Evaluation of Eco-Environmental Carrying Capacity: A Case Study of Henan Province (Postprint)

Authors: Zhu Jiawei, Xie Xiaotong, Li Xinhui

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Abstract

Measuring whether human activities remain within the bounds of ecological environment carrying capacity constitutes the core content of ecological environment carrying capacity evaluation and is requisite for scientific decision-making and planning in regional land development. However, both the threshold of ecological environment carrying capacity and the magnitude of pressure imposed by human activities upon the ecological environment are difficult to quantify. To resolve this challenge confronting ecological environment carrying capacity evaluation, this study proposes a novel methodology termed the "Dynamic Evaluation Method of Ecological Environment Quality Index." Grounded in ecological balance theory and ecological stability principles, this approach transforms carrying capacity evaluation into operational status assessment, employing "whether the ecological environment system is in a benign operational state" as the criterion for determining whether the ecological environment exists in a carryable condition. The methodology first applies the Ecological Environment Quality Index (EI) model to calculate multi-year EI values for the evaluation area, then evaluates the "operational status of the ecological environment system" based on the dynamic trend of EI, thereby achieving the objective of regional ecological environment carrying capacity evaluation. Using Henan Province as an example, the method and process are introduced. Results indicate: Evaluation of current ecological environment quality status does not constitute carrying capacity evaluation, yet carrying capacity evaluation can be realized through regression analysis of the dynamic trend of ecological environment quality; This methodology closely aligns with the connotation of ecological environment carrying capacity, circumventing the difficulty of calculating ecological environment system carrying capacity thresholds, is concise and readily implementable, yields results with clear significance and strong practicality, and provides a new perspective and approach for carrying capacity evaluation; The current quality status of ecological environment systems cannot reflect their carrying status; Xinyang

City possesses the finest ecological environment quality in Henan Province, yet currently exists in a state of overload and degradation, whereas the situations in Puyang and Anyang Cities exhibit the opposite pattern, which should merit attention from governmental decision-making departments.

Full Text

A Solution to the Problem of Ecological Environmental Carrying Capacity Evaluation: A Case Study of Henan Province

ZHU Jiawei*, XIE Xiaotong, LI Xinhui
College of Resources and Environment, Henan Agricultural University, Zhengzhou 450002, China

Abstract

Measuring whether the intensity of human activity falls within the threshold value of ecological environmental carrying capacity constitutes the core task of carrying capacity evaluation, which is essential for scientific decision-making in regional land development planning. However, both the threshold of ecological carrying capacity and the magnitude of pressure exerted by human activities on the environment are difficult to quantify accurately. To address this challenge in ecological environmental carrying capacity evaluation, this study proposes a novel method called the "Eco-environment Index dynamic evaluation method," based on ecological balance theory and the ecological stability principle. The evaluation process involves three key steps: first, establishing an evaluation criterion for carrying status—specifically, whether the eco-environment system is operating in a healthy state; second, calculating values of the eco-environment index (EI) for different years using an existing EI model; and third, judging the operational status of the eco-environment system based on the changing trend of EI through regression analysis. Using these steps, ecological environmental carrying capacity can be effectively evaluated. Taking Henan Province as a case study, the results demonstrate clear significance: the overall ecological environment of the province is in a basically sustainable state, while Xinyang and Zhumadian cities are in an overload state despite having the best environmental quality in the province. This method provides a new approach for carrying capacity evaluation by transforming it into an assessment of operational status, thereby avoiding the difficulty of calculating carrying capacity thresholds. The method is concise, practical, and has promising application prospects.

Keywords: ecological environment; carrying capacity; eco-environment index; dynamic evaluation method; Henan Province

1. Theoretical Foundation and Technical Approach

Since both the pressure value of human activities and the supporting capacity threshold of the ecological environment are difficult to quantify, evaluating ecological carrying capacity using the carrying rate method presents significant challenges. According to ecological balance theory and the ecological stability principle, a close causal relationship exists between the carrying status and operational status of an ecological environment system. If a regional ecological environment system is within its carrying capacity, the system will be in a virtuous cyclic development state; conversely, if it is in an overload state, the system' s structure and function will degrade and enter a non-virtuous cyclic development state. Therefore, evaluating ecological environmental carrying status can be transformed into evaluating operational status. The operational status of an ecological environment system can be assessed by analyzing the dynamic change trend of regional ecological environmental quality. If the quality remains stable or shows an improving trend, the system is in a virtuous cycle; if it shows a declining trend, the system is in a degraded state. This transformation allows ecological carrying capacity evaluation to be converted into dynamic change trend assessment of ecological environment system quality. As long as ecological environment quality data for a region across different time periods are available, the dynamic change trend can be analyzed.

The calculation method for the ecological environment index (EI) is a standardized technical method specified in the "Technical Specification for Eco-environmental Status Evaluation" [31]. Based on this method, the technical approach is formulated as follows: use the ecological environment index model to calculate EI values for a region across different years, then analyze the dynamic change trend and parameters of EI values, and finally evaluate the carrying capacity based on the trend analysis results. This approach uses whether the ecological environment system is in healthy operation as the evaluation criterion for whether it is within carrying capacity, thereby avoiding the difficulty of calculating carrying rates while leveraging ecological quality evaluation methods to assess trends rather than static conditions.

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2. Specific Methodological Steps

2.1 Ecological Environment Index Calculation

Using the ecological environment index evaluation model specified in the "Technical Specification for Eco-environmental Status Evaluation" [31], calculate the EI values for the evaluation region across different years. The evaluation model is:

$$EI = 0.25 \times \text{bio} + 0.2 \times \text{veg} + 0.2 \times \text{riv} + 0.15 \times (100 - \text{ero}) + 0.1 \times \text{env}$$

Where: - bio = biological abundance index - veg = vegetation coverage index - riv = water network density index - ero = land degradation index - env = environmental quality index

The component indices are calculated as follows:

Biological abundance index:

bio = (0.35×forest area+0.21×water area+0.28×grassland area+0.11×cropland area+0.04×construction land

Vegetation coverage index:

veg = (0.38×forest area+0.34×grassland area+0.19×cropland area+0.07×construction land area+0.02×unuse

Water network density index:

riv = (river length×river normalization coefficient+lake area×lake normalization coefficient+reservoir capacit

Land degradation index:

ero = 0.05×slight erosion area+0.25×moderate erosion area+0.7×severe erosion area

Environmental quality index:

env = 0.4×(100−COD emissions×COD normalization coefficient)+0.4×(100−SO_2 emissions×SO_2 normalizat

2.2 Regression Analysis of Ecological Environment Index Dynamic Trends

Inter-annual fluctuation of the ecological environment index is normal. When the fluctuation amplitude does not exceed the system's self-regulation threshold, the system can recover to its normal state through self-regulation. Therefore, short-term fluctuations cannot accurately reflect the system's operational status, and long-term trends must be analyzed. This study uses regression analysis to assess the changing trend of regional ecological environment quality and solve for specific change parameters to evaluate the operational status of the ecological environment system.

The regression model for the ecological environment index is:

$$EI_t = kt + b$$

Where: - EI_t is the ecological environment index in year t - k reflects the regression trend and magnitude of EI change - b is the regression constant

Significance testing of regression results: - Correlation coefficient squared value $R^2 < 0.1$: poor regression effect, insignificant trend - $0.1 \leq R^2 \leq 0.5$:

moderate regression effect, relatively obvious trend - $R^2 > 0.5$: good regression effect, significant trend

Analysis of ecological environment quality change degree: Based on the grading standards for ecological environment status changes specified in the "Technical Specification for Eco-environmental Status Evaluation" [33]: - $|\Delta EI| < 0.1$: no obvious change - $0.1 \leq |\Delta EI| \leq 0.5$: relatively obvious change - $|\Delta EI| > 0.5$: obvious or significant change

2.3 Ecological Environmental Carrying Capacity Evaluation

Based on the dynamic trend analysis results of the ecological environment index, the carrying capacity is evaluated according to the following criteria:

1. **ΔEI 0.5, stable trend (R² 0.5):** Ecological environment quality has significantly improved, the system is in an obvious virtuous cycle, i.e., sustainable state.
2. **0.1 ΔEI < 0.5, relatively stable trend (0.1 R² < 0.5):** Ecological environment quality has slightly improved, basically in a virtuous cycle, i.e., basically sustainable state.
3. **-1 ΔEI < 0.1, stable trend (R² 0.5):** Ecological environment quality is basically stable, in a balanced state, i.e., basically sustainable state.
4. **-3 ΔEI < -1, slightly improving or degrading trend (0.1 R² < 0.5):** Ecological environment quality has slightly decreased, in a lightly degraded state with obvious degradation trend, i.e., lightly overloaded state.
5. **ΔEI < -3, stable trend (R² 0.5):** Ecological environment quality has significantly decreased, in an obviously degraded state, i.e., overloaded state.

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3. Data Sources

The ecological environment index (EI) data for Henan Province from 2000 to 2014 were calculated from collected materials, with data sources as follows:

- **Biological abundance index and vegetation coverage index:** Land use change data (forest, water, grassland, cropland, construction land, unused land areas and regional area) from Henan Provincial Department of Land and Resources annual land use change databases.
- **Water network density index:** Regional area data from Henan Provincial Department of Land and Resources; water resources data from Henan Provincial Water Resources Bulletin.

- **Land degradation index:** Slight, moderate, and severe erosion land area data from remote sensing interpretation results of the "Central Plains Economic Zone Resource and Environment Carrying Capacity Evaluation and Zoning" project using Landsat-7 ETM imagery.
- **Environmental quality index:** COD emissions, SO emissions, and solid waste emissions data from the annual Henan Provincial Environmental Quality Reports.

shows the calculated ecological environment index values for Henan Province from 2000 to 2014.

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4. Evaluation Results

4.1 Provincial-Level Ecological Environmental Carrying Capacity Evaluation

The provincial ecological environment index values for 2000-2014 are shown in . The scatter plot of provincial EI change trends [Figure 1: see original paper] reveals a fluctuating upward trend over the 15-year period. Regression analysis yields the following model:

$$EI_t = 2.45t - 4902.52 \quad (R = 0.7416)$$

Where t represents the year. With $R = 0.7416 \geq 0.7$, the regression effect is significant, indicating a stable, gradually improving trend in ecological environment quality. The positive regression coefficient ($k = 2.45$) reflects a stable improvement in the provincial ecological environment system. According to the evaluation criteria, with $\Delta EI = 0.252$ (0.1-0.5) and a stable trend, the ecological environment quality has slightly improved, placing the province in a basically virtuous cycle state—that is, a basically sustainable state.

4.2 City-Level Ecological Environmental Carrying Capacity Evaluation

Regression analysis was performed on the ecological environment index values for various cities in Henan Province from 2000-2014. The regression equations, correlation coefficients (R), and ΔEI values for each city are summarized in .

Cities in sustainable state: Jiyuan, Kaifeng, and Jiaozuo show significantly improved ecological environment quality with obvious virtuous operation. Kaifeng' s improvement is attributed to strengthened management of desertified land in the Yellow River' s old course area, while Jiaozuo' s improvement results from the construction of the Xiaolangdi Reservoir.

Cities in basically sustainable state: Anyang, Hebi, Xinxiang, Luohe, Sanmenxia, Nanyang, Shangqiu, Zhoukou, and Zhengzhou show slightly improved

ecological environment quality with relatively stable regression trends, basically in virtuous operation.

Cities in balanced fluctuation state: Xuchang, Pingdingshan, and Luoyang show no obvious change in ecological environment quality ($R^2 \leq 0.1$) with insignificant regression trends, exhibiting fluctuating balance.

Cities in lightly overloaded state: Puyang shows slightly decreased ecological environment quality with an insignificant but fluctuating degradation trend.

Cities in overloaded state: Xinyang and Zhumadian show significantly decreased ecological environment quality with obvious degradation trends. It should be emphasized that Xinyang currently has the best ecological environment quality in the province ($EI > 55$) but is in an overload state due to intensive development of low hills and gentle slopes for urbanization, warranting serious attention from decision-makers.

[Figure 1: see original paper] and [Figure 2: see original paper] illustrate the EI change trends for Henan Province and Xinyang City, respectively.

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5. Conclusion

Evaluation of ecological environment quality status cannot substitute for carrying capacity evaluation. While excellent regional ecological environment quality indicates strong carrying capacity, it does not necessarily mean human activity intensity is within the system' s carrying threshold. Under destructive overdevelopment, even environmentally superior systems can become overloaded and experience structural and functional degradation.

Because both the threshold of ecological carrying capacity and the magnitude of human pressure are difficult to quantify, this constrains the application of the carrying rate method in ecological environmental carrying capacity evaluation. The ecological environment index dynamic evaluation method, based on ecological balance theory and stability principles, transforms carrying capacity evaluation into operational status assessment, circumventing the difficulty of calculating carrying rates. The method is concise, practical, and yields clear results.

The 15-year evaluation of Henan Province shows overall ecological environment quality has remained stable with slight improvement, placing the province in a sustainable or basically sustainable state. However, Xinyang and Zhumadian cities are in an overload state, with Xinyang—despite having the province' s best environmental quality—requiring heightened attention from government decision-makers due to its declining quality trend. This method offers promising prospects for broader application.

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6. Discussion

(1) **Conceptual understanding of ecological carrying capacity:** Scholars hold differing interpretations of "ecological environmental carrying capacity." The ecological environment is part of the natural environment, and carrying capacity research must not deviate from its fundamental connotation. Currently, mainstream Chinese environmental scientists generally view carrying capacity as the threshold of human socio-economic activities that a regional environmental system can sustain without undergoing qualitative structural changes or functional degradation toward malignant evolution. The concept of ecological environmental carrying capacity should be no exception.

(2) **Pressure studies cannot replace carrying capacity evaluation:** Research on human activity pressure on ecological environment systems cannot substitute for carrying capacity evaluation, which is always associated with environmental degradation and economic development issues. Due to the complexity of ecosystem structure and function, ecological carrying capacity evaluation faces numerous difficulties. Methods such as vegetation primary productivity estimation, resource supply-demand balance, and ecological footprint only assess certain aspects of ecological carrying capacity, failing to consider the substitutability of biological resources and the openness of environmental systems. Consequently, evaluation results do not prominently reflect region-specific ecological environmental issues of concern.

(3) **Methodological considerations:** The ecological environment index dynamic evaluation method assesses regional ecological carrying status based on ecosystem dynamics, balance, and stability principles, using the consequences and manifestations of carrying status as entry points. The evaluation results reflect the dynamic changes in ecosystem structure and function. However, improvements are needed in the ecological environment index calculation, and establishing a more scientific, rational, and straightforward EI model is key to promoting this method' s application.

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Note: Figure translations are in progress. See original paper for figures.