Comprehensive Evaluation and Empirical Analysis of Global Ecosystem

Shengyue Ding¹, Chia-kan Chang¹,*, Wenqi Wang², Guoyi Yan², Ting Chen¹ and Jun Ke³

¹School of optoelectronic information and energy engineering, Wuhan Institute of Technology, Wuhan, China
²School of mathematical, Wuhan Institute of Technology, Wuhan, China
³School of chemical and environmental engineering, Wuhan Institute of Technology, Wuhan, China

*Corresponding author e-mail: 1042474404@qq.com

Abstract. With economic development, people often ignore the changes to the ecological system of the constructed area. However, whenever we change an ecosystem, it is possible to limit or remove ecosystem services. Therefore, we measure the degradation of ecosystem service values before and after a development project by establishing ecological health evaluation and social-ecological economic compound model. Through the establishment and calculation of these models, we find that in order to achieve scientific and sustainable development in a certain region, the restoration value of the ecosystem must be taken into consideration, and the optimal solution of social, ecological and economic composition can be found based on the actual geographical situation. The method in this paper is more concise and intuitive, which has a strong economic measurement effect on the policy of minimum ecological damage in current engineering construction, and the optimal solution can be find according to engineering requirements to ensure the balance between environment and construction.

1. Introduction

Nowadays, resource consumption is excessive and energy distribution is unreasonable. The neglect of the change of ecological environment and energy structure in the construction has weakened the originally fragile environmental resilience. For reducing the project construction change and destruction of the original ecological environment, this paper tries to prejudge the cost of restore the ecosystem to its original state after construction, as well as land ecological destruction of a larger system, in order to determine whether is suitable for the construction, or find a proper measure to maximize the ecosystem restoration to the original value. In addition, this paper also aims to find the main influencing factors on the overall ecological environment system of a large region, including political, economic, geographical, ecological, social and so on. Taking national development as an example, according to the different impact degrees of different impact factors on the environment, this paper analyzes the strong and weak impact factors of different countries, and finds out the direct causes of the current ecological environment status. The first model aims to evaluate the ecosystem health [1] of four administrative units at the same level. In this paper, the pressure, state, response weighting model [2] as well as the
overall health weighting model of ecosystem health under the combined action of three factors are established on the premise of clarifying the ecosystem health assessment indicators. The comprehensive index weights of pressure, state and response are determined by the analytic hierarchy process (AHP) [3]. The second model evaluates the comprehensive value of social ecological economy in America, India and Afghanistan. This paper selects 9 indicators, with factor analysis, principal component analysis (PCA), and SPSS to calculate the comprehensive scores of the three countries, and then compares the results with the national conditions of different countries.

2. Constraint condition
   1. Assume that the selected indicators are independent, so the superposition can be ignored.
   2. Assume that the ecosystem occupied by land-use project is in a stable state before the start of the project and after the end of the project.
   3. Assume that during the construction of the project, no new organisms flow into the ecosystem.
   4. Assume that all the data referenced in this article is true and valid.
   5. Assume that the total value of services in the land ecosystem is equal to the sum of the monetary ESV.

3. The development of model
   Our goal is to create an ecological services valuation [4] model as well as use this model to perform a cost benefit analysis of land use development projects of varying sizes.
   Our approach can be divided into two steps.
   The first step is to establish an ecological health evaluation model. In order to achieve this goal, we selected health values to describe ecosystem excellence and selected seven indicators that affect health values most. The values of 7 indicators were calculated according to the data, and then the health value was determined based on the values of 7 indicators. The data were substituted into the formula to calculate the results, and were divided into five grades: very healthy, healthy, sub-healthy, unhealthy and pathosis.
   The second step is to establish the social-ecological economic compound model. Combining the indicators of the first model, a new evaluation value model is developed to calculate the monetary value of environmental damage loss after the completion of the project. At the same time, we will predict the future ecological service value and its change over time based on the data of different regions and different years, and work out how the model should change.

3.1. Model one: Ecological health evaluation model
   In the process of sustained and rapid economic development, it is inevitable to destroy the ecological environment in the process of development projects, resulting in the decline of ecological environment service value. How to find the social, economic and ecological optimization methods under the resource constraints has become the most concerned problem. In order to compare the ecological and environmental health of different provinces, municipalities and autonomous regions, the pressure-state-response model was adopted in model 1 to evaluate the health of the ecosystem. In this paper, four administrative units at the same level, namely Hubei province, Jiangxi province, Beijing city and Chongqing city, were selected, and eight sub indicators, including population density, ratio of cultivated land to construction land, Normalized difference vegetation Index(NDVI), comprehensive elasticity value, diversity index(DIV), evenness index, degree of soil erosion and GDP per capita, were selected to grade the ecological health of each provinces, municipalities and autonomous regions.

3.1.1. The selection and calculation of indicators. The source of data is mainly came form Geographic Information monitoring cloud platform [5].
   Beijing is a heavy industry development zone, its early foundation is poor, after the renovation and improvement in recent years, it become the representative of environmental improvement city, Beijing is not suitable for environmental development. Hubei province’s environment and climate are suitable,
but the speed of urban development in each administrative region is not consistent, it is suitable for large-scale environmental development. Jiangxi province’s geographical location is not good, the strength of land-use project is relatively small compared with Hubei province and Beijing city, economic construction of Jiangxi is not yet begin. Chongqing, which focus on developing tourism, it’s development intensity is small, while the environment is good, Chongqing can be regarded as the representative of tourism developed administrative unit.

3.1.2. Establishment of evaluation index system. In this paper, population pressure and human disturbance are taken as the main contents of the pressure indicator. NDVI, comprehensive elastic value, diversity index and evenness index were set as parameters for the establishment of state index from three aspects of vitality, resilience and organization. Natural system impact and human system impact are taken as the evaluation basis of corresponding indicators, and soil erosion degree and per capita GDP are set as parameters. The specific structure level is shown as fig.1.

![Figure 1. Detailed indexes of evaluation index system](image)

3.1.3. The calculation of NDVI. Normalized difference vegetation Index, which is used to evaluate vegetation growth state, vegetation coverage and eliminate part of radiation error. According to the data from Geographic condition monitoring cloud platform, the NDVI data of four administrative units were obtained.

3.1.4. The calculation of composite elasticity. The comprehensive elastic value is reflected by the resilience of the ecosystem. According to the contribution of different land use types to ecological recovery, different resilience values are given to each land use type as shown on table 1.

| Land use type | Cultivated land | Construction land | Woodland | Water area | Grassland | Garden land |
|---------------|-----------------|-------------------|----------|------------|-----------|------------|
| Resilience    | 0.9             | 0.1               | 0.9      | 0.9        | 0.3       | 0.3        |

The calculation of composite elasticity could be calculated according to Eq. (1):
\[ ECO_{res} = \sum_{i=1}^{m} s_i \times P_i \]  

(1)

Where ECOres is the composite elasticity, si is the ratio of land use type i to total area, Pi is the score of resilience of different land use types, m is the number of land use types.

3.1.5. The calculation of diversity index. The diversity index refers to the degree of diversification of land use types, calculated by following Eq. (2):

\[ H = \sum_{i=1}^{m} s_i \times \ln s_i \]  

(2)

3.1.6. The calculation of evenness index. Evenness index reflects the uneven distribution of land use types in four different administrative units in China, calculated by following Eq. (3):

\[ E = \frac{H}{H_{\text{max}}} \]  

(3)

3.1.7. The calculation of degree of soil erosion. In this paper, we define three correction factor water of three erosion state according to the value of degree of soil erosion, shown on table 2.

The formula to calculate degree of soil erosion is as follows Eq. (4):

\[ M = \sum_{i=0}^{m} A_i \times B_i \]  

(4)

3.2. Dimensionless process of evaluation indicators

The original values of the 8 sub indicators found in each database website [5][7] and calculated according to the above formulas are shown in the table 2.

| Sub indicator | Hubei province | Jiangxi province | Beijing city | Chongqing city |
|---------------|---------------|-----------------|-------------|---------------|
| Density of population(person/km\(^2\)) | 317.4825 | 276.9323 | 1322.8126 | 373.1796 |
| Area ratio of cultivated land to construction land | 3.0140 | 2.3626 | 0.5933 | 3.4616 |
| NDVI | 0.8530 | 0.7134 | 0.7617 | 0.8183 |
| Composite elasticity | 0.6532 | 0.7586 | 0.4992 | 0.6339 |
| Diversity index | 1.1725 | 1.0286 | 1.2328 | 1.1220 |
| Evenness index | 0.6544 | 0.5741 | 0.6880 | 0.6262 |
| Degree of soil erosion | 0.1101 | 0.0104 | 0.1136 | 0.1980 |
| GDP per capia(RMB) | 618.8233 | 450.4219 | 1289.7444 | 634.1551 |

Due to the different data properties and dimensions of each evaluation index, dimensionless processing of data is required. In this paper, dimensionless data is formed through extreme value normalization processing. The sub indicator values are normalized using the following formula Eq. (5):

\[ P_i = \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \]  

(5)
Where \( P_i \) is the value of 8 sub indicators after dimensionless processing. The values after dimensionless process shown in table 3.

**Table 3.** Dimensionlessed data of 8 sub indicators.

| Sub indicator                                      | Hubei province | Jiangxi province | Beijing city | Chongqing city |
|----------------------------------------------------|----------------|------------------|--------------|---------------|
| Density of population (person/km\(^2\))            | 0.0388         | 0                | 1.0000       | 0.0920        |
| Area ratio of cultivated land to construction land  | 0.8440         | 0.6168           | 0            | 1.0000        |
| NDVI                                               | 1.0000         | 0                | 0.3460       | 0.7514        |
| Composite elasticity                               | 0.5938         | 1.0000           | 0            | 0.5192        |
| Diversity index                                    | 0.7050         | 0                | 1.0000       | 0.4572        |
| Evenness index                                     | 0.7050         | 0                | 1.0000       | 0.4572        |
| Degree of soil erosion                             | 0.5315         | 0                | 0.5501       | 1.0000        |
| GDP per capia (RMB)                                | 0.2006         | 0                | 1.0000       | 0.2189        |

The Delphi method [6] is adopted to calculate the weight of each evaluation index. Experts grade the importance of each factor according to their experience. According to the results, the average importance of each factor are calculated to fall below a certain limit. The weight of each factor was determined according to the final scoring result. In this paper, the weight of each evaluation index is appropriately selected based on the expert scoring results. Specific indicator weights are shown in table 4.

**Table 4.** Specific indicator weights

| Main indicator       | Weight | Sub indicator                                      | Weight |
|----------------------|--------|----------------------------------------------------|--------|
| Pressure indicator   | 0.2980 | Population density                                 | 0.4455 |
|                      |        | Area ratio of cultivated land to construction land | 0.5545 |
|                      |        | NDVI                                               | 0.2885 |
| State indicator      | 0.5445 | Composite elasticity                               | 0.1873 |
|                      |        | Diversity index                                    | 0.2255 |
|                      |        | Evenness index                                     | 0.2987 |
| Response indicator   | 0.1575 | Degree of soil erosion                             | 0.6428 |
|                      |        | GDP per capia (RMB)                                | 0.3572 |

### 3.3. Ecosystem Health Assessment

Based on formulas listed above, get the table 5.

**Table 5.** Final value of main indicators of four administrative unit

| Administrative unit      | Pressure indicator | State indicator | Response indicator |
|--------------------------|--------------------|-----------------|--------------------|
| Hubei province           | 0.7737             | 0.4808          | 0.4133             |
| Jiangxi province         | 0.3420             | 0.1873          | 0                  |
| Beijing city             | 0.5453             | 0.5242          | 0.7108             |
| Chongqing city           | 0.8123             | 0.3369          | 0.7210             |

Define health index \( G \) as Eq. (6):

\[
G = \sum_{i=0}^{8} \omega_i s_i \tag{6}
\]

Where \( \omega_i \) is the weight of main indicators. If the value of \( G \) is larger than 0.8 or equals 0.8, the ecosystem health is categorized as very healthy. If the value of \( G \) is larger than 0.6 or equals 0.6, but smaller than 0.8, the ecosystem health is categorized as healthy. If the value of \( G \) is larger than 0.4 or
equals 0.4, but smaller than 0.6, the ecosystem health is categorized as sub-healthy. If the value of G is larger than 0.2 or equals 0.2, but smaller than 0.4, the ecosystem health is categorized as unhealthy. If the value of G is smaller than 0.2, the ecosystem health is categorized as pathosis. The value of G is calculated by Eq. (6) and listed below: the health index of Hubei province is 0.5574, the health index of Jiangxi province is 0.2039, the health index of Beijing City is 0.5599, the health index of Chongqing City is 0.5391.

The first model in this paper makes ecosystem health evaluation on four administrative units at the same level and draws the following conclusions:

In this paper, on the premise of defining the evaluation index of ecosystem health, the weighted model of pressure, state and response as well as the overall health weighted model of ecosystem health under the combined action of three main indicators are established, and the weight of pressure, state and response comprehensive indicator is determined by the analytic hierarchy process.

According to the results, although the ecological and environmental health index of Beijing was low five years ago, after years of improvement, the ecological health value of Beijing in 2017 has been greatly improved, which is in line with the current situation of Beijing. Hubei paid attention to economic development in recent years, ignored environmental management, compare with Beijing, Hubei’s overall healthy value is little low, its healthy level is a little worse than few years ago. Chongqing is dominated by tourism, but in recent years it has also put more emphasis on the economy than the environment, as in Hubei province. The geographical environment of Jiangxi province is slightly better than that of Beijing and worse than that of Hubei and Chongqing. It can be seen that in the process of project construction in a certain region, the restoration value of the ecosystem must be taken into account.

3.4. Model two: social-ecological economic compound model

In order to evaluate the excellence of a country or region, the entropy weight method were used to calculate the weight of each indicators we selected, and the score of the comprehensive index of a country's social, environmental and economic model was calculated. The excellence of each country can be evaluated by observing and analyzing their comprehensive scores over several years. Among many indicators, we have selected 9 indicators that obviously affect the result of the social environment as well as economy. Specific indicators are shown in the table 6.

| Table 6. Comprehensive evaluation indicators of urban ecosystem list |
|-------------------------|-----------------------------|
| Indicator name | Unit |
| Travel services | % of commercial service exports |
| Agricultural raw materials exports | % of merchandise |
| Final consumption expenditure | Current US$ |
| Cereal yield | Kg per hectare |
| Corp production index | - |
| GDP per capia | US $ |
| Agriculture, forestry, and fishing, value added | Annual % growth |
| Population density | Population per km² of land area |
| PM2.5 air pollution, mean annual exposure | Micrograms per cubic meter |

The $x_{ij}$ represents the value of the j-th indicator for the i-th country. As the measurement units of various indicators are not uniform, they should be standardized before the comprehensive indicators are calculated with them. Let $x_{ij} = |x_{ij}|$, so as to solve the problem of homogenization of different quality index values. Moreover, due to the higher the positive index value is, the better; the lower the negative index value is, the better, thus we use different algorithms to conduct data dimensionless processing for the indicators with various values. The specific method is as follows, to positive indicators Eq. (7):
To negative indicators Eq. (8):

\[
x'_{ij} = \frac{\max \{x_{ij}, L \} - x_{ij}}{\max \{x_{ij}, L \} - \min \{x_{ij}, L \}}
\]

The \( x'_{ij} \) represents the value of the \( j \)-th indicator for the \( i \)-th country after dimensionless process, for convenience, the dimensionlessed data is still denoted as \( x_{ij} \). Then calculate the weight of the \( i \)-th country in indicator \( j \) Eq. (9):

\[
p_{ij} = \frac{x_{ij}}{\sum_{i} x_{ij}}
\]

Where \( p_{ij} \) is the weight of the \( i \)-th country in indicator \( j \). Then calculate information entropy redundancy \( d_{j} \), the weight of each index \( w_{j} \) as well as composite score for each country \( a_{i} \) based on following Eq. (10), Eq. (11), Eq. (12):

\[
d_{j} = 1 - e_{j}
\]

\[
w_{j} = \frac{d_{j}}{\sum_{j=1}^{m} d_{j}}
\]

\[
a_{i} = \sum_{j=1}^{m} w_{j} \cdot p_{ij}
\]

Based on the data from Word Bank [8], collect 9 indicators in table 9, calculate it with Eq. (7) to (12). Getting figure 2.

**Figure 2.** State change figure of three country’s urban ecosystem

Through the analysis of a number of indicators of the United States, India and Afghanistan from 2010 to 2016, the above table shows the change trend (not the quality) of urban ecosystem in the three countries intuitively. Afghanistan shows an overall upward trend after a period of significant decline and rise, indicating that it is affected by some larger external factors. However, the rising trend in India and the United States is relatively stable, indicating that India and the United States have enjoyed relatively good development in recent years.
We selected the values of various indicators in the United States, India and Afghanistan in 2016, and used these values as the original variables for factor analysis and principal component analysis, shown on figure 3.

| X1  | X2  | X3  | X4  | X5  | X6  | X7  | X8  | X9  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 13.909807 | 1.3794485 | 16906398908000.0000000000000000000000000000 | 2992.8 | 142.83 | 36306.765 | 6.2658334 | 446.370670 | 75.800790 |
| 12.564865 | 16.3591100 | 1610279484200.0000000000000000000000000000 | 1991.7 | 147.96 | 6275.910 | 5.9717517 | 53.083495 | 62.654860 |
| 27.955270 | 2.3008850 | 15478720000000.0000000000000000000000000000 | 8142.9 | 122.19 | 111587.160 | 11.2814700 | 36.354880 | 9.156934 |

**Figure 3.** Data table in SPSS.

Where X1 refers Travel services, X2 refers Agricultural raw materials exports, X3 refers Final consumption expenditure, X4 refers Cereal yield, X5 refers Corp production index, X6 refers GDP per capia. X7 refers Agriculture, forestry, and fishing, value added. X8 refers Population density. X9 refers PM2.5 air pollution, mean annual exposure.

With gravel figure (figure 4), It can be intuitively seen that the variance of the first two principal components accounts for the majority of the variation of the total variance, so it is appropriate to take the number of principal components as 2.

![Scree Plot](image)

**Figure 4.** Gravel figure

As can be seen from the fig.5, the first principal component takes up 82.230% of the total amount, and the second principal component takes up 17.770% of the total amount. These two principal components add up to 100% of the total amount, which further confirms the correctness of taking two principal components. And the overall size = the size of the first principal component * 82.230% + the size of the second principal component * 17.770%.

To find out whether the relationship between principal component and each variable is close or positive or negative correlation, according to SPSS analyse, we got the figure 5.
The loading values of the two principal factors extracted by the principal component method can be obtained from figure 6.

It can be seen from factor analysis that each factor has only a few indicators with a large factor load. Therefore, according to the above table, the six indicators can be divided into two categories according to the high load: X1, X3, X4, X5, X6, X7 and X9 have large load on the first factor, and the above factors can be divided into one category; X2 and X8 have a large load on the second factor, which can be divided into another category. Then assign the values in the composition matrix to the new variables V1 and V2, get the figure 7.
Figure 7. The new variable defined by the factor result

According to the formula: 

\[ F1/2 = \frac{V1/2}{\sqrt{\text{Initial eigenvalues of corresponding principal factors in factor analysis}}} \]

we get the figure 8.

Figure 8. Eigenvector matrix

Then standardize the original variables, with the data and process above, we can calculate y1 and y2 below, shown on figure 9 and figure 10.

Figure 9. calculate the first principal component y1

Where ZX1 refers the value of X1 after standardized, so as ZX2 to ZX9.

\[ y1 = 0.368*ZX1 - 0.189*ZX2 + 0.368*ZX3 + 0.366*ZX4 - 0.365*ZX5 + 0.368*ZX6 + 0.368*ZX7 - 0.173*ZX8 - 0.355*ZX9. \]
y2=0.006*ZX1-0.678*ZX2+0.016*ZX3+0.064*ZX4-0.093*ZX5+0.011*ZX6-
0.015*ZX7+0.698*ZX8+0.201*ZX9.

As it’s shown on figure 11, the Total=0.8223*y1+0.1777*y2.

After the processes above, we get the final result, shown on figure 12.

The first column is India with a score of -0.89, the second column is Afghanistan with a score of -1.66 and the third column is the United States with a score of 2.56. According to the result above, ignore environmental factors will cause huge damage to the ecosystem, return it to its original state takes enormous resources. After factor analysis and principal component analysis, we obtained the comprehensive scores of the three countries in the comprehensive indicators in 2016 and compared them. It is concluded that the ecological health value and socio-economic value of the United States are greater than India, while India is greater than Afghanistan. According to the real situation of three countries from 2010 to 2016, it is consistent with the above results, so the model is in line with the facts and effective. As time changes, the regional structure will change, as a result the value of different lands and the weight in the model will change.

The United States scored highest overall, followed by India and Afghanistan. For y1, the first principal component, travel services; final consumption expenditure; cereal yield; GDP per capia; agriculture, forestry, and fishing, value added is the positive influencing factor. Agricultural raw materials exports; corp production index; population density; PM2.5 air pollution as well as mean annual exposure is the negative factor. For y2, the second principal component, travel services; final consumption expenditure; cereal yield; GDP per capia; population density; PM2.5 air pollution as well as mean annual exposure is the positive factor. Agricultural raw materials exports; Agriculture, forestry, and fishing, value added; Corp production index is the negative influencing factor. The United States has good economic development and effective environmental protection measures and governance methods. Its domestic and international situation is relatively stable, so its highest comprehensive score is in line with the status quo. India has a large population, few resources and it is in a period of rapid development with the cost of environmental consumption. Compared with the United States, India has a big gap. The geographical environment of Afghanistan is worse than that of the first two countries. In
recent years, the domestic situation became more and more unstable, the economic development is sluggish, and external disturbances such as unrest are more serious to the environment, so its lowest score is in line with the real situation.

4. Conclusion
The advantage of this paper is to measure the ecological value of the region or the total value of social ecological economy by monetary value. The core of two models is using different mathematical methods to dimensionless various indexes, analysis of correlation between various parameters, and then measure the total monetary value. This method is different from today's conventional method[9]. The method introduced in this paper is more concise and intuitive, and has a strong economic measurement effect on the current policy of minimum ecological damage in engineering construction, and the optimal solution can be find according to the required engineering requirements to ensure the balance between environment and construction.

The first model’s aim is to evaluate the ecosystem health. The second model evaluates the socio-ecological and economic comprehensive value and compare the result with the national conditions of it’s country.

It can be seen from the results of the two models that in order to obtain a healthy and stable ecological environment, it is necessary to consider the consequences caused by ecosystem damage while carrying out economic project development and construction. In the process of ecological economic construction, it is necessary to combine the characteristics of regional ecological structure, and select appropriate development methods while ensuring the complexity and diversity of the ecological system. Develop economic with the cost of ecological destruction is strictly prohibited.

Acknowledgments
This work was supported financially by the President's fund of Wuhan Institute of Technology (2018133).

References
[1] COSTANZA R.: Ecosystem health and ecological engineering, J. Ecological Engineering, 45(8):24-29, doi:10.1016/j.ecoeng.2012.03.023, 2012.
[2] ZHOU BINGZHONG, YANG HAO, BAO HAOSHENG: PSR model and its application in land sustainable use evaluation, J. Journal of natural resources., 17(5):541-548, doi:10.3321/j.issn:1000-3037.2002.05.003, 2002.
[3] SAATY T L.:How to Make a Decision: The Analytic Hierarchy Process, J.European Journal of Operational Research., 24(6):19-43, doi:10.1016/0377-2217(90)90057-I,1994.
[4] OYOYANG Z Y , WANG R S : Ecosystem services and their economic valuation, J. WORLD SCI-TECH R & D, 2000.
[5] Beijing Digital View Technology Co., Ltd.: Geographic Information monitoring cloud platform., Beijing Digital View Technology Co., Ltd., http://www.dsac.cn/, 2019.
[6] SKULMOSKI G , HARTMAN F , KRAHN J .: The Delphi Method for Graduate Research, J. Journal of Information Technology Education,  6(1):1-21,doi:10.28945/199, 2007.
[7] State Statistics Bureau: China Statistical Yearbook of 2017, State Statistics Bureau, http://www.stats.gov.cn/tjsj/ndsj/2017/indexch.htm, 2019.
[8] World Bank Open Data: https://data.worldbank.org/indicator/EN.POP.DNST., last access: 26 January 2019.
[9] PENG J , WANG Y , WU J , et al. Evaluation for regional ecosystem health: methodology and research progress, J. Acta Ecologica Sinica, 27(11):4877-4885, doi:10.1016/s1872-2032(08)60009-8, 2007.