Ecological Security Assessment of Oases in the North-Central Tarim Basin (Postprint)

Authors: He Zhenzhen, Wang Hongwei, Yang Shengtian, Liu Xiangyun, Wang Pan, Wang Hui, Wang Hongwei

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Abstract

Maintaining the ecological security of oases in the ecologically fragile arid regions of northwestern China constitutes an important prerequisite for achieving regional sustainable development. This study takes the Weigan River-Kuche River Oasis as the research area and constructs an evaluation index system from three dimensions: oasis ecosystem structure, function, and benefit. The triangle model is applied to calculate and analyze the state and trend of ecological security in this oasis from 2005 to 2014, while grey relational analysis is employed to analyze the factors influencing its ecological security. The results indicate: The ecosystem non-structural index (NSI) demonstrates an overall year-by-year decreasing trend; the ecosystem non-functional index (NFI) exhibits a fluctuating and undulating variation trend; and the ecosystem benefit index (BI) shows a continuous upward trend overall. During the 2005–2014 period, the ecological security of the Weigan River-Kuche River Oasis experienced two states—unsafe and weakly safe—and displayed a gradual trend toward safe and stable development. The primary factors affecting the ecological security of the Weigan-Kuche Oasis from 2005 to 2014 were the soil-water coordination degree and afforestation area. These research findings will provide a scientific basis for maintaining and further improving the ecological environment of this oasis.

Full Text

1 Introduction

1.1 Study Area

The Ugan-Kuqa oasis is located in the central-northern part of the Tarim Basin in Xinjiang, between 81°28 30 -84°05 06 E and 39°29 51 -42°38 01 N, covering an area of 5.24×10 km² at an elevation of 1500–2000 m. By 2014, the oasis had a population of 9.62×10 , with a population growth rate of 30.21% and urbanization rate of 23.7%. As a typical arid zone oasis in Northwest China, it faces severe ecological and environmental challenges, making it an ideal region for studying oasis ecological security [FIGURE 1].

The oasis ecosystem is evaluated through three dimensions: structure, function, and benefit. The non-structural index (NSI) represents structural characteristics, the non-functional index (NFI) represents functional status, and the benefit index (BI) represents the comprehensive benefits of the ecosystem.

2 Methods

2.1 Ecological Security Evaluation Index System

Based on the structure-function-benefit framework, we constructed an evaluation index system for oasis ecological security [TABLE 1]. The indices are classified into five levels: excellent (0.8-1.0], good (0.6-0.8], moderate (0.4-0.6], poor (0.2-0.4], and very poor (0-0.2] [TABLE 2].

2.2 Triangle Model Method

The triangle model evaluates ecological security status and trends by plotting the three indices (NSI, NFI, BI) on a ternary diagram [FIGURE 2]. The model visually represents the ecosystem state and its trajectory over time.

2.3 Weight Determination

We combined Analytic Hierarchy Process (AHP) and entropy method to determine index weights, reducing subjectivity while preserving expert knowledge.

2.3.1 AHP Weight Calculation (W) AHP calculates weights through expert scoring and consistency checking. The weights for each index are shown in [TABLE 3].

2.3.2 Entropy Weight Method (W) The entropy method calculates weights based on data variability:

$$e_j = -k \sum_{i=1}^{n} (Y_{ij} \times \ln Y_{ij})$$

$$d_j = 1 - e_j$$

$$W_{2j} = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

where $k = 1/\ln m$, m is the number of evaluation years, n is the number of indices, and Y_{ij} is the normalized value of index j in year i.

2.3.3 Combined Weight Calculation The final weights combine AHP and entropy weights:

$$W_{ij} = \sqrt{W_{1j} \times W_{2j}} \quad (j = 1, 2, 3 \dots m) \tag{4}$$

2.4 Index Calculation

Using 2005-2014 data, we calculated NSI, NFI, and BI:

$$NSI = 1 - SI = 1 - \sum_{i=1}^{10} \sum_{j=1}^{25} X_{ij} \times W_j \tag{5}$$

$$NFI = 1 - FI = 1 - \sum_{i=1}^{10} \sum_{j=1}^{25} X_{ij} \times W_j \tag{6}$$

$$BI = \sum_{i=1}^{10} \sum_{j=1}^{25} X_{ij} \times W_j$$

where $i = 1, 2, 3 \dots 10$ represents years, $j = 1, 2, 3 \dots 25$ represents indices, and X_{ij} is the normalized value.

2.5 Grey Correlation Analysis

We used grey correlation analysis to identify key influencing factors. The correlation coefficient is:

$$\zeta_i(k) = \frac{\min_i \min_k |X_0(k) - X_i(k)| + \rho \max_i \max_k |X_0(k) - X_i(k)|}{|X_0(k) - X_i(k)| + \rho \max_i \max_k |X_0(k) - X_i(k)|} \tag{1}$$

where $X_0(k)$ and $X_i(k)$ are reference and comparison sequences, ρ is the distinguishing coefficient (set to 0.5), and $\zeta_i(k)$ is the correlation coefficient.

3 Results

3.1 Temporal Variation of Ecological Security Indices

Structural Index (NSI): The NSI showed a decreasing trend from 2005-2014, indicating improving ecosystem structure. However, it remained in the "moderate" range, suggesting structural components were becoming more rational but still required optimization.

Functional Index (NFI): The NFI exhibited fluctuating trends, primarily due to changes in the natural population growth rate, per capita water resources, and soil-water coordination stability index. The index remained in the "high" range, indicating weak functional status.

Benefit Index (BI): The BI increased continuously from 0.08 in 2005 to 0.69 in 2014, showing significant improvements in economic, social, and ecological benefits [FIGURE 3].

3.2 Ecological Security States

The oasis experienced two distinct states during 2005–2014:

2005–2010: Unsafe State. NSI was in the medium range, NFI in the high range, and BI in the low range, reflecting poor structural characteristics, weak function, and low benefits. The "pressure-state-response" framework revealed severe water-land contradictions and lagging afforestation efforts.

2011–2014: Weak Security State. NSI decreased to a relatively low range, NFI remained high but showed upward trends, and BI rose gradually. The ecosystem transitioned from unsafe to weakly secure, moving toward stable weak security [FIGURE 4].

3.3 Key Influencing Factors

Grey correlation analysis identified soil-water coordination and afforestation area as the primary factors affecting ecological security, with correlation degrees >0.9 [TABLE 4]. Cluster analysis grouped indices into three categories: water-land coordination factors, socio-economic factors, and ecological restoration factors [FIGURE 5].

4 Discussion

4.1 Water-Land Coordination

Water resources are the core constraint in arid oasis ecosystems. The analysis shows that per capita water resources, soil-water coordination stability, and water use efficiency significantly impact ecological security. Implementing water-land balance and returning farmland to forest/grassland according to local conditions are essential for sustainable development.

4.2 Policy Implications

The "pressure-state-response" analysis indicates that population growth and economic development create pressure on the oasis ecosystem. Strengthening ecological restoration, improving water resource management, and optimizing land use structure are critical for maintaining ecological security. The results provide scientific basis for early warning and management of oasis ecological security in arid regions.

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