Grey differential equation

$$x^{(0)}(k) + az^{(1)}(k) = b\,,\quad k = 2,3,\cdots,n \tag{14}$$

The corresponding albino differential equation is

$$\frac{dx^{(1)}}{dt} + ax^{(1)}(t) = b \tag{15}$$

Let $\vec{u} = [a,b]^T$ , $\vec{Y} = [x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n)]^T$ , $\vec{B} = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}$ , by least square method, the estimate of $\vec{u}$ to minimize $J(\vec{u}) = (\vec{Y} - \vec{B}\vec{u})^T(\vec{Y} - \vec{B}\vec{u})$ is

$$\hat{u} = [\hat{a}, \hat{b}]^T = (\vec{B}^T\vec{B})^{-1}\vec{B}^T\vec{Y}$$

Then solving equation (15), get

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k} + \frac{\hat{b}}{\hat{a}}, \quad k = 0,1,\cdots,n-1,\cdots \tag{16}$$

### (2) Data verification and processing

In order to ensure the feasibility of the model method, the known data columns need to be examined and processed. Let the reference be $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$, Calculate the level ratio of sequence

$$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}, \quad k = 2,3,\cdots,n$$

If all level ratios $\lambda(k)$ fall within the allowable coverage of $\Theta = (e^{-\frac{2}{n+1}}, e^{\frac{2}{n+2}})$ , sequence $x^{(0)}$ can be used as the data of model $GM(1,1)$ for gray prediction.

After checking the data (see appendix) of unit area cost, total area of crops and disaster area of crops obtained from the Chinese national bureau of statistics, we found that the data satisfies the requirements of GM (1,1) model.

### (3) Level ratio deviation test

Firstly, Level ratio $\lambda(k)$ is calculated from reference data $x^{(0)}(k-1)$ , $x^{(0)}(k)$ .Then, the development coefficient $a$ is used to calculate the level ratio deviation.

$$\rho(k) = 1 - \left(\frac{1-0.5a}{1+0.5a}\right)\lambda(k),$$

If $\rho(k) < 0.2$, it is considered to meet the general requirements; If $\rho(k) < 0.1$, the higher requirements are considered to be met.

### (4) Solution of model

The data from 2011 to 2016 are substituted into the model we established, and the predicted results based on our model were obtained and compared with the original data. Finally, the data of the next ten years are predicted. We get the equations of these three factors (the cost of farmland, the area of crops and the disaster area of crops) over time. They are shown as below:

$$C(k) = -17506200e^{-0.0361545k} + 18119100$$

$$S(k) = -160467000e^{-0.0104502t} + 162136000$$

$$Z(k) = 2839511e^{-0.0104502t} - 2577300$$

Where, k: The difference between the current year and 2010

C(k): the cost of farmland in year (k+2010)

S(k): the area of crops in year (k+2010)

Z(k): the disaster area of crops in year (k+2010)

## 6.2 Multiple linear regression analysis

Using the method of regression analysis, a multiple linear regression model is established: $\gamma = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_n x_n + \varepsilon$

Matlab software is used for regression calculation to get the point estimation of regression coefficient.

Finally, the linear regression equation is established.

$$E_n(k) = 0.456C(k) - 0.8435S(k) - 0.2078Z(k) + 1404553.3664 \tag{17}$$

The following table lists the predicted data for 2019. All the predicted data for the decade after 2016 are shown in the appendix.

**Table 12**: The predicted data of ecosystem service value in 2019

| 2019 | farmland | forest | grassland | river/lake | wetland | desert |
|---|---|---|---|---|---|---|
| Gas regulation | 248122.7747 | 147411.5446 | 177902.1005 | 176270.3181 | 293185.9036 | 219771.9069 |
| Food production | 234225.2961 | 212528.1864 | 202536.0963 | 202113.8116 | 197254.563 | 215478.232 |
| Aesthetic landscape | 196942.8547 | 236104.5761 | 207507.0473 | 202939.8892 | 180876.3528 | 216955.0916 |
| Waste treatment | 73067.08572 | 205615.6499 | 189346.4659 | 232934.4611 | 290014.1384 | 210613.8116 |
| Hydrological adjustment | 205517.7675 | 202020.612 | 204643.4786 | 264478.3718 | 201577.4793 | 202086.4831 |
| Soil conservation | 197837.4143 | 339601.0314 | 186825.2595 | 197563.3022 | 185579.8372 | 0 |
| Raw material production | 91347.86549 | 697991.3825 | 84321.10661 | 81978.85365 | 56214.07107 | 9369.011845 |
| Climate adjustment | 227198.5373 | 953296.9553 | 365391.462 | 482504.11 | 3173752.763 | 30449.2885 |
| Biodiversity maintaining | 238909.8021 | 1056356.086 | 438001.3038 | 803392.7657 | 864291.3427 | 93690.11845 |

# 7 Testing the Model

## 7.1 Sensitivity Analysis

In this section, we test the sensitivity of the three regression coefficients of our Dynamic model. The regression coefficients reflect the contribution of their corresponding variables to the result to a great extent. In our model, $\alpha_1$ is the regression coefficient of the farmland's cost of unit area. $\alpha_2$ is the regression coefficient of the total area of various crops. And $\alpha_3$ is the regression coefficient of the total area of the farmland that is affected by disaster.

To test the sensitivity of our model, we decide to make every regression coefficient increase by 10%, 20%, 30%, 40% and 50% successively. Then we can get the change of the farmland service function value per unit area shown in the Figure 3, Figure 4, Figure 5 below.

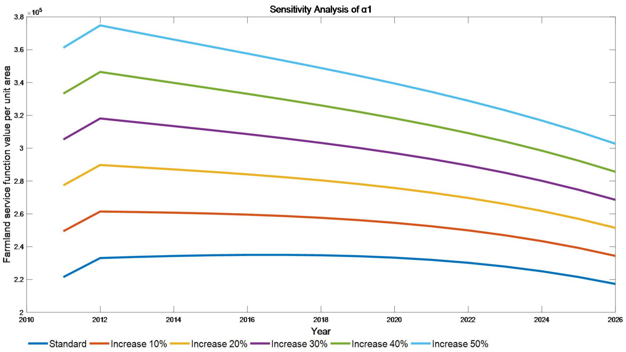


**Figure 3**: Sensitivity analysis of $\alpha_1$

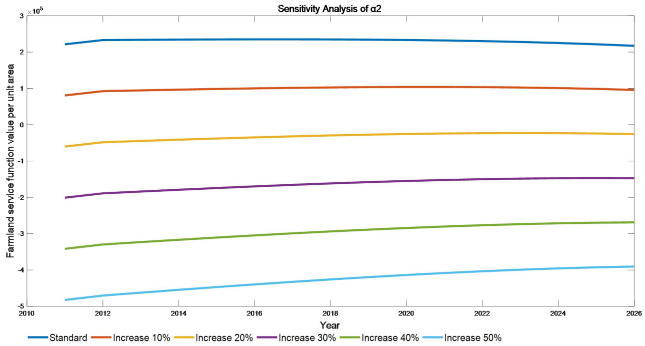


**Figure 4**: Sensitivity analysis of $\alpha_2$

The Figure 3 indicates that the influences of the change of $\alpha_1$ to the result gets smaller and smaller as time goes by. The Figure 4 indicates that the change of $\alpha_2$ influences the result greatly all the time.

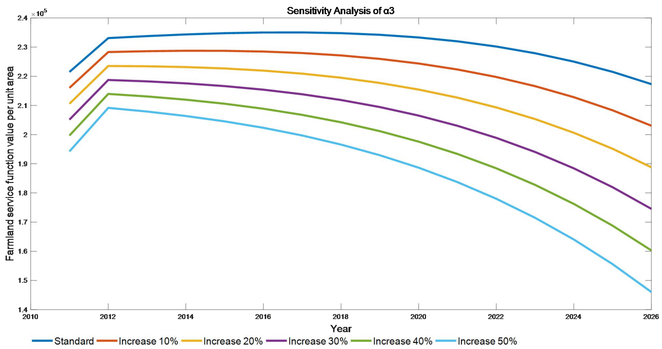


**Figure 5**: Sensitivity analysis of $\alpha_3$

The Figure 5 indicates that the influences of the change of $\alpha_3$ to the result gets larger and larger as time goes by.

As a conclusion, the sensitivity of $\alpha_1$ is higher in the short term while the sensitivity of $\alpha_3$ is higher in the long term. The sensitivity of $\alpha_3$ is always very high.

## 7.2 Error Analysis

In the Dynamic model, we predict the theoretical value of En in recent years. The theoretical value also include the value between 2011 and 2016. They are different from the actual value. By analyzing the error, we can obtain the conclusion that whether our model is accurate or not. The error is shown in the Table 13.

**Table 13**: the value of error analysis

| Actual value | Theoretical value | Absolute error | Relative error |
|---|---|---|---|
| 209904.7173 | 221484.4171 | 11579.6998 | 0.0552 |
| 231032.8919 | 233093.3976 | 2060.5057 | 0.0089 |
| 251473.1478 | 233775.1764 | 17697.9713 | 0.0704 |
| 234831.8854 | 234347.5675 | 484.3178 | 0.0021 |
| 240839.4310 | 234773.9365 | 6065.4945 | 0.0252 |
| 224319.3124 | 235016.0129 | 10696.7005 | 0.0477 |

We define a variable that is AARE to finally determine whether the error is acceptable. AARE is defined as $\mathrm{AARE}=\frac{1}{\mathrm{n}}\sum_{\mathrm{k}=1}^{n} R_k$ . And $\mathrm{R_k}$ is the relative error of the $\mathrm{k}_{th}$ value, and n is the number of data. When AARE is smaller than 0.1, the error is acceptable, else the error is unacceptable.

At last the AARE equals 0.0349. The error is acceptable. The other error analyses can be seen in the appendix.

# 8 Strength and Weakness

## 8.1 Strength

- Our team use objective weighting method to make the relative factor table of ecosystem service function value per unit area. It can reflect the objective laws between the ecosystem service function value and the ecosystem. Using this method, we reduce the influence of subjectivity to our model.

- The cost-benefit analysis model is able to calculate both benefit and cost of a project. We can intuitively find which project is better and whether a project is worth the government to approve it or not through making comparison of the cost-benefit analysis coefficient.

- Our Dynamic model can reflect the changes of the En over time. It makes us able to change our model. This make our model is still effective a few years later.

## 8.2 Weakness

- The data we use to build our model is not exact enough. This makes slight error to our model and makes it a little deviate from reality.We find no data about the bio-diversity, climate condition and the raw material production which makes us unable to quantify them.

- The Dynamic model is built to make our Ecological services valuation model able to adapt to the future project. However, gray prediction model can only be used to predict the data a few years later. This makes our model cannot predict the data many years later.

# 9 Future work

Data acquisition and representation: Although we tried our best to obtain accurate data in many ways in the limited time, we could not get all-sided data inevitably. Especially for some unusual data, statistics office would not collect these data. We will try our best to obtain the data to improve our model accuracy. We will also find a better representation way to quantify the bio-diversity, climate condition and the raw material production to make our model correspond to the objective laws more.

Model refinement: The model should also reflect the subjective willing of people. So we will combine the objective laws and the people’s subjective willing to define the ecosystem service function value of various ecosystems per unit area.

# Reference & Appendix

## Reference

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## Appendix

### 6.1 MATLAB of Gray prediction model

```
En=[209904.7173 231032.8919 251473.1478 234831.8854 240839.431 224319.3124]';
C=[612945.4742 610307.0566 598430.7174 596492.3694 574539.1049 515456.8988]';
S=[1669390.4 1668292.8 1649658.3 1634531.2 1618274 1598593.6]';
Z=[262207 217698 248907 313498 249620 324705]';
n=length(C);
lamda=C(1:n-1)./C(2:n);
range=minmax(lamda');
if range(1)>exp(-2/(n+1))&range(2)<exp(2/(n+1))
biaozhi=1
else
biaozhi=0
end
```

```
lamda=S(1:n-1)./S(2:n);
range=minmax(lamda');
n=length(S);
if range(1)>exp(-2/(n+1))&range(2)<exp(2/(n+1))
biaozhi=1
else
biaozhi=0
end
lamda=Z(1:n-1)./Z(2:n);
range=minmax(lamda');
n=length(Z);
if range(1)>exp(-2/(n+1))&range(2)<exp(2/(n+1))
biaozhi=1
else
biaozhi=0
end

n=length(C);
lamda=C(1:n-1)./C(2:n);
C1=cumsum(C);
BC=[-0.5*(C1(2:n)+C1(1:n-1)),ones(n-1,1)];
YC=C(2:n);
uC=BC\YC;
syms x(t)
x=dsolve(diff(x)+uC(1)*x==uC(2),x(0)==C(1));
Ct=vpa(x,6)
yuceC1=subs(x,t,[0:n-1]);
yuceC1=double(yuceC1);
yuceC=[C(1),diff(yuceC1)];
epsilonC=C'-yuceC;
deltaC=abs(epsilonC./C');
rhoC=1-(1-0.5*uC(1))/(1+0.5*uC(1))*lamda';
clear lamda
n=length(S);
lamda=S(1:n-1)./S(2:n);
lamda=prod(1:n-1)./prod(2:n);
S1=cumsum(S);
BS=[-0.5*(S1(2:n)+S1(1:n-1)),ones(n-1,1)];
YS=S(2:n);
uS=BS\YS;
syms x(t)
x=dsolve(diff(x)+uS(1)*x==uS(2),x(0)==S(1));
St=vpa(x,6)
yuceS1=subs(x,t,[0:n-1]);
```

```
yuceS1=double(yuceS1);
yuceS=[S(1),diff(yuceS1)];
epsilonS=S'-yuceS;
deltaS=abs(epsilonS./S');
rhoS=1-(1-0.5*uS(1))/(1+0.5*uS(1))*lamda';
clear lamda
n=length(Z);
lamda=Z(1:n-1)./Z(2:n);
Z1=cumsum(Z);
BZ=[-0.5*(Z1(2:n)+Z1(1:n-1)),ones(n-1,1)];
YZ=Z(2:n);
uZ=BZ\YZ;
syms x(t)
x=dsolve(diff(x)+uZ(1)*x==uZ(2),x(0)==Z(1));
Zt=vpa(x,6)
yuceZ1=subs(x,t,[0:n-1]);
yuceZ1=double(yuceZ1);
yuceZ=[Z(1),diff(yuceZ1)];
epsilonZ=Z'-yuceZ;
deltaZ=abs(epsilonZ./Z');
rhoZ=1-(1-0.5*uZ(1))/(1+0.5*uZ(1))*lamda';
```

## The result of MATLAB

```
biaozhi =

     1


biaozhi =

     1


biaozhi =

     1

Ct =

1.81191e7 - 1.75062e7*exp(-0.0361545*t)


epsilonC =
```

```
    1.0e+04 *

            0   -1.1315   -0.1119    1.8232    1.6812   -2.2466


deltaC =

            0    0.0185    0.0019    0.0306    0.0293    0.0436


rhoC =

    0.0313    0.0164    0.0324   -0.0013   -0.0750


St =

1.62136e8 - 1.60467e8*exp(-0.0104502*t)


epsilonS =

    1.0e+03 *

            0    0.1118   -1.1807    0.8540    1.5802   -1.2934


deltaS =

    1.0e-03 *

            0    0.0670    0.7157    0.5225    0.9765    0.8091


rhoS =

    0.1009    0.0908   -0.0597    0.0351   -0.0625


Zt =

2839511.0*exp(0.0779801*t) - 2577300.0
```

```
epsilonZ =

    1.0e+04 *

         0   -1.2590   -0.0057    4.4343   -4.1364    1.0122


deltaZ =

         0    0.0578    0.0002    0.1414    0.1657    0.0312


rhoZ =

   -0.3022    0.0544    0.1416   -0.3578    0.1689
```

## 6.2 MATLAB of Linear regression method

```
[B,Bint,R,Rint,Stats]=regress(En,[ones(6,1),C,S,Z])
```

## The result of MATLAB

```
B =

    1.0e+06 *

    1.4046
    0.0000
   -0.0000
   -0.0000


Bint =

    1.0e+06 *

   -2.3514    5.1605
```

```
   -0.0000    0.0000
   -0.0000    0.0000
   -0.0000    0.0000


R =

   1.0e+04 *

   -1.1580
    0.0578
    1.7200
    0.2104
   -0.8863
    0.0560


Rint =

   1.0e+05 *

   -1.4382    1.2066
   -1.8857    1.8972
   -1.1337    1.4777
   -1.0065    1.0486
   -0.5188    0.3416
   -0.1337    0.1449


Stats =

   1.0e+08 *

    0.0000    0.0000    0.0000    2.5678
```

## 7.1 MATLAB of Sensitivity analysis

```
for i=1:6
En=1404553.366385746+(1+(i-1)*0.1)*0.455994457*yuceC-0.843473853*yuceS-0.207780628*y
```

```
uceZ;
plot([2011:2026],En','LineWidth',3)
hold on
clear En
end


for i=1:6
En=1404553.366385746+0.455994457*yuceC-(1+(i-1)*0.1)*0.843473853*yuceS-0.207780628*y
uceZ;
plot([2011:2026],En','LineWidth',3)
hold on
clear En
end


for i=1:6
En=1404553.366385746+0.455994457*yuceC-0.843473853*yuceS-(1+(i-1)*0.1)*0.207780628*y
uceZ;
plot([2011:2026],En','LineWidth',3)
hold on
clear En
end
```

## 5.1 MATLAB of Dimensionless treatment

```
C=[159928400 11495286.55   59515150        72018000]';
V=[1175200000       4295163000]';
Cmax=200000000;
Cmin=0;
Vmin=0;
Vmax=5000000000;
m=size(C);
n=size(V);
for i=1:m
Cdless(i)=1/2-1/2*sin(pi/(Cmax-Cmin)*(C(i)-(Cmax+Cmin)/2));
end
for i=1:n
Vdless(i)=1/2+1/2*sin(pi/(Vmax-Vmin)*(V(i)-(Vmax+Vmin)/2));
```

```
end




C=[220900000000   164862909718.04   843950000000.00   19770000000]';
V=[2857500000000.00    1479750000000.00 ]';
Cmax=1000000000000;
Cmin=100000000;
Vmin=0;
Vmax=5000000000000;
m=size(C);
n=size(V);
for i=1:m
Cdless(i)=1/2-1/2*sin(pi/(Cmax-Cmin)*(C(i)-(Cmax+Cmin)/2));
end
for i=1:n
Vdless(i)=1/2+1/2*sin(pi/(Vmax-Vmin)*(V(i)-(Vmax+Vmin)/2));
end
```

## The result of MATLAB

```
Cdless =

    0.0958    0.9919    0.7970    0.7128

Vdless =

    0.1302    0.9518


Cdless =

    0.8844    0.9345    0.0589    0.9990

Vdless

Vdless =

    0.6114    0.2010
```

## 4.2 MATLAB of Entropy method

```
X=[0 0.188739987 0.757662991 0.935834315 0.85614896 0.902614999 0.971093592 1
1 0.935951395 0.825955932 0.726307463 0.616350046 0.45315855 0.26955088 0
1 0.810441039 0.653405278 0.536020677 0.414023155 0.306109247 0.203307034 0
0.473730439 0.70258924 0.627137535 1 0.753632876 0.172273893 0.078885013 0
0.597685049 1 0.510972127 0.435432207 0.510457452 0.68103087 0 0.830614461
0 0.200986214 0.060670212 0.109722724 0.488588837 0.114886147 0.50840347 1]';
for i=1:8
for j=1:6
    p(i,j)=X(i,j)/sum(X(:,j));
end
end
k=-log(8);
for j=1:6
    e(j)=-k*sum(p(:,j).*log(p(:,j)));
end
e(find(isnan(e)))=0;
d=ones(1,6)-e;
w=d./sum(d);
```

## The result of MATLAB

```
w =

    0.1839    0.1408    0.1490    0.2573    0.1367    0.1324
```

## 4.2 MATLAB of Least squares

```
X=[1 0.836575875 0.708171206 0.552529183 0.416342412 0.26848249 0.093385214 0
0.383561644 0.609589041 0.979452055 0 0.424657534 1 0.52739726 0.02739726
0.610653069 1 0.517333863 0.447039281 0.510564772 0.679851661 0 0.837060583
0 0.106116775 0.3197405 0.445319741 0.611677479 0.714087118 0.759962929 1
1 0.792114695 0.716845878 0.670250896 0.415770609 0.372759857 0.200716846 0
0.9402078 1 0.989190467 0.805671656 0.656694899 0.496588537 0.302769352 0]';
Y=[1 0.811260013 0.242337009 0.064165685 0.14385104 0.097385001 0.028906408 0]';
[B1,Bint1,R1,Rint1,Stats1]=regress(Y,[ones(8,1),X]);
Y=[1 0.935951395 0.825955932 0.726307463 0.616350046 0.45315855 0.26955088 0]';
[B2,Bint2,R2,Rint2,Stats2]=regress(Y,[ones(8,1),X]);
Y=[1 0.810441039 0.653405278 0.536020677 0.414023155 0.306109247 0.203307034
```

```
    0]';
[B3,Bint3,R3,Rint3,Stats3]=regress(Y,[ones(8,1),X]);
Y=[0.5262    0.29741076 0.372862465   0      0.246367124   0.827726107   0.921114987   1]';
[B4,Bint4,R4,Rint4,Stats4]=regress(Y,[ones(8,1),X]);
Y=[0.59768      1    0.510972127     0.435432207   0.510457452   0.68103087     0
    0.830614461]';
[B5,Bint5,R5,Rint5,Stats5]=regress(Y,[ones(8,1),X]);
Y=[1    0.799013786       0.939329788   0.890277276   0.511411163   0.885113853   0.49159653
    0]';
[B6,Bint6,R6,Rint6,Stats6]=regress(Y,[ones(8,1),X]);
```

## The result of MATLAB

```
B1 =

    1.5976
    0.5963
    0.0262
    0.1207
   -1.6794
   -0.4985
   -0.8454

B2 =

    0.1159
    0.4152
   -0.0311
   -0.0540
   -0.0439
   -0.1064
    0.6421


B3 =

    0.4818
    0.6672
    0.0198
   -0.0710
   -0.4083
   -0.0267
   -0.1017

B4 =
```

```
    2.0950
    0.3036
    0.6469
   -0.0311
   -1.1064
    0.3007
   -2.5401


B5 =

    0.0192
   -0.0455
    0.0014
    1.0041
   -0.0284
   -0.0248
    0.0367


B6 =

    0.6333
   -0.5284
    0.4414
   -0.0453
   -0.5235
    1.0444
   -0.3556
```

## 5.1 MATLAB of Consistency test

```
clear A
clear W
clear Q
A=[1 1
1    1];
W=[0.5
0.5];
Q=A*W;
lamda1=0;
```

```
[m,n]=size(Q);
for i=1:m
lamda1=lamda1+Q(i)/m/W(i);
end
lamda1
clear A
clear W
clear Q
A=[1   1/5   1/7   1/5
5              1         1/3 1
7      3              1      3
5      1                1/3 1]';
W=[0.632291626    0.153001515   0.061705344   0.153001515]';
Q=A*W;
lamda2=0;
[m,n]=size(Q);
for i=1:m
lamda2=lamda2+Q(i)/m/W(i);
end
lamda2
clear A
clear W
clear Q
A=[1 5
  1/5 1];
W=[0.833333333
0.166666667];
Q=A*W;
lamda3=0;
[m,n]=size(Q);
for i=1:m
lamda3=lamda3+Q(i)/m/W(i);
end
lamda3
```

## The result of MATLAB

```
lamda1 =

     2

lamda2 =

    4.0732
```

| |
|---|
| *lamda3 =*<br><br>*2* |

## *Ratio deviation test*

| | | | | | |
|---|---|---|---|---|---|
| *rhoC* | *0.0313* | *0.0164* | *0.0324* | *-0.0013* | *-0.0750* |
| *rhoS* | *0.1009* | *0.0908* | *-0.0597* | *0.0351* | *-0.0625* |
| *rhoZ* | *-0.3022* | *0.0544* | *0.1416* | *-0.3578* | *0.1689* |

## *Cost-benefit analysis of Beijing-Shanghai High-speed Railway*

| | cost | weight | dimensionless | normalization |
|---|---|---|---|---|
| construction cost(￥) | 220900000000 | 0.31615 | 0.88440 | 0.30742 |
| ecological services value(￥) | 164862909718.04400 | 0.07650 | 0.93450 | 0.32484 |
| operating cost(￥) | 843950000000.00000 | 0.03085 | 0.05890 | 0.02047 |
| Maintenance cost(￥) | 19770000000.00000 | 0.07650 | 0.99900 | 0.34726 |
| Indirect benefit(￥) | 2857500000000.00000 | 0.08333 | 0.61140 | 0.75258 |
| Direct benefit(￥) | 1479750000000.00000 | 0.41667 | 0.20100 | 0.24742 |

| Type | Area |
|---|---|
| farmland($km^2$) | 1027.467591 |
| woodland($km^2$) | 393.2460133 |
| grassland($km^2$) | 130.5362507 |

| | |
|---|---|
| wetland($km^2$) | 10.58537866 |

*Ecosystem area occupied by Beijing-Shanghai high-speed railway*

*Yield Value and Planting Area of Major Crops in 2016*

| | unhusked rice | wheat | corn | soybean | peanut |
|---|---|---|---|---|---|
| unit area output value | 2015655.00 | 1395540.00 | 1148835.00 | 702945.00 | 2526720.00 |
| area | 307458.90 | 246939.70 | 441776.10 | 72023.00 | 44484.00 |

*Comparison matrix and weight of cost without ecological services value*

| | construction cost | operating cost | maintenance cost | weight |
|---|---|---|---|---|
| construction cost | 1 | 7 | 5 | 0.730644671 |
| operating cost | 0.142857143 | 1 | 0.333333333 | 0.080961232 |
| maintenance cost | 0.2 | 3 | 1 | 0.188394097 |

*The relative and absolute weight without ecological services value*

| | relative weight | | relative weight | absolute weight |
|---|---|---|---|---|
| cost | 0.5 | construction cost | 0.730644671 | 0.365322336 |
| | | operating cost | 0.080961232 | 0.040480616 |
| | | Maintenance cost | 0.188394097 | 0.094197048 |
| benefit | 0.5 | Indirect benefit | 0.833333333 | 0.416666667 |
| | | Direct benefit | 0.166666667 | 0.083333333 |

| | woodland | grassland | rivers/lakes | wetland | desert | farmland |
|---|---|---|---|---|---|---|
| Gas regulation | −0.6833 | −0.119 | −0.1492 | 2.0146 | 0.6559 | 1.1806 |
| Food production | 0.1618 | −0.0062 | −0.0133 | −0.095 | 0.2114 | 0.5266 |
| Aesthetic | 0.5019 | 0.0279 | −0.0478 | −0.4135 | 0.1845 | −0.1472 |

| | | | | | | |
|---|---|---|---|---|---|---|
| landscape | | | | | | |
| Waste disposal | -0.3467 | -0.5892 | 0.0605 | 0.9113 | -0.2722 | -2.3224 |
| Hydrologic adjustment | -0.0379 | 0.0059 | 1.0051 | -0.0453 | -0.0368 | 0.0205 |
| Soil conservation | 2.2875 | -0.2763 | -0.0961 | -0.2972 | -3.4115 | -0.0915 |

*The regression coefficients between ecosystem and ecosystem services*

*The regression coefficients after Non-negative treatment*

| | woodland | grassland | rivers/lakes | wetland | desert | farmland |
|---|---|---|---|---|---|---|
| Gas regulation | 2.7282 | 3.2925 | 3.2623 | 5.4261 | 4.0674 | 4.5921 |
| Food production | 3.5733 | 3.4053 | 3.3982 | 3.3165 | 3.6229 | 3.9381 |
| Aesthetic landscape | 3.9134 | 3.4394 | 3.3637 | 2.998 | 3.596 | 3.2643 |
| Waste disposal | 3.0648 | 2.8223 | 3.472 | 4.3228 | 3.1393 | 1.0891 |
| Hydrologic adjustment | 3.3736 | 3.4174 | 4.4166 | 3.3662 | 3.3747 | 3.432 |
| Soil conservation | 5.699 | 3.1352 | 3.3154 | 3.1143 | 0 | 3.32 |

*The regression coefficients after Standardized Processing(make the sum of every line equal 1)*

| | woodland | grassland | rivers/lakes | wetland | desert | farmland |
|---|---|---|---|---|---|---|
| Gas regulation | 0.116746403 | 0.140894191 | 0.139601859 | 0.232196195 | 0.174054073 | 0.196507279 |
| Food production | 0.168121274 | 0.160216991 | 0.159882941 | 0.156039013 | 0.17045492 | 0.18528486 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aesthetic landscape | 0.19020355 | 0.167165659 | 0.163486401 | 0.14571223 | 0.174776912 | 0.158655248 |
| Waste disposal | 0.171119412 | 0.157579717 | 0.193854933 | 0.241358325 | 0.175279029 | 0.060808585 |
| Hydrologic adjustment | 0.157788639 | 0.159837235 | 0.206571409 | 0.157442529 | 0.157840088 | 0.1605201 |
| Soil conservation | 0.306663295 | 0.16870517 | 0.178401735 | 0.16758054 | 0 | 0.178649261 |

## *The absolute weight of ecosystem services value to the cost-benefit analysis*

| | woodland | grassland | rivers/lakes | wetland | desert | farmland |
|---|---|---|---|---|---|---|
| Gas regulation | 0.021469664 | 0.025910442 | 0.025672782 | 0.04270088 | 0.032008544 | 0.036137689 |
| Food production | 0.023671475 | 0.022558552 | 0.022511518 | 0.021970293 | 0.024000053 | 0.026088108 |
| Aesthetic landscape | 0.027560494 | 0.024222304 | 0.023689179 | 0.021113702 | 0.025325174 | 0.022989145 |
| Waste disposal | 0.044029025 | 0.040545261 | 0.049878874 | 0.062101497 | 0.045099294 | 0.015646049 |
| Hydrologic adjustment | 0.021569707 | 0.02184975 | 0.028238312 | 0.021522394 | 0.02157674 | 0.021943098 |
| Soil conservation | 0.04060222 | 0.022336564 | 0.02362039 | 0.022187664 | 0 | 0.023653162 |

## *Raw data of ecosystem services*

| | Major Air Pollutants (t) | Food output value(￥) $*10^8$ | Total Domestic Tourism Consumption(￥) $*10^8$ | Completion of Investment in Industrial | Total water resources ($m^3$) | Drought and flood disaster area |
|---|---|---|---|---|---|---|

| | | | | Pollution Control(￥) $*10^4$ | $*10^8$ | ($hm^2$) $*10^4$ |
|---|---|---|---|---|---|---|
| 2017 | 29304941.99 | 104351.17 | 45660.8 | 6815345 | 28761.2 | 15290 |
| 2016 | 35078379.04 | 101842.83 | 39390 | 8190041 | 32466.4 | 18404 |
| 2015 | 52481374.61 | 97535.07 | 34195.1 | 7736822 | 27962.6 | 16230 |
| 2014 | 57931522.92 | 93632.53 | 30311.9 | 9976511 | 27266.9 | 16990 |
| 2013 | 55493998.21 | 89326.26 | 26276.1 | 8496647 | 27957.86 | 22860 |
| 2012 | 56915365.01 | 82935.18 | 22706.2 | 5004573 | 29528.79 | 17070 |
| 2011 | 59010081.95 | 75744.54 | 19305.4 | 4443610 | 23256.7 | 23167 |
| 2010 | 59894310.72 | 65188.1 | 12579.8 | 3969768 | 30906.41 | 30783.6 |

*The Normalization to raw data of ecosystem services*

| | Major Air Pollutants (t) | Food output value(￥) $*10^8$ | Total Domestic Tourism Consumption(￥) $*10^8$ | Completion of Investment in Industrial Pollution Control(￥) $*10^4$ | Total water resources $*10^8$ | Drought and flood disaster area $*10^4$ |
|---|---|---|---|---|---|---|
| 2017.00 | 0.00000 | 1.00000 | 1.00000 | 0.47373 | 0.59769 | 0.00000 |
| 2016.00 | 0.18874 | 0.93595 | 0.81044 | 0.70259 | 1.00000 | 0.20099 |
| 2015.00 | 0.75766 | 0.82596 | 0.65341 | 0.62714 | 0.51097 | 0.06067 |
| 2014.00 | 0.93583 | 0.72631 | 0.53602 | 1.00000 | 0.43543 | 0.10972 |
| 2013.00 | 0.85615 | 0.61635 | 0.41402 | 0.75363 | 0.51046 | 0.48859 |
| 2012.00 | 0.90261 | 0.45316 | 0.30611 | 0.17227 | 0.68103 | 0.11489 |
| 2011.00 | 0.97109 | 0.26955 | 0.20331 | 0.07889 | 0.00000 | 0.50840 |
| 2010.00 | 1.00000 | 0.00000 | 0.00000 | 0.00000 | 0.83061 | 1.00000 |

*Raw data of ecosystem services*

| | woodland(k ㎡)$*10^4$ | grassland(h ㎡)$*10^8$ | rivers/lakes($m^3$)$*10^8$ | wetland(h ㎡) $*10^4$ | desert (k ㎡) $*10^4$ | farmland(h ㎡)$*10^3$ |
|---|---|---|---|---|---|---|
| 2017 | 223.3 | 392832.67 | 27746.3 | 5360 | 130.8 | 166331.91 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2016 | 219.1 | 392833 | 31273.9 | 5589 | 130.22 | 166939.04 |
| 2015 | 215.8 | 392833.54 | 26900.8 | 6050 | 130.01 | 166829.28 |
| 2014 | 211.8 | 392832.11 | 26263.91 | 6321 | 129.88 | 164965.83 |
| 2013 | 208.3 | 392832.73 | 26839.47 | 6680 | 129.17 | 163453.12 |
| 2012 | 204.5 | 392833.57 | 28373.26 | 6901 | 129.05 | 161827.4 |
| 2011 | 200 | 392832.88 | 22213.6 | 7000 | 128.57 | 159859.36 |
| 2010 | 197.6 | 392832.15 | 29797.62 | 7518 | 128.01 | 156785.04 |

## *The Normalization to raw data of ecosystem services*

| | woodland(k m²)*$10^4$ | grassland(h m²)*$10^8$ | rivers/lakes($m^3$)*$10^8$ | wetland(h m²)*$10^4$ | desert (k m²)*$10^4$ | farmland(h m²)*$10^3$ |
|---|---|---|---|---|---|---|
| 2017 | 1 | 0.383561644 | 0.610653069 | 0 | 1 | 0.9402078 |
| 2016 | 0.836575875 | 0.609589041 | 1 | 0.106116775 | 0.792114695 | 1 |
| 2015 | 0.708171206 | 0.979452055 | 0.517333863 | 0.3197405 | 0.716845878 | 0.989190467 |
| 2014 | 0.552529183 | 0 | 0.447039281 | 0.445319741 | 0.670250896 | 0.805671656 |
| 2013 | 0.416342412 | 0.424657534 | 0.510564772 | 0.611677479 | 0.415770609 | 0.656694899 |
| 2012 | 0.2684824 9 | 1 | 0.679851661 | 0.714087118 | 0.372759857 | 0.496588537 |
| 2011 | 0.093385214 | 0.52739726 | 0 | 0.759962929 | 0.200716846 | 0.302769352 |
| 2010 | 0 | 0.02739726 | 0.837060583 | 1 | 0 | 0 |

## *The error analysis of the three influencing factors*

| | actual value | Theoretical value | absolute error | relative error | AARE |
|---|---|---|---|---|---|
| Unit area cost | 612945.4742 | 612945.4742 | 0.0000 | 0.0000 | 0.0206 |
| | 610307.0566 | 621622.4478 | 11315.3912 | 0.0185 | |
| | 598430.7174 | 599549.4407 | 1118.7232 | 0.0019 | |
| | 596492.3694 | 578260.2174 | 18232.1520 | 0.0306 | |
| | 574539.1049 | 557726.9468 | 16812.1581 | 0.0293 | |

| | | | | | |
|---|---|---|---|---|---|
| | 515456.8988 | 537922.7860 | 22465.8872 | 0.0436 | |
| Affected farmland area | 262207.0000 | 262207.0000 | 0.0000 | 0.0000 | 0.0661 |
| | 217698.0000 | 230287.5175 | 12589.5175 | 0.0578 | |
| | 248907.0000 | 248964.0945 | 57.0945 | 0.0002 | |
| | 313498.0000 | 269155.3629 | 44342.6371 | 0.1414 | |
| | 249620.0000 | 290984.1659 | 41364.1659 | 0.1657 | |
| | 324705.0000 | 314583.3095 | 10121.6905 | 0.0312 | |
| Total planting area | 1669390.4000 | 1669390.4000 | 0.0000 | 0.0000 | 0.0005 |
| | 1668292.8000 | 1668181.0222 | 111.7778 | 0.0001 | |
| | 1649658.3000 | 1650838.9569 | 1180.6569 | 0.0007 | |
| | 1634531.2000 | 1633677.1762 | 854.0238 | 0.0005 | |
| | 1618274.0000 | 1616693.8057 | 1580.1943 | 0.0010 | |
| | 1598593.6000 | 1599886.9909 | 1293.3909 | 0.0008 | |

## *Cost-benefit analysis of construction of typical residential areas*

| | cost | weight | dimensionless | normalization |
|---|---|---|---|---|
| construction cost(￥) | 159928400 | 0.316145813 | 0.095822297 | 0.03689134 |
| ecological services value(￥) | 11495286.55 | 0.076500757 | 0.991870964 | 0.381867793 |
| operating cost(￥) | 59515150 | 0.030852672 | 0.796964812 | 0.306829421 |
| Maintenance cost(￥) | 72018000 | 0.076500757 | 0.71276172 | 0.274411446 |
| Indirect benefit(￥) | 1175200000 | 0.416666667 | 0.1302 | 0.120332717 |
| Direct benefit(￥) | 4295163000 | 0.083333333 | 0.9518 | 0.879667283 |

## *Raw data of staple crops*

| 2016 | Unit area output | planting area | output | Unit area cost | total cost |
|---|---|---|---|---|---|
| unhusked rice | 2015655 | 307459 | 619731069080 | 726795 | 223459591226 |
| wheat | 1395540 | 246940 | 344614228938 | 651900 | 160979990430 |
| corn | 1148835 | 441776 | 507527845844 | 554325 | 244887536633 |
| soybean | 702945 | 72023 | 50628207735 | 301995 | 21750585885 |
| peanut | 2526720 | 44484 | 112398612480 | 695430 | 30935508120 |
| 2015 | | | | | |
| unhusked rice | 2066280 | 307841 | 636085494852 | 718035 | 221040540632 |

| | | | | | |
|---|---|---|---|---|---|
| wheat | 1502565 | 245965 | 369577648943 | 630345 | 155042492753 |
| corn | 1424310 | 449684 | 640489275609 | 564330 | 253770115287 |
| soybean | 839430 | 65061 | 54614155230 | 302715 | 19694940615 |
| peanut | 2240310 | 43855 | 98249243112 | 669495 | 29360837124 |
| 2014 | | | | | |
| unhusked rice | 2072070 | 307651 | 637474821984 | 704700 | 216801800640 |
| wheat | 1579440 | 244723 | 386525453064 | 628545 | 153819480890 |
| corn | 1718565 | 429968 | 738928127777 | 547200 | 235278544320 |
| soybean | 962415 | 67999 | 65443257585 | 304365 | 20696515635 |
| peanut | 2230755 | 43697 | 97477301235 | 643290 | 28109843130 |
| 2013 | | | | | |
| unhusked rice | 1958850 | 307097 | 601557741990 | 702780 | 215821910772 |
| wheat | 1352895 | 244701 | 331055029974 | 625620 | 153089964744 |
| corn | 1634340 | 412992 | 674969508714 | 539565 | 222836082437 |
| soybean | 989370 | 67905 | 67183169850 | 306405 | 20806431525 |
| peanut | 2162550 | 43961 | 95067644295 | 674760 | 29663056884 |
| 2012 | | | | | |
| unhusked rice | 2011245 | 304760 | 612946422827 | 680265 | 207317357321 |
| wheat | 1277595 | 245756 | 313976125782 | 595035 | 146233183446 |
| corn | 1682850 | 391092 | 658149845340 | 516870 | 202143928788 |
| soybean | 1060245 | 71711 | 76030805097 | 307095 | 22021966707 |
| peanut | 2758995 | 44008 | 121417851960 | 676215 | 29758869720 |
| 2011 | | | | | |
| unhusked rice | 1902375 | 303384 | 577150327238 | 614010 | 186280871241 |
| wheat | 1245300 | 245235 | 305391145500 | 535995 | 131444733825 |
| corn | 1540980 | 367665 | 566564719896 | 462675 | 170109496410 |
| soybean | 916080 | 78885 | 72265337232 | 269115 | 21229244421 |
| peanut | 2522190 | 43362 | 109367959437 | 605460 | 26254138158 |

*Raw data of gray prediction model*

| En | unit area cost | planting areea | affected farmland area |
|---|---|---|---|
| 209904.71734 | 612945.47425 | 1669390.40000 | 262207.00000 |
| 231032.89194 | 610307.05656 | 1668292.80000 | 217698.00000 |
| 251473.14778 | 598430.71744 | 1649658.30000 | 248907.00000 |
| 234831.88536 | 596492.36940 | 1634531.20000 | 313498.00000 |
| 240839.43096 | 574539.10489 | 1618274.00000 | 249620.00000 |
| 224319.31244 | 515456.89883 | 1598593.60000 | 324705.00000 |

*The predicted value of En and the three factors*

| | affected farmland area | planting areea | unit area cost | En |
|---|---|---|---|---|
| 2011 | 262207.00000 | 612945.47420 | 1669390.40000 | 221484.41709 |
| 2012 | 230287.51750 | 621622.44781 | 1668181.02220 | 233093.39763 |
| 2013 | 248964.09450 | 599549.44066 | 1650838.95691 | 233775.17645 |
| 2014 | 269155.36291 | 578260.21737 | 1633677.17615 | 234347.56755 |
| 2015 | 290984.16594 | 557726.94680 | 1616693.80572 | 234773.93648 |
| 2016 | 314583.30947 | 537922.78604 | 1599886.99089 | 235016.01294 |
| 2017 | 340096.37011 | 518821.84536 | 1583254.89624 | 235033.70706 |
| 2018 | 367678.56870 | 500399.15431 | 1566795.70541 | 234784.91262 |
| 2019 | 397497.71466 | 482630.62913 | 1550507.62093 | 234225.29613 |
| 2020 | 429735.22694 | 465493.04125 | 1534388.86401 | 233308.07051 |
| 2021 | 464587.23776 | 448963.98690 | 1518437.67436 | 231983.75205 |
| 2022 | 502265.78590 | 433021.85783 | 1502652.30998 | 230199.89928 |
| 2023 | 543000.10673 | 417645.81309 | 1487031.04699 | 227900.83223 |
| 2024 | 587038.02685 | 402815.75177 | 1471572.17942 | 225027.33037 |
| 2025 | 634647.47188 | 388512.28670 | 1456274.01904 | 221516.30747 |
| 2026 | 686118.09652 | 374716.71913 | 1441134.89518 | 217300.46155 |

*The predicted value of value table of ecological services*

| 2011 | woodland | grassland | river/lake | wetland | desert | farmland |
|---|---|---|---|---|---|---|
| Gas regulation | 139392.9715 | 168224.9683 | 166681.9481 | 277237.8134 | 207817.232 | 234625.9308 |
| Food production | 200967.5396 | 191518.9776 | 191119.6633 | 186524.7376 | 203757.115 | 221484.4171 |
| Aesthetic landscape | 223261.472 | 196219.5296 | 191900.8058 | 171037.4337 | 205153.6397 | 186229.985 |
| Waste disposal | 194431.0163 | 179046.808 | 220263.7981 | 274238.5791 | 199157.2988 | 69092.54106 |
| Hydrologic adjustment | 191031.5335 | 193511.7271 | 250091.8516 | 190612.5053 | 191093.8214 | 194338.4583 |

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|---|---|---|---|---|---|---|
| Soil conservation | 321128.1519 | 176662.7447 | 186816.6827 | 175485.0682 | 0 | 187075.8843 |
| Raw material production | 660023.5629 | 79734.39015 | 77519.54598 | 53156.2601 | 8859.376684 | 86378.92266 |
| Climate adjustment | 901441.5776 | 345515.6907 | 456257.8992 | 3001113.852 | 28792.97422 | 214839.8846 |
| Biodiversity maintaining | 998894.7211 | 414175.86 | 759691.5506 | 817277.4991 | 88593.76684 | 225914.1054 |
| | | | | | | |
| 2012 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 146699.1753 | 177042.385 | 175418.4882 | 291769.0767 | 218709.8547 | 246923.7163 |
| Food production | 211501.1396 | 201557.3365 | 201137.0925 | 196301.3263 | 214436.929 | 233093.3976 |
| Aesthetic landscape | 234963.5959 | 206504.2653 | 201959.1781 | 180002.2642 | 215906.6517 | 195991.1244 |
| Waste disposal | 204622.0081 | 188431.4453 | 231808.8006 | 288612.6392 | 209596.0161 | 72713.98755 |
| Hydrologic adjustment | 201044.3433 | 203654.5349 | 263200.2747 | 200603.352 | 201109.8961 | 204524.5987 |
| Soil conservation | 337959.9025 | 185922.4226 | 196608.5736 | 184683.0188 | 0 | 196881.361 |
| Raw material production | 694618.3249 | 83913.62315 | 81582.68917 | 55942.41543 | 9323.735905 | 90906.42507 |
| Climate adjustment | 948690.1283 | 363625.7003 | 480172.3991 | 3158415.538 | 30302.14169 | 226100.5957 |
| Biodiversity maintaining | 1051251.223 | 435884.6536 | 799510.3539 | 860114.6372 | 93237.35905 | 237755.2656 |
| | | | | | | |
| 2013 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147128.2582 | 177560.2192 | 175931.5727 | 292622.477 | 219349.5629 | 247645.9477 |
| Food production | 212119.7628 | 202146.875 | 201725.4017 | 196875.4914 | 215064.1392 | 233775.1764 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aesthetic landscape | 235650.8449 | 207108.2731 | 202549.8919 | 180528.7558 | 216538.1608 | 196564.3821 |
| Waste disposal | 205220.5105 | 188982.5916 | 232486.8221 | 289456.8072 | 210209.067 | 72926.66992 |
| Hydrologic adjustment | 201632.3813 | 204250.2075 | 263970.1136 | 201190.1002 | 201698.1258 | 205122.8162 |
| Soil conservation | 338948.4071 | 186466.2302 | 197183.6373 | 185223.2013 | 0 | 197457.2226 |
| Raw material production | 696650.0258 | 84159.06352 | 81821.31176 | 56106.04235 | 9351.007058 | 91172.31881 |
| Climate adjustment | 951464.9681 | 364689.2753 | 481576.8635 | 3167653.641 | 30390.77294 | 226761.9212 |
| Biodiversity maintaining | 1054326.046 | 437159.58 | 801848.8552 | 862630.4011 | 93510.07058 | 238450.68 |
| | | | | | | |
| 2014 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147488.4971 | 177994.9698 | 176362.3356 | 293338.9539 | 219886.6333 | 248252.3009 |
| Food production | 212639.1313 | 202641.8252 | 202219.32 | 197357.5348 | 215590.717 | 234347.5675 |
| Aesthetic landscape | 236227.8285 | 207615.3711 | 203045.8289 | 180970.7748 | 217068.3476 | 197045.6638 |
| Waste disposal | 205722.9864 | 189445.3095 | 233056.0587 | 290165.533 | 210723.7572 | 73105.22856 |
| Hydrologic adjustment | 202126.0718 | 204750.3076 | 264616.4361 | 201682.7078 | 202191.9773 | 205625.0529 |
| Soil conservation | 339778.3116 | 186922.7869 | 197666.4352 | 185676.7145 | 0 | 197940.6904 |
| Raw material production | 698355.7513 | 84365.12432 | 82021.64864 | 56243.41621 | 9373.902702 | 91395.55134 |
| Climate adjustment | 953794.5999 | 365582.2054 | 482755.9891 | 3175409.54 | 30465.18378 | 227317.1405 |
| Biodiversity maintaining | 1056907.53 | 438229.9513 | 803812.1567 | 864742.5242 | 93739.02702 | 239034.5189 |
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|---|---|---|---|---|---|---|
| 2015 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147756.8357 | 178318.8115 | 176683.207 | 293872.651 | 220286.6922 | 248703.968 |
| Food production | 213026.0042 | 203010.5091 | 202587.2352 | 197716.6045 | 215982.9599 | 234773.9365 |
| Aesthetic landscape | 236657.6184 | 207993.1039 | 203415.2479 | 181300.0306 | 217463.2789 | 197404.1661 |
| Waste disposal | 206097.2761 | 189789.9838 | 233480.0779 | 290693.4564 | 211107.1453 | 73238.23526 |
| Hydrologic adjustment | 202493.8174 | 205122.8277 | 265097.8758 | 202049.6467 | 202559.8427 | 205999.1644 |
| Soil conservation | 340396.4998 | 187262.8718 | 198026.0669 | 186014.5323 | 0 | 198300.8211 |
| Raw material production | 699626.3307 | 84518.61713 | 82170.87777 | 56345.74475 | 9390.957459 | 91561.83523 |
| Climate adjustment | 955529.9215 | 366247.3409 | 483634.3091 | 3181186.839 | 30520.61174 | 227730.7184 |
| Biodiversity maintaining | 1058830.454 | 439027.2612 | 805274.6021 | 866315.8256 | 93909.57459 | 239469.4152 |
| | | | | | | |
| 2016 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147909.1885 | 178502.6769 | 176865.3858 | 294175.6644 | 220513.8308 | 248960.4077 |
| Food production | 213245.6563 | 203219.8342 | 202796.1238 | 197920.471 | 216205.6609 | 235016.0129 |
| Aesthetic landscape | 236901.6371 | 208207.5665 | 203624.9902 | 181486.9699 | 217687.5063 | 197607.7104 |
| Waste disposal | 206309.784 | 189985.6771 | 233720.8202 | 290993.1918 | 211324.8188 | 73313.75154 |
| Hydrologic adjustment | 202702.6096 | 205334.3307 | 265371.2194 | 202257.981 | 202768.7031 | 206211.5711 |
| Soil conservation | 340747.4842 | 187455.9594 | 198230.2525 | 186206.3327 | 0 | 198505.29 |
| Raw material production | 700347.7186 | 84605.76466 | 82255.60453 | 56403.84311 | 9400.640518 | 91656.24505 |

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|---|---|---|---|---|---|---|
| Climate adjustment | 956515.1727 | 366624.9802 | 484132.9867 | 3184466.975 | 30552.08168 | 227965.5326 |
| Biodiversity maintaining | 1059922.218 | 439479.9442 | 806104.9244 | 867209.0878 | 94006.40518 | 239716.3332 |
| | | | | | | |
| 2017 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147920.3244 | 178516.1162 | 176878.7018 | 294197.8126 | 220530.4331 | 248979.1517 |
| Food production | 213261.7113 | 203235.1344 | 202811.3921 | 197935.3723 | 216221.9388 | 235033.7071 |
| Aesthetic landscape | 236919.4732 | 208223.2422 | 203640.321 | 181500.6339 | 217703.8958 | 197622.5881 |
| Waste disposal | 206325.3168 | 189999.981 | 233738.4169 | 291015.1003 | 211340.7293 | 73319.27125 |
| Hydrologic adjustment | 202717.8709 | 205349.7902 | 265391.1989 | 202273.2088 | 202783.9693 | 206227.0966 |
| Soil conservation | 340773.1387 | 187470.0727 | 198245.1771 | 186220.352 | 0 | 198520.2352 |
| Raw material production | 700400.447 | 84612.13454 | 82261.79747 | 56408.08969 | 9401.348282 | 91663.14575 |
| Climate adjustment | 956587.1877 | 366652.583 | 484169.4365 | 3184706.731 | 30554.38192 | 227982.6958 |
| Biodiversity maintaining | 1060002.019 | 439513.0322 | 806165.6152 | 867274.3791 | 94013.48282 | 239734.3812 |
| | | | | | | |
| 2018 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147763.7437 | 178327.1483 | 176691.4672 | 293886.3901 | 220296.991 | 248715.5954 |
| Food production | 213035.9636 | 203020.0002 | 202596.7066 | 197725.8482 | 215993.0575 | 234784.9126 |
| Aesthetic landscape | 236668.6826 | 208002.8279 | 203424.7579 | 181308.5068 | 217473.4457 | 197413.3951 |
| Waste disposal | 206106.9116 | 189798.8569 | 233490.9935 | 290707.0469 | 211117.015 | 73241.65929 |
| Hydrologic adjustment | 202503.2843 | 205132.4176 | 265110.2696 | 202059.0929 | 202569.3128 | 206008.7953 |

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|---|---|---|---|---|---|---|
| Soil conservation | 340412.414 | 187271.6267 | 198035.325 | 186023.2288 | 0 | 198310.092 |
| Raw material production | 699659.0396 | 84522.56854 | 82174.71942 | 56348.37903 | 9391.396505 | 91566.11592 |
| Climate adjustment | 955574.5944 | 366264.4637 | 483656.92 | 3181335.566 | 30522.03864 | 227741.3652 |
| Biodiversity maintaining | 1058879.956 | 439047.7866 | 805312.2503 | 866356.3276 | 93913.96505 | 239480.6109 |
| | | | | | | |
| 2019 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 147411.5446 | 177902.1005 | 176270.3181 | 293185.9036 | 219771.9069 | 248122.7747 |
| Food production | 212528.1864 | 202536.0963 | 202113.8116 | 197254.563 | 215478.232 | 234225.2961 |
| Aesthetic landscape | 236104.5761 | 207507.0473 | 202939.8892 | 180876.3528 | 216955.0916 | 196942.8547 |
| Waste disposal | 205615.6499 | 189346.4659 | 232934.4611 | 290014.1384 | 210613.8116 | 73067.08572 |
| Hydrologic adjustment | 202020.612 | 204643.4786 | 264478.3718 | 201577.4793 | 202086.4831 | 205517.7675 |
| Soil conservation | 339601.0314 | 186825.2595 | 197563.3022 | 185579.8372 | 0 | 197837.4143 |
| Raw material production | 697991.3825 | 84321.10661 | 81978.85365 | 56214.07107 | 9369.011845 | 91347.86549 |
| Climate adjustment | 953296.9553 | 365391.462 | 482504.11 | 3173752.763 | 30449.2885 | 227198.5373 |
| Biodiversity maintaining | 1056356.086 | 438001.3038 | 803392.7657 | 864291.3427 | 93690.11845 | 238909.8021 |
| | | | | | | |
| 2020 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 146834.2814 | 177205.4363 | 175580.044 | 292037.7884 | 218911.2807 | 247151.1266 |
| Food production | 211695.9266 | 201742.9655 | 201322.3344 | 196482.1147 | 214634.4198 | 233308.0705 |

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|---|---|---|---|---|---|---|
| Aesthetic landscape | 235179.9912 | 206694.4503 | 202145.1772 | 180168.0415 | 216105.4961 | 196171.6271 |
| Waste disposal | 204810.4596 | 188604.9857 | 232022.2904 | 288878.4439 | 209789.0485 | 72780.95522 |
| Hydrologic adjustment | 201229.4999 | 203842.0953 | 263442.6752 | 200788.1025 | 201295.113 | 204712.9605 |
| Soil conservation | 338271.1547 | 186093.6522 | 196789.6449 | 184853.107 | 0 | 197062.6835 |
| Raw material production | 695258.0501 | 83990.90538 | 81657.82468 | 55993.93692 | 9332.322821 | 90990.1475 |
| Climate adjustment | 949563.847 | 363960.59 | 480614.6253 | 3161324.355 | 30330.04917 | 226308.8284 |
| Biodiversity maintaining | 1052219.398 | 436286.0919 | 800246.6819 | 860906.7802 | 93323.22821 | 237974.2319 |
| | | | | | | |
| 2021 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 146000.8111 | 176199.5713 | 174583.4052 | 290380.1044 | 217668.6823 | 245748.2313 |
| Food production | 210494.2843 | 200597.819 | 200179.5755 | 195366.8301 | 213416.0979 | 231983.752 |
| Aesthetic landscape | 233845.0472 | 205521.1978 | 200997.7476 | 179145.3599 | 214878.824 | 195058.1049 |
| Waste disposal | 203647.9011 | 187534.4138 | 230705.2704 | 287238.6932 | 208598.2302 | 72367.83122 |
| Hydrologic adjustment | 200087.2679 | 202685.0336 | 261947.3047 | 199648.3759 | 200152.5086 | 203550.9555 |
| Soil conservation | 336351.0379 | 185037.3353 | 195672.6147 | 183803.8318 | 0 | 195944.1035 |
| Raw material production | 691311.5811 | 83514.15074 | 81194.31322 | 55676.10049 | 9279.350082 | 90473.6633 |
| Climate adjustment | 944173.8708 | 361894.6532 | 477886.5292 | 3143379.84 | 30157.88777 | 225024.2395 |
| Biodiversity maintaining | 1046246.722 | 433809.6163 | 795704.2695 | 856020.0451 | 92793.50082 | 236623.4271 |
| | | | | | | |

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|---|---|---|---|---|---|---|
| | | | | | | |
| 2022 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 144878.1292 | 174844.6743 | 173240.9357 | 288147.2095 | 215994.9061 | 243858.5357 |
| Food production | 208875.6761 | 199055.3102 | 198640.2828 | 193864.5453 | 211775.0222 | 230199.8993 |
| Aesthetic landscape | 232046.8819 | 203940.8304 | 199452.1635 | 177767.8111 | 213226.5006 | 193558.1941 |
| Waste disposal | 202081.9386 | 186092.3568 | 228931.2486 | 285029.9543 | 206994.2018 | 71811.3545 |
| Hydrologic adjustment | 198548.685 | 201126.475 | 259933.0455 | 198113.168 | 198613.424 | 201985.7384 |
| Soil conservation | 333764.6467 | 183614.4798 | 194167.9786 | 182390.4614 | 0 | 194437.3797 |
| Raw material production | 685995.6999 | 82871.96374 | 80569.96475 | 55247.97583 | 9207.995971 | 89777.96072 |
| Climate adjustment | 936913.5901 | 359111.8429 | 474211.7925 | 3119208.635 | 29925.98691 | 223293.9023 |
| Biodiversity maintaining | 1038201.546 | 430473.8117 | 789585.6545 | 849437.6283 | 92079.95971 | 234803.8973 |
| | | | | | | |
| 2023 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 143431.1932 | 173098.4545 | 171510.7329 | 285269.4074 | 213837.708 | 241423.0563 |
| Food production | 206789.5797 | 197067.2923 | 196656.41 | 191928.369 | 209659.9693 | 227900.8322 |
| Aesthetic landscape | 229729.3686 | 201904.0196 | 197460.1822 | 175992.3971 | 211096.9513 | 191625.0774 |
| Waste disposal | 200063.693 | 184233.8034 | 226644.8519 | 282183.2851 | 204926.8962 | 71094.15559 |
| Hydrologic adjustment | 196565.727 | 199117.7719 | 257337.0257 | 196134.5596 | 196629.8194 | 199968.4536 |
| Soil conservation | 330431.2513 | 181780.6736 | 192228.7718 | 180568.8798 | 0 | 192495.4824 |
| Raw material production | 679144.4801 | 82044.2996 | 79765.29128 | 54696.19974 | 9116.033289 | 88881.32457 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Climate adjustment | 927556.3872 | 355525.2983 | 469475.7144 | 3088056.277 | 29627.10819 | 221063.8073 |
| Biodiversity maintaining | 1027832.753 | 426174.5563 | 781699.8546 | 840954.0709 | 91160.33289 | 232458.8489 |
| | | | | | | |
| 2024 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 141622.732 | 170915.9318 | 169348.2291 | 281672.5702 | 211141.5219 | 238379.0586 |
| Food production | 204182.2604 | 194582.5571 | 194176.8553 | 189508.4282 | 207016.4585 | 225027.3304 |
| Aesthetic landscape | 226832.8115 | 199358.3002 | 194970.4932 | 173773.386 | 208435.3223 | 189208.9606 |
| Waste disposal | 197541.1774 | 181910.88 | 223787.1861 | 278625.3595 | 202343.0626 | 70197.76049 |
| Hydrologic adjustment | 194087.3157 | 196607.1831 | 254092.3757 | 193661.5847 | 194150.6001 | 197447.1388 |
| Soil conservation | 326264.9882 | 179488.6807 | 189805.0433 | 178292.1658 | 0 | 190068.3911 |
| Raw material production | 670581.4445 | 81009.83893 | 78759.56563 | 54006.55929 | 9001.093215 | 87760.65884 |
| Climate adjustment | 915861.2346 | 351042.6354 | 463556.3006 | 3049120.326 | 29253.55295 | 218276.5105 |
| Biodiversity maintaining | 1014873.26 | 420801.1078 | 771843.7432 | 830350.8491 | 90010.93215 | 229527.877 |
| | | | | | | |
| 2025 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 139413.0419 | 168249.1902 | 166705.9478 | 277277.7314 | 207847.1545 | 234659.7133 |
| Food production | 200996.4758 | 191546.5534 | 191147.1816 | 186551.5944 | 203786.4529 | 221516.3075 |
| Aesthetic landscape | 223293.6183 | 196247.7822 | 191928.4366 | 171062.0605 | 205183.1787 | 186256.7993 |
| Waste disposal | 194459.0114 | 179072.588 | 220295.5128 | 274278.0653 | 199185.9744 | 69102.48933 |
| Hydrologic adjustment | 191059.0391 | 193539.5898 | 250127.861 | 190639.9506 | 191121.336 | 194366.44 |

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|---|---|---|---|---|---|---|
| Soil conservation | 321174.3895 | 176688.1814 | 186843.5815 | 175510.3353 | 0 | 187102.8203 |
| Raw material production | 660118.5963 | 79745.87069 | 77530.70761 | 53163.91379 | 8860.652299 | 86391.35991 |
| Climate adjustment | 901571.3714 | 345565.4396 | 456323.5934 | 3001545.966 | 28797.11997 | 214870.8182 |
| Biodiversity maintaining | 999038.5467 | 414235.495 | 759800.9346 | 817395.1746 | 88606.52299 | 225946.6336 |
| | | | | | | |
| 2026 | woodland | grassland | river/lake | wetland | desert | farmland |
| Gas regulation | 136759.7659 | 165047.1114 | 163533.2397 | 272000.6473 | 203891.4566 | 230193.7252 |
| Food production | 197171.1585 | 187901.0847 | 187509.3137 | 183001.1886 | 199908.0374 | 217300.4615 |
| Aesthetic landscape | 219043.947 | 192512.8408 | 188275.7001 | 167806.4479 | 201278.181 | 182712.0039 |
| Waste disposal | 190758.1135 | 175664.5209 | 216102.9007 | 269058.0701 | 195395.1141 | 67787.34711 |
| Hydrologic adjustment | 187422.8487 | 189856.1902 | 245367.4868 | 187011.7362 | 187483.96 | 190667.304 |
| Soil conservation | 315061.8745 | 173325.4938 | 183287.6187 | 172170.0642 | 0 | 183541.9238 |
| Raw material production | 647555.3754 | 78228.16616 | 76055.16154 | 52152.11077 | 8692.018462 | 84747.18 |
| Climate adjustment | 884412.8785 | 338988.72 | 447638.9508 | 2944421.254 | 28249.06 | 210781.4477 |
| Biodiversity maintaining | 980025.0816 | 406351.8631 | 745340.5831 | 801838.7031 | 86920.18462 | 221646.4708 |