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2019
MCM/ICM
Summary Sheet
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Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

A New Ecological Services Cost Valuation Model

Ecosystem services have an important impact on natural, economic and social life, but most of the traditional land use projects do not consider the changes or impacts on ecosystem services.

In order to understand the true economic cost of land use projects when considering ecosystem services, we build a new Ecological Services Cost Valuation Model based on spectral remote sensing technology, InVEST model and its ecological parameters.

Firstly, we collect remote sensing image data, DEM data, meteorological data, soil data, statistical yearbook and other data on the regions where land use projects have been executed. Afterwards, habitat quality index, soil conservation, water conservation and carbon fixation are calculated by habitat qality module, improved USLE soil conservation module, water source conservation module and carbon fixation module under InVEST model. Then they are converted to habitat value, soil conservation value, water conservation value and carbon fixation value. Consequently, we can evaluate the environmental cost of the land use projects.

Secondly, we build the Quantitative Classification Model by measuring the environmental cost volatility of each indicator over time. Based on this, the sustainable-use ability of land is quantified and graded, and the extent of land degradation is evaluated by the variation of the sustainable-use ability degree.

Thirdly, Ecological Services Cost Valuation Model is based on spectral remote sensing technology, InVEST model and its ecological parameters. As for land use projects of different scales, we can use the corresponding data to accurately calculate the environmental cost, and then evaluate the real economic cost of the projects. Therefore, our model is suitable for different scales of land use projects with excellent adaptability. In addition, the model is improved to make it applicable for land use projects with long duration.

Finally, using the Ecological Services Cost Valuation Model, we evaluate the environmental cost and analyze the environmental degradation of land use projects in Chongqing, China from 2000 to 2015. The inspection and evaluation of the model are carried out. According to this, we give managers and decision makers of land use projects some recommendations.

Contents

1 Introduction

1.1 Background

Humans can freely gain many and varied benefits from the natural environment and from properly-functioning ecosystems, which is the definition of ecosystem services [1]. Nevertheless, human activities, no matter local small-scale changes or large-scale projects in the biosphere, would bring in changes and disturbance to the environment that perceived to be deleterious and undesirable [2]. For example, Industrial production often discharges pollutants into rivers, preventing the use of these resources for other purposes. Unsustainable agricultural practices reduce crop productivity and cause dam sedimentation [3].

The damage caused to several environmental categories usually measured in cost of environmental degradation (COED) are air quality, forests, waster, water, agricultural land and coastal zone. Spatially, the analysis can be done at the local level (for example, a city or a coast), the national level (a country), the multinational level (several countries), or even the regional level (for example, the entire Middle East and North Africa region) [4]. CEOD will raise the awareness of the existing environmental damage. Furthermore, it can push effective actions into practical land use projects considering ecosystem services.

1.2 Our Work

In order to understand the true economic cost of land use projects when considering ecosystem services, we build a new Ecological Services Cost Valuation Model based on spectral remote sensing technology, InVEST model and its ecological parameters.

Firstly, we collect remote sensing image data, DEM data, meteorological data, soil data, statistical yearbook and other data on the regions where land use projects have been executed. Afterwards, habitat quality index, soil conservation, water conservation and carbon fixation are calculated by habitat qality module, improved USLE soil conservation module, water source conservation module and carbon fixation module under InVEST model. Then they are converted to habitat value, soil conservation value, water conservation value and carbon fixation value. Consequently, we can evaluate the environmental cost of the land use projects.

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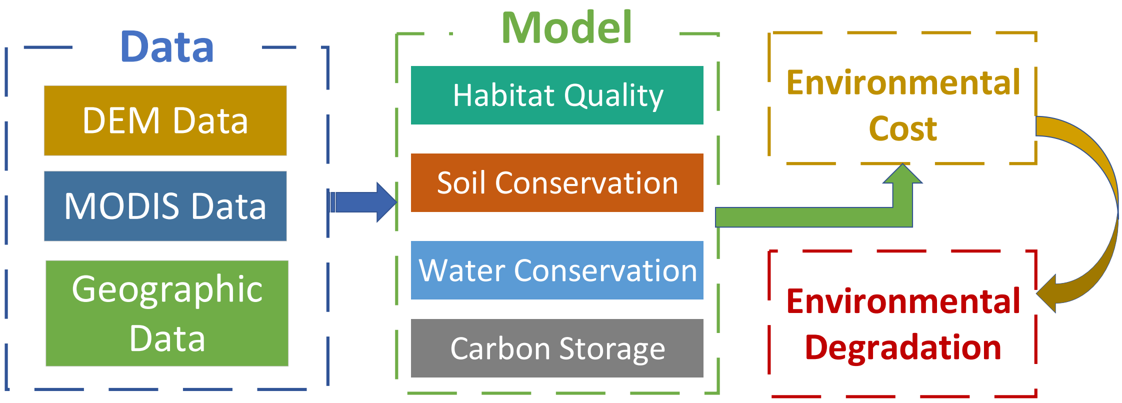


Fig.1 Frame of the Model

2 Assumption and Justification

- **Extremely unstable carbon in the above-ground carbon pool is not under consideration.** The carbon cycle will be very complex if considering extremely unstable carbon.
- **Biodiversity is high in area where the habitat quality is high.** In general, the better the habitat quality, the higher the biodiversity. However, it is not infallible for a small part of the ecosystem.
- **The effects of extreme condition are not taken into consideration in water conservation model.** The water conservation model is based on the data of annual value.

3 Notations

Tab.1 Variables

Notations	Definitions
Q_{xj}	Habitat quality of grid x in land use and land cover j
D_{xj}^{z}	The level of stress factor between land use and land cover j and grid x
i_{rxy}	Stress level of r_y on habitat grid x
W_r	Weight of stress factor (between 0 and 1)

$USLE$	Potential soil erosion
T_h	Soil conservation capacity
R_i	Rainfall erosivity
K_i	Soil erodibility factor
LS_i	Topographic factor
C_i	Vegetation cover factor
f_c	Vegetation coverage
P_i	Soil and water conservation measures factor
V_h	Nutrient value of the soil
Y_{xj}	Annual water supply on grid cell x in landscape type j
$\frac{AET_{xj}}{P_x}$	Ratio of the actual evapotranspiration to the precipitation
ϖ_x	A non-physical parameter
R_{xj}	Budyko drying index on cell x in the forest landscape type j
ET_0	Potential evapotranspiration
AEC_{xj}	The water content of the plant
$PWAC_x$	Available water for vegetation
C_z	Total carbon storage

4 Ecological Services Cost Valuation Model

4.1 Introduction of InVEST

Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) Model is a model tool jointly developed by Stanford University, Nature Conservation Association (TNC) and World Wildlife Fund (WWF) for the quantitative assessment of the value of ecosystem services, including three modules: freshwater, marine ecology and terrestrial ecosystem assessment. This model is suitable for most ecological processes and can apply to different regional scales. Its biggest advantage is that it can be combined with GIS and remote sensing related software to realize the visual expression of the value evaluation of ecosystem services. This model has been widely used in the quantitative assessment of ecosystem services such as habitat quality, water conservation, soil conservation and carbon fixation. It provides scientific support for regional ecological environmental protection, resource development and utilization and social economic development.

4.2 Habitat Quality Model

The Habitat Quality Index was evaluated by InVEST-Habitat Qality module to obtain habitat quality, which is range between 0 and 1. The larger the index is, the better the habitat quality is. The factors affecting habitat quality include five aspects: the type of land use in the habitat itself, the intensity of stress of each source, the sensitivity of each habitat type to each threat source, the spatial distance of habitat (habitat patches) from the source of stress and the extent to which the land is protected by policy laws. The specific method is as follows [5, 6]:

$$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + K^z}\right)\right) \tag{4.1}$$

Where:

Q_{xj} : Habitat quality of grid x in land use and land cover j

H_j : Habitat fitness of land use and land cover j

D_{xj}^z : The level of stress factor between land use and land cover j and grid x

K : Semi-saturation constant

Z : Normalization constant, Z=2.5 generally

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{W_r}{\sum_{r=1}^{R} W_r}\right) r_y i_{rxy} \beta_x S_{jr} \tag{4.2}$$

Where:

R : Stress factor

y : Number of grids of the grid layer of stress factor r

Y_r : Number of grids of stress factors

W_r : Weight of stress factor (between 0 and 1)

r_y : Stress value of the grid y (between 0 and 1)

i_{rxy} : Stress level of r_y on habitat grid x

β_x : Reachability level of x (between 0 and 1)

S_{jr} : Sensitivity of habitat type j to stress factor r (between 0 and 1)

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\max}} \right) \tag{4.3}$$

Where:

d_{xy} : Linear distance between grid x and grid y

$d_{r\max}$: Maximum influence distance of stress factor r

The parameters of the InVEST habitat model are landscape type sensitivity and stress factors, and each stress factor is obtained via TM image interpretation in the study area including cultivated land, rural construction land, urban construction land, industrial and mining and transportation. The sensitivity of a habitat type to external stress is based on the general protection of landscape ecological diversity [7, 8]. In general, the natural environment is most sensitive to external threat factors, followed by semi-environment, and the sensitivity of the artificial environment to external ecological stress factors is relatively small or not at all. The sensitivity of the ecological stress factor to the ecological importance of each species is between 0 and 1.

4.3 Soil Conservation Model

The common soil erosion equation is applied to calculate the potential soil erosion and the actual soil erosion. Then the soil type and its related nutrient content combined with the economic model is applied to complete the assessments of soil conservation value. Researches can be achieved on regional landscape pattern change and soil erosion, soil conservation capacity and the value of its ecological services. This method can accurately reflect the regional soil erosion status. The principle is that the soil conservation capacity is the difference between the potential soil erosion amount and the actual soil erosion amount. The specific formula is as follows:
USLE(Universal Soil Loss Equation):

$$USLE = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i \tag{4.4}$$

SC (Soil Conservation):

$$T_h = R_i \cdot K_i \cdot LS_i \cdot (1 - C_i \cdot P_i) \tag{4.5}$$

Where:
$USLE$: Potential soil erosion

T_h : Soil conservation capacity

R_i : Rainfall erosivity

K_i : Soil erodibility factor

LS_i : Topographic factor

C_i : Vegetation cover factor

P_i : Soil and water conservation measures factor

4.3.1 Rainfall Erosivity

Rainfall erosivity is a grid dataset. The calculation formula of this study is suitable for the annual estimation of the southern region in China.

$$R_i = \sum_{i=0}^{12} 0.3046 P_i - 2.6398 \quad (4.6)$$

Where:

P_i : Average monthly rainfall

4.3.2 Soil Erodibility Factor

K_i is a relatively comprehensive indicator of the soil's ability to resist water erosion. The larger the value, the smaller the erosion resistance of the soil.

4.3.3 Topographic Factor

LS_i is the largest elevation difference over a certain distance from the ground, and the topography is the most direct cause of soil erosion. Using DEM as the data source with the ArcGIS Grid Neighborhood Calculation Tool to take the 3×3 window extraction maximum (MaxDEM) and minimum (MinDEM) , the terrain relief is calculated.

4.3.4 Vegetation Cover Factor

Vegetation coverage refers to the ratio of soil loss to the amount of soil loss from continuous recreational land under a specific crop or vegetation condition under the same rainfall, topography and soil conditions [9]. The formula is as follows:

$$\left\{\begin{array}{cc} C = 1 & f_c = 0 \\ C = 0.6508 - 0.3436 \lg f_c & 0 < f_c < 78.3\% \\ C = 0 & f_c > 78.3\% \end{array}\right\} \quad (4.7)$$

Extracting vegetation coverage using Gutman Model [10]:

$$f_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \quad (4.8)$$

Where,

f_c : Vegetation coverage

$NDVI_{soil}$: NDVI value of completely bare or unvegetated area

$NDVI$: NDVI value of a cell completely covered by vegetation

4.3.5 Soil and Water Conservation Measures Factor

P_i is a mixed model based on experience and physical processes. It is the ratio of the amount of soil loss after special measures to the amount of soil loss when planted along a slope. The value is between 0 and 1. When it is 0, it represents the areas where soil erosion does not occur at all. When it is 1, it represents the areas where no soil and water conservation measures have been taken. Wener empirical formula is adapted to estimate the P_i value of cultivated land.

$$P_i = 0.2 + 0.03S \tag{4.9}$$

Where,

S : Slope

P_i : equals 0 for the water body and the artificial surface and equals 1 for the forest land, grassland and unused land[10, 11].

4.3.6 Nutrient Value of the Soil

$$V_h = T_h \times \sum C_i \times P_i \tag{4.10}$$

Where,

V_h : Nutrient value of the soil

T_h : Soil conservation capacity

i : Nutrient species in the soil

C_i : Content of nutrient i in the soil

P_i : Market price of the nutrient i

4.4 Water Conservation Model

The InVEST model of water conservation model is based on the principle of water balance, that is, the water supply per pixel in the study area is equal to the rainfall minus the actual evaporation. Use the annual precipitation, surface evaporation, vegetation evapotranspiration, soil thickness and root depth to calculate the water production in the basin, and then calculate the water conservation with the topographic factors and soil permeability, including canopy interception, soil water content, water holding capacity of litter and surface runoff. The specific method is as follows:

$$Y_{xj} = P_x - AET_{xj} \tag{4.11}$$

$$Y_{xj} = (1 - AET_{xj} / P_x)P_x \tag{4.12}$$

Y_{xj}: Annual water supply on grid cell x in landscape type j

P_x: Annual rainfall on cell x

AET_{xj}: Actual annual evapotranspiration on cell x in landscape type j

$$\frac{AET_{xj}}{P_x} = \frac{1 + \varpi_x + R_{xj}}{1 + \varpi_x + R_{xj} + {}^{1}\!/_{R_{xj}}} \tag{4.13}$$

$\frac{AET_{xj}}{P_x}$: Ratio of the actual evapotranspiration to the precipitation

R_{xj}: Budyko drying index (the ratio of potential evapotranspiration to rainfall) on cell x in the forest landscape type j

ϖ_x: A non-physical parameter that represents the ratio of the amount of water required for vegetation to the annual precipitation

$$\varpi_x = Z \times ({}^{AWC_x}\!/_{P_x}) \tag{4.14}$$

Z: An empirical constant that reflects the seasonal characteristics of regional precipitation (between 1 and 10)

AET_{xj}: The water content of the plant

$$R_{xj} = k_{xj} ET_{0x} / P_x \tag{4.15}$$

ET_{0x}: Potential evapotranspiration of cell x

k_{xj}: Vegetation evapotranspiration coefficient, which means the ratio of evapotranspiration ET to potential evapotranspiration ET_{0x} during different developmental periods, calculated by vegetation leaf area index LAI.

$$ET_0 = 0.0013 \times 0.408 \times RA \times (T_{avg} + 17) \times (TD - 0.0123P)^{0.76} \tag{4.16}$$

RA: Top radiation of the sun ($MJ \cdot m^{-2} \cdot d^{-1}$)

T_{avg}: Average of the daily maximum temperature and the daily minimum temperature

TD: Difference between the daily maximum temperature and the daily minimum temperature

$$AWC_X = min(Max\ Soil\ Depth_x, Root\ Depth_x) \times PWAC_x \tag{4.17}$$

$$PWAC_x = 54.509 - 0.132sand - 0.003(sand)^2 - 0.055silt - 0.006(silt)^2 \\ -0.738clay + 0.007(clay)^2 - 2.688OM + 0.501(OM)^2 \tag{4.18}$$

$PWAC_X$: Available water for vegetation

$sand$: Sand content of soil

$silt$: Particle content of soil

$clay$: Clay content of soil

OM : Organic matter content of soil

4.5 Carbon Fixation Model

Carbon storage and carbon density are indicators of capacity for carbon storage, and carbon density is the ability to absorb and store carbon per unit area. The In VEST model calculates the carbon pools of different periods and different land types based on the data of different types of land use and the carbon density of the five major carbon pools. The five carbon pools are above-ground biomass, underground biomass, dead organic matter, soil, forestry and other by-products carbon pools. Since the information such as the wood decay rate in the Chinese market is difficult to obtain, only the first four basic carbon pools are considered. The basic principle of carbon fixation calculation is as follow.

$$C_z = C_{above} + C_{below} + C_{dead} + C_{soil} \tag{4.19}$$

Where,

C_z : Total carbon storage

C_{above} : Aboveground carbon storage

C_{below} : Underground carbon storage

C_{dead} : Dead organic carbon storage

C_{soil} : Soil carbon storage

4.6 Environmental Cost Model

4.6.1 Estimation of Environmental Value

• Estimation of Habitat Model

Since the InVEST model cannot directly show the estimated habitat quality by economic value, we refer to the research results of Xiao Qiang [7], Costanza [13] and other researchers to obtain the habitat value.

- Estimation of Soil Conservation Model

Soil conservation model is used to determine the soil conservation capacity. According to the nutrient content of different soil types and fertilizer price, we estimate the soil conservation value.

- Estimation of Water Conservation Model

According to the annual water conservation capacity multiplied by the water price, the water price is replaced by the shadow engineering price.

- Estimation of Carbon Fixation Model

The carbon fixation price is obtained by querying the data, and the carbon fixation value is calculated on the basis of carbon fixation capacity.

4.6.2 Calculation of Environmental Cost

Vector $X_1 = [x_{10}, x_{20}, x_{30}, x_{40}]^T$ indicates the habitat value, soil conservation value, water conservation value, and carbon fixation value of the land at the initial stage of the project.

Vector $X_2 = [x_{11,} x_{21}, x_{31}, x_{41}]^T$ indicates the habitat value, soil conservation value, water conservation value, and carbon fixation value of the land at the completion stage of the project.

Vector $\Delta X = |X_2 - X_1| = [\Delta x_1, \Delta x_2, \Delta x_3, \Delta x_4]^T$ indicates the environmental cost of the land use project.

5 Model Implementation and Results

Using the Ecological Services Cost Valuation Model, we analyzed the impact of human land use and development projects on environmental degradation in Chongqing from 2000 to 2015, including four aspects: habitat quality, soil conservation, water conservation and carbon fixation. The ecosystem services are included in the cost-benefit ratio of the project to determine and assess the true economic cost of the project. Due to the large time span from 2000 to 2015, we have subdivided it into three intervals to analyze the environmental costs of 2000, 2005, 2010 and 2015, and analyze the environmental degradation of the land use and development projects to enhance the accuracy and reliability of the assessment of environment.

5.1 Change of Land Use Distribution

Since 2000, with the economic developing rapidly, the urbanization of Chongqing is a tendency. When a growing number of people are moving from rural area to urban area annually and the urban area is constantly broadening, housing, transportation, public facilities and so on need to be constructed and improved, which makes urbanization a large project that has impact on the biosphere.

Based on land use data in 2000, 2005, 2010 and 2015, we use the transfer matrix to analyze the area change, internal structure change and landscape pattern change of various ecosystem types such as cultivated land, forest land, grassland, water area and construction land during the period of rapid urbanization in Chongqing since 2000.

5.1.1 Verification of Land Use Data Accuracy

The Landsat 4-5 TM and Landsat 8 TM image data[13] are pre-processed in the ENVI5.0 remote sensing image processing platform including radiometric calibration, atmospheric correction, mosaic, data fusion, cropping, etc. Then the data randomly generates 1000 points. The analyses of error, leak error, user precision, charting precision, Kappa coefficient and overall precision are performed. The precision of land use data is verified according to the statistical published data.

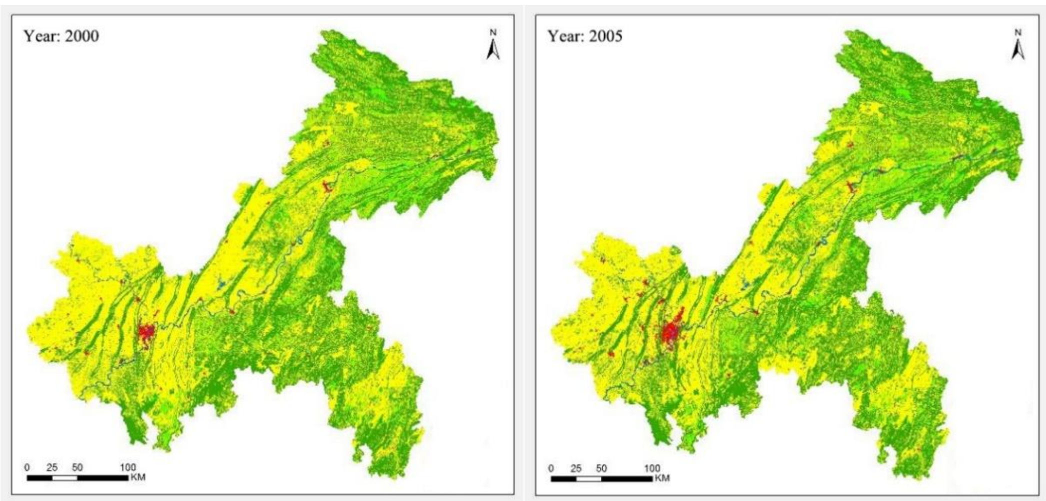
Tab.2 Construction Land of Four Stages

Year	Actual Construction Area(km^2)	Calculated Construction Area(km^2)	Precision (%)
2015	1301.20	1300.77	99.97
2010	1136.53	1067.45	93.92
2005	732.87	689.46	94.08
2000	406.46	352.60	86.75

From the table, it can be concluded that the precisions of four-stage construction land are over 86% and go up year by year. Besides, the overall precisions of four-stage TM image are over 93% and overall Kappa coefficient are over 88%. Hence, the precisions of the data is adequate in the study.

5.1.2 Spatial Distribution of Land Use

According to the remote sensing imagery interpretation, the distribution of land use in the four stages of the study area was obtained. The area and proportion of different land use types and the transformation and distribution pattern of different land use types in different periods were calculated by ArcGIS.



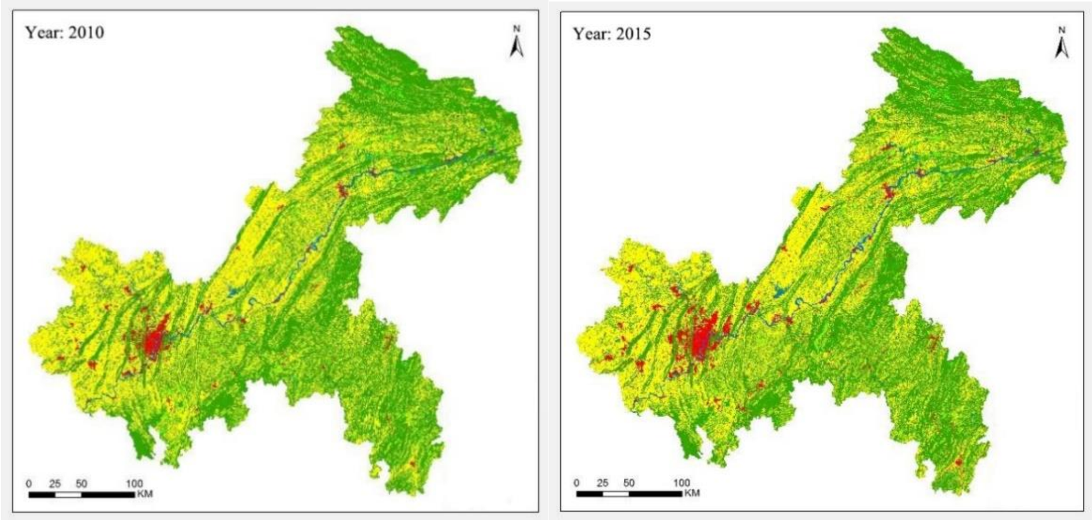


Fig.2 Distribution of Land Use of Four Stages

The main types of land are cultivated land, forest land, grassland, water area, construction land, etc. Using of grid computing tools of ArcGIS software to analyze the land use transfer in 2000, 2005, 2010 and 2015, the land distribution shown in the following figure can be obtained as follow (the red points represent construction land).

By comparing the land distribution map from 2000 to 2015, the land for construction of land use in Chongqing mainly spreads from the urban core area. The continuous increase in construction land is mainly due to the expansion of urbanization in recent years and most land use projects including roads, sewers, bridges, houses, or parks are conducted in this area. This area is called expansion area and its impact of construction projects in the region on the degree of environmental degradation is calculated. The economic costs to mitigate negative results of land use changes are calculated as well.

5.2 Analysis of Habitat Value

5.2.1 Habitat Quality Index

Due to its special geographical location and natural environment, Chongqing has abundant natural resources and extremely high species diversity. According to the results of the InVEST habitat model, the habitat quality index of the urban expansion area in 2000, 2005, 2010 and 2015 is obtained.

Tab.3 Habitat Quality Index of Four Stages

Year	2000	2005	2010	2015
Habitat Quality Index	0.9705	0.9296	0.8980	0.8205

From the table, we know that the annual average habitat quality index of the study area is decreasing year by year. Land use projects have negative impact on habitats and biodiversity to varying degrees, leading to degradation of ecosystem functions and fragmentation of habitats, affecting the habitat of living organisms and resulting in changes or losses of biological species diversity.

From the Fig.3 (red points represent area with lower habitat quality index), the area with low habitat quality index mainly spreads from the urban core area, which incorporates with the construction of land use. Urbanization construction and human development projects lead to a significant decline in habitat quality in the urban expansion area, and the quality of habitats deteriorates along the main urban area.

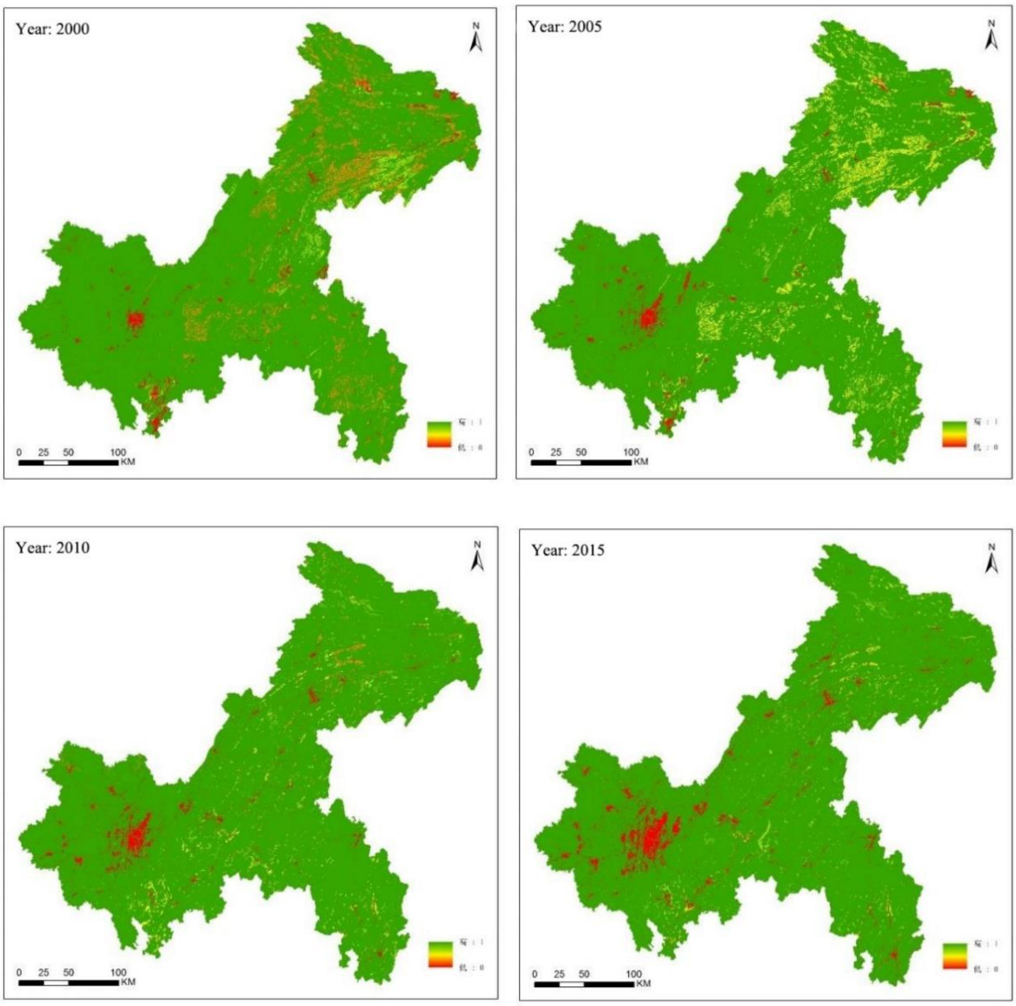


Fig.3 Distribution of Habitat Quality Index of Four Stages

5.2.2 Estimation of the Habitat Value

Since the evaluation results of habitat quality of InVEST model cannot be directly expressed in the form of economic value, this study applies the method referring to the research results of Xiao Qiang [7], Costanza [13] etc. to calculate ecological benefits of forest biodiversity services in Chongqing. The habitat values of Chongqing in the four-stage of 2000, 2005, 2010 and 2015 are obtained.

Tab.4 Estimation of Habitat Values of Four Stages

Year	2000	2005	2010	2015
Habitat Value (million yuan)	620	587	575	560

5.3 Analysis of Soil Conservation Value

5.3.1 Estimation of Water Conservation Value

According to the results of the InVEST soil conservation model, we can obtain the soil conservation capacity in the four stages of the study area in 2000, 2005, 2010 and 2015.

Tab.5 Soil Conservation Capacity of Four Stages

Year	2000	2005	2010	2015
Soil Conservation Capacity (thousand tons)	37260.2	33497.3	32359.0	34342.2

The trend of soil conservation capacity decreased from 2000 to 2015, while the trend of that increased from 2010 to 2015.

The flat area in the central and western regions are area with low soil value. The soil in this area is mostly purple soil that is loose, shallow and the weathering is rapid, making it not conducive to soil conservation [15]. The central and western areas are the main areas of urbanization. The continuous expansion of construction land and the overexploitation of natural resources have resulted in lower soil conservation in the central and western regions.

5.3.2 Estimation of Soil Conservation Value

Soil nutrient content data derive from an investigation report about soil pollution condition in Chongqing. According to the average price of fertilizers produced in China in recent years, the prices of urea, superphosphate and potassium chloride are calculated at 200 yuan/t, 500 yuan/t, and 2000 yuan/t, respectively [16].

Tab.6 Estimation of Soil Conservation Value of Four Stages

Year	2000	2005	2010	2015
Soil Conservation Value (million yuan)	962	867	836	887

5.4 Analysis of Water Conservation Value

5.4.1 Calculation of Water Conservation Capacity

According to the operation results of the InVEST water source conservation model, the water conservation capacity of the study area in 2000, 2005, 2010 and 2015 was obtained.

Tab.7 Water Conservation Capacity of Four Stages

Year	2000	2005	2010	2015
Water Conservation Capacity (million stere)	51.0322	57.0189	47.1061	63.8007

5.4.2 Estimation of Water Conservation Value

The estimation of water conservation value is based on the annual water source conservation water volume of the study area multiplied by the water price, and the water price is replaced by the shadow-engineering price. Due to the special topography and complex geological structure of Chongqing, the cost of the reservoir is much higher than that of the national average. With the statistics of the existing reservoirs, reservoirs under construction, and the total storage capacity and investment of the reservoirs, the average unit storage capacity of the reservoirs in the study area is 35.49 yuan [17]. The water conservation value of 2000, 2005, 2010 and 2015 was calculated on the basis of water conservation.

Tab.8 Estimation of Water Conservation Value of Four Stages

Year	2000	2005	2010	2015
Water Conservation Value (million yuan)	181127	202376	167193	226446

5.5 Analysis of Carbon Fixation Value

5.5.1 Calculation of Carbon Fixation Capacity

Enter the data and carbon density data of four stages in the InVEST model, we obtain carbon fixation in the study area in 2000, 2005, 2010 and 2015.

Tab.9 Carbon Fixation Capacity of Four Stages

Year	2000	2005	2010	2015
Carbon Fixation Capacity (thousand tons)	10646.0	11470.0	14027.0	13341.7

The carbon fixation capacity is less in urban expansion area and fluctuate largely. It rose first and then fell down, which is relative to the development of urban expansion area, CO_2 emissions from construction projects, timber harvesting and so on.

5.5.2 Estimation of Carbon Fixation

According to Chongqing's carbon price, carbon discount rate, market discount rate and other economic indicators to calculate the practical significance and social value of carbon storage and carbon fixation, the carbon fixation price is 114.94 yuan per ton [18]. Therefore, the carbon fixation value of 2000, 2005, 2010 and 2015 can be obtained.

Tab.10 Estimation of Carbon Fixation of Four Stages

Year	2000	2005	2010	2015
Carbon Fixation (billion yuan)	12.24	13.18	16.12	15.33

5.6 Calculation of Environmental Costs

By calculating the data of habitat value, soil conservation value, water conservation value and carbon fixation value of 2000, 2005, 2010 and 2015, the environmental costs of environmental factors of three time intervals including 2000-2005, 2005-2010 and 2010-2015 are obtained.

From the table, we can calculate the environmental costs of human land use and development projects in Chongqing during the three time intervals are 22.32 billion yuan, 38.16 billion yuan and 60.11 billion yuan, respectively. Therefore, the environmental cost of human land use and development projects in Chongqing from 2000 to 2015 was 120.59 billion yuan, so we can obtain the true economic cost of land use projects considering ecosystem services.

Tab.11 Environmental Costs of Environmental Factors of Three Time Intervals

Year	2000-2005	2005-2010	2010-2015
Habitat Value (million yuan)	33	12	15
Soil Conservation Value (million yuan)	95	31	51
Water Conservation Value (billion yuan)	21.25	35.18	59.25
Carbon Fixation (billion yuan)	0.94	2.94	0.79

5.7 Analysis of Environment Degradation

The ratio of the environmental cost of land use projects to the initial ecological value of land can be obtained from Tab.10.

$$\omega_i = \frac{\Delta x_i}{x_{i0}}, i = 1, 2, 3, 4 \tag{5.1}$$

Quantitative analysis model is built:

$$Y = \sum_{i=1}^{4} b_i . \omega_i ; i = 1, 2, 3, 4 \tag{5.2}$$

Where,

b_i is the weight of ω_i.

Since the weighting coefficient changes dynamically in different stages of different ecosystems and ecosystems, it needs to be adjusted manually. To facilitate the model evaluation, our default weight coefficients are equal.

We use Y as a criterion for quantifying the degree of environmental degradation. We grade the degree of environmental degradation as shown in the following table.

Tab.12 Classification Level of Sustainable Land Use

level	Land environmental degradation stage	Transitional stage of sustainable land use and environmental degradation	Primary sustainable use stage of land	Sustainable use stage
Y (%)	>50	25-50	10-25	<10

From the comprehensive evaluation model, we can see the volatility of environmental costs in three intervals. Since the degradation of the ecological environment means the decline of the stability of the ecological environment, which means the increase of volatility is a criterion of the degree of environmental degradation.

It can be seen from the Fig.4 that the environmental degradation index is 8.65%, 14.94%, and 16.94% in the three intervals of 2000-2005, 2005-2010, and 2010-2015, respectively. Taking the international land sustainable management evaluation standard as a reference, compare the calculated values of the land sustainable use level, we can find the corresponding level in the land sustainable use level classification table. The table of the level of sustainable land use is shown in the following table.

Comparing the comprehensive land use level of Chongqing with the level of land sustainable use level, it can be seen that between 2000 and 2015, Chongqing has transitioned from the sustainable use stage to the primary sustainable use stage of land, and the degradation degree of environment has gradually increased.

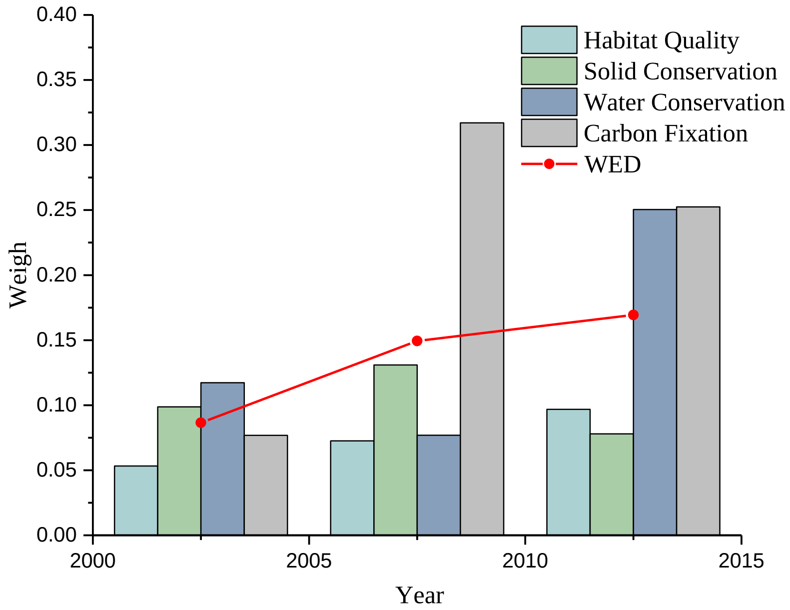


Fig.4 Weigh of Environment Degradation

6 Model Adaptability and Improvement

6.1 Adaptability of Models Under Different Scale Land Use Projects

The model is based on spectral remote sensing technology, InVEST model and its ecological parameters, which provides new data foundations and measures for dynamic accounting of ecosystem service values [19]. What's more, associating with the Geographic Information System (GIS) spatial analysis technology, it is possible to conduct quantitative ecological asset valuation and dynamic change research on land use engineering areas [20].

For land use projects of different scales, we can use the corresponding data to accurately calculate the ecosystem service function value of habitat quality, soil conservation, water conservation and carbon fixation, and determine the environmental cost of land use projects and then the true economic cost of the project is determined and evaluated. Therefore, our model can be adapted to land use projects of different regional scales and different scales, and has good adaptability.

6.2 Improvement of Model Under Time Variation

For land use projects with short durations, we only consider the changes in the ecosystem service capacity during the initial and completion stages of the project, which can be solved by the previous model.

For land use projects with long duration, we set $T=[t_0,t_1,t_2,...,t_n]$ as project duration, where t_0 is the time when project starts, t_n is the time when project ends; and the time is subdivided into different stages $[t_0,t_1),[t_1,t_2),...,[t_{n-1},t_n]$. We set $X_t=[X_0,X_1,...,X_n]^T$ as the ecological benefits of the project in each stage and then calculate the environmental cost $\Delta X_t=[\Delta X_1,\Delta X_2,...,\Delta X_n]^T$ of the project at each stage, the ratio of the environmental cost to the initial ecological value of each staged land $Y_t=[Y_1,Y_2,...,Y_n]^T$ is obtained, where $Y_i=\dfrac{\Delta X_i}{X_{i-1}};i=1,2,...,n$.

• Comparing $Y_t=[Y_1,Y_2,...,Y_n]^T$ with the land sustainable use level classification, we can obtain the extent of environmental degradation during the period of land use projects with longer duration.

• If there are more stages of sustainable land use level in the same classification level of sustainable land use, it may be considered to use the known data to modify the land use level classification table, and then continue to subdivide the interval where level index Y the is located to get more classification levels. As a result, the extent of environmental degradation during the land use project will be more detailed and effective.

7 Strengths and Weaknesses

7.1 Strengths

- The algorithm has been simplified, which reduces the need for data information, and reduces the difficulty of applying the model.
- It is effective to apply the model to different scales of land use and development projects.
- The optimized model can be applied to land use projects with long duration.
- The model quantifies and classifies the degree of sustainable land use while quantifying environmental costs [21].

7.2 Weaknesses

- Each model involves numerous parameters, and the limitations of some indicators are great.
- The carbon fixation model over-simplifies the carbon cycle process, and it does not calculate the carbon transferred between the carbon pools.
- Model limitations mentioned above affect the accuracy and lead to uncertainty of

the estimation results.

8 Implications

When planning and deciding the land use and development projects, ecological benefit value should be taken into consideration. Whether the degree of urban land expansion is consistent with the urban center environmental load capacity should be considered as well. The projects cannot unilaterally pursue output benefits, and try to avoid regional environmental belts during production and life.

The reduction of habitat quality is closely related to the reduction of forestland and grassland. The protection of forestland and grassland should be improved, and the scale of cultivated land and construction land should be controlled properly.

The use of land resources should aim at achieving favorable economic, social and ecological benefits [22]. When pursuing economic benefits, it is necessary to pay attention to ecological benefits to achieve coordinated development of human and land systems.

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