ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0027

Ecological Environment Assessment of Baiyangdian Wetland based on Remote Sensing Ecological Index

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Abstract

In order to study the ecological environment changes of Baiyangdian wetland, a total of six Landsat remote sensing images from 2003,2007,2011,2015,2019 and 2023 were selected, and the Principal Component Analysis method(*PCA*) was used to integrate four ecological indicators: greenness (*NDVI*),humidity (*WET*),dryness (*NDBSI*) and heat (*LST*) to construct a remote sensing ecological index model (*RSEI*),and to study and analyze the changes of ecological environment quality of Baiyangdian wetland from 2003 to 2023.The study revealed that the environment of Baiyangdian wetland is primarily influenced by vegetation coverage, with overall ecological quality demonstrating a fluctuating upward trend during this period. These findings can reflect the changes of ecological environment quality of Baiyangdian wetland to a certain extent and can provide a theoretical reference and scientific basis for the management and protection of wetland ecological environment.

Keywords

Baiyangdian Wetland; RSEI; Ecological Environment.

1. Introduction

Wetland ecosystems, known as the "kidneys of the earth" and "reservoirs of species genes," are crucial for maintaining ecological balance, conserving biodiversity, purifying water, controlling pollution, fixing carbon, and enhancing landscapes[1]. Assessing wetland ecological environments is therefore highly significant.

Remote sensing data is an effective tool for evaluating ecological environment quality[2]. This can be done through single indicators or comprehensive indicators. Single indicators focus on specific ecosystem functions, such as Alawadi Wisam A et al[3]. using the normalized water index to monitor wetland hydrology, and Li Ting et al[4]. using vegetation coverage to assess the ecological environment of Zhalong Wetland. However, this approach has limitations as it only provides a partial view. Comprehensive indicators consider multiple factors for an overall assessment. Since 2006, the ecological environment status index (EI)[5], which includes biological abundance, vegetation coverage, water network density, land stress, and pollution, has been widely used in China. Yet, it has been found to have shortcomings: incomplete coverage (e.g., ignoring surface temperature and building indicators), difficulty in data acquisition, and subjective weighting, making accurate assessments challenging[6].

2. Overview of the Study Area and Data Sources

The Baiyangdian Wetland Nature Reserve, a key national ecological wetland and the largest freshwater wetland in North China, plays a vital role in water conservation, water purification, and biodiversity protection[7]. Previous studies have mainly focused on the impacts of ecological water replenishment on vegetation patterns and ecosystem services, with limited research on the changes in

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the ecological environment quality[8]. To analyze these changes and their driving factors in Baiyangdian Wetland, this study uses Landsat remote sensing images from 2003, 2007, 2011, 2015, 2019, and 2023. It constructs a remote sensing ecological index model by coupling four ecological indicators-greenness (*NDVI*), wetness (*WET*), dryness (*NDBSI*), and land surface temperature (*LST*)-using principal component analysis, to evaluate the ecological quality changes in Baiyangdian Wetland, providing references for its protection.

3. Research Methods

The remote sensing ecological index (*RSEI*) is a key metric for assessing ecological environment quality. It integrates four indicators-greenness (*NDVI*), wetness (*WET*), dryness (*NDBSI*), and land surface temperature (*LST*)-which are extracted from raw remote sensing images. The RSEI uses principal component analysis to determine the weights of these normalized indicators, forming an evaluation system that emphasizes natural factors[9]. This method avoids subjective weighting, highlights data properties, and enables quick, objective, and comprehensive ecological assessments. The *RSEI* is expressed as the principal component function of its four indicators.

$$RSEI = f(NDVI, WET, NDBSI, LST) \tag{1}$$

(1) Formulas for Calculating Component Indexes[10-13]

- NDVI (Normalized Difference Vegetation Index)

$$NDVI = (\rho_{NIR} - \rho_R) / (\rho_{NIR} + \rho_R) \tag{2}$$

- WET (Wetness Index)

$$WET_{TM} = 0.0315\rho_B + 0.2021\rho_G + 0.3102\rho_R + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR1} - 0.6109\rho_{SWIR2} \tag{3}$$

$$WET_{OLI} = 0.1511\rho_B + 0.1973\rho_G + 0.3283\rho_R + 0.3407\rho_{NIR} - 0.7117\rho_{SWIR1} - 0.4559\rho_{SWIR2} \tag{4}$$

- NDBSI (Normalized Difference Bare Soil Index)

$$NDBSI = \frac{IBI + SI}{2} \tag{5}$$

$$SI = [(\rho_{SWIR1} + \rho_R) - (\rho_{NIR} + \rho_R)] / [(\rho_{SWIR1} + \rho_R) + (\rho_{NIR} + \rho_R)] \tag{6}$$

$$IBI = [\frac{2\rho_{SWIR1}}{\rho_{SWIR1} + \rho_{NIR}} - \frac{\rho_{NIR}}{\rho_{NIR} + \rho_R} - \frac{\rho_G}{\rho_G + \rho_{SWIR1}}] / [\frac{2\rho_{SWIR1}}{\rho_{SWIR1} + \rho_{NIR}} + \frac{\rho_{NIR}}{\rho_{NIR} + \rho_R} + \frac{\rho_G}{\rho_G + \rho_{SWIR1}}] \tag{7}$$

- LST (Land Surface Temperature)

$$LST = b_{10} \times 0.00341802 + 149 - 273.15 \tag{8}$$

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Note: ρ_G, ρ_B, ρ_R, ρ_{NIR}, ρ_{SWIR1}, ρ_{SWIR2} represent the reflectivity of the green, blue, red, near-infrared, short-wave infrared 1, and short-wave infrared 2 bands of the remote sensing image, respectively. b_{10} is the 10th band of the L2 level data.

(2) Normalization and Principal Component Analysis

To address the inconsistent scales of the four ecological indexes and differences in remote sensing images over time, the following steps were taken:

a. Normalization: Standardized the four ecological indexes.

b. Water Body Masking: Applied a water body mask within the study area to eliminate the impact of water bodies on model construction[14].

c. Principal Component Analysis (*PCA*): Conducted *PCA* on the normalized and masked indexes to calculate principal component (*PC*) values. The first principal component (*PC1*) was used to derive the initial remote sensing ecological index $RSEI_0$.

$$RSEI_0 = PC1[f(NDVI, WET, NDBSI, LST)] \tag{9}$$

In the formula, f denotes the positive normalization of the four indicators. *RSEI* represents the first principal component from the *PCA* of the four indicators. The initial $RSEI_0$ is standardized to obtain the final *RSEI* in the range [0,1]. A higher *RSEI* value (closer to 1) indicates better ecological quality, while a lower value (closer to 0) indicates poorer quality. *NDVI* and *WET* positively impact the ecological environment with positive loadings in *PC1*, whereas *NDBSI* and *LST* negatively impact it with negative loadings in *PC1*.

4. Results and Analysis

The remote sensing ecological indexes (*NDVI, WET, NDBSI, LST*) were extracted for Baiyangdian Wetland from 2003 to 2023, and the *RSEI* was calculated for each year, as shown in Table 2. The average *RSEI* values from 2003 to 2023 were 0.4610, 0.5241, 0.6233, 0.5616, 0.6011, and 0.6265, respectively. These values indicate an "increase-decrease-increase" trend in the ecological quality of Baiyangdian Wetland over the past two decades.

Table 1. Average Values of Ecological Indicators and *RSEI* for Baiyangdian from 2003 to 2023

Year	*NDVI*	*WET*	*NDBSI*	*LST*	*RSEI*
2003	0.4471	0.6060	0.6083	0.4096	0.4610
2007	0.5239	0.6556	0.4763	0.3738	0.5241
2011	0.5909	0.6823	0.4698	0.3603	0.6233
2015	0.5548	0.7282	0.4877	0.3367	0.5616
2019	0.5773	0.6753	0.4144	0.3460	0.6011
2023	0.6429	0.6992	0.3758	0.3119	0.6265
2003	0.4471	0.6060	0.6083	0.4096	0.4610

To spatially analyze the *RSEI* of the Baiyangdian area more intuitively, the equal interval classification method was used. The RSEI values in the range [0,1] were divided into five levels with an interval of 0.2: Poor [0,0.2), Fair [0.2,0.4), Average [0.4,0.6), Good [0.6,0.8), and Excellent [0.8,1). The reclassification results are shown in Figure 1. Between 2003 and 2023, the ecological environment quality of Baiyangdian experienced fluctuations but showed an overall improving trend. In 2023, the area with ecological grades of "Average" or above reached the maximum among all years, indicating significant improvement in the ecological environment quality of Baiyangdian.

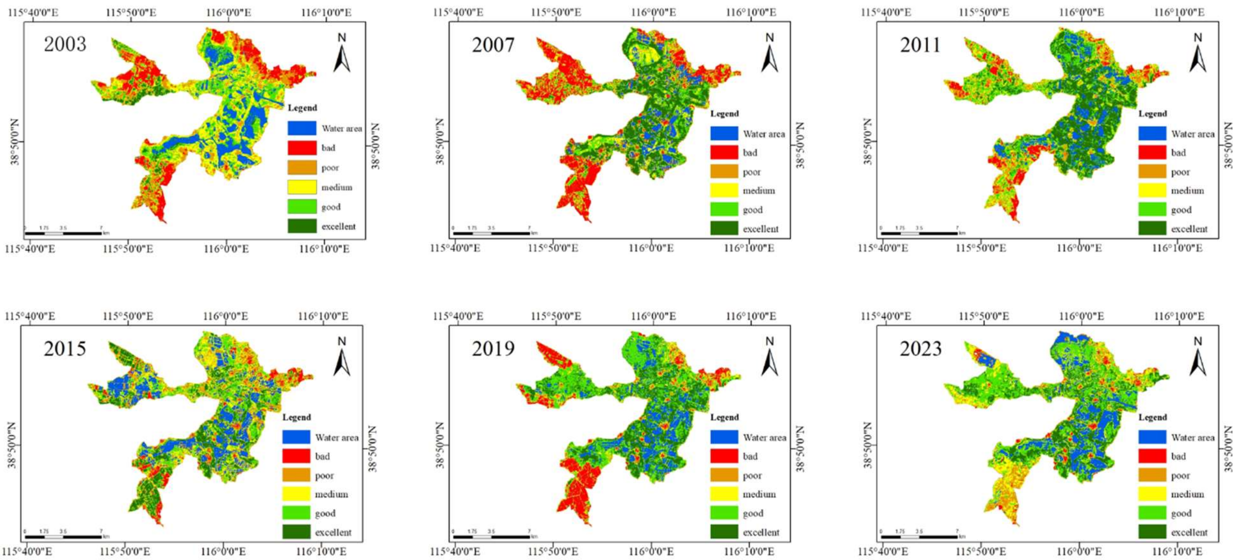

Fig. 1 Baiyangdian *RSEI* Graded Distribution Map from 2003 to 2023

5. Conclusion

Landsat remote sensing images from 2003 to 2023 were used to construct the Remote Sensing Ecological Index (*RSEI*) for a quantitative analysis of the spatial - temporal changes in the ecological environment quality of Baiyangdian Wetland over the past twenty years. The average *RSEI* values were 0.4610, 0.5241, 0.6233, 0.5616, 0.6011, and 0.6265 for the respective years. Results show that the overall ecological environment quality in the study area has improved with fluctuations, and the RSEI increased by 35.09% over the twenty years, indicating significant ecological improvement in Baiyangdian.

Acknowledgments

National Innovative Training Project for College Students: Ecological Environment Assessment of Baiyangdian Wetland based on Remote Sensing in the context of carbon Neutrality (No. 202410081068).

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