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Assessing the Ecological Environment Quality of Yellow River Delta according to the Remote Sensing Ecological Index

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Abstract. This study focuses on the ecological and environmental quality of the Yellow River Delta. Utilizing remote sensing data from 2013 to 2021, we employed the Remote Sensing Ecological Index (RSEI) derived from Landsat 8 OLI_TIRS graphics to gauge the ecological health of the region. The study reveals significant spatial heterogeneity in the ecological environment quality, with the coastal areas exhibiting the most degraded conditions. Temporal analysis indicates a fluctuating trend, underscoring the region's ecological vulnerability and the imperative for strategic interventions to balance ecological preservation with economic progress. The findings provide crucial insights for policymakers to devise sustainable development strategies that address the delicate equilibrium between environmental stewardship and economic growth in the Yellow River Delta. This study's comprehensive approach, integrating multiple ecological indices and principal component analysis, enhances the understanding of the dynamic interplay between human activities and natural processes, offering a robust framework for future ecological assessments and environmental management in the region.

1. Introduction

Estuarine deltas are the core regional types of river-sea-land interactions with unique and complex ecosystems [1]. Due to its superior physical geographical conditions and convenient water transportation, the region is often regarded as an advantageous economic development center. [2] Overburdened populations and human activities have made estuarine deltas the most heavily subjected to environmental pressure. At the same time, estuarine deltas are typical regions prone to imbalance [3]. Strong temporal and spatial pulsation, sensitive response to changes, significant edge effects, and high environmental heterogeneity characterize the evolution of estuarine deltas. Over the past century, there has been a widespread phenomenon of beach erosion and land subsidence in large estuarine deltas around the world [4]. These factors are closely related to urban sustainable development and ecological security, making the landform evolution of estuarine delta a hot research topic at present and in the future.

The Yellow River basin has a high sediment content due to soil erosion, a large amount of sediment is deposited in the estuary [5], forming the youngest, largest, and most complete wetland ecosystem in the warm temperate zone of the world [6] - the Yellow River Delta. However, in recent years, human activities such as farmland reclamation, aquaculture, rapid urbanization, and industrial development have over exploited resources, and climate change has caused hydrological damage to wetland ecosystems. The area of wetlands in the Yellow River Delta has been continuously reduced, the ecological Environment has been destroyed and the ecological health has been threatened [7]. As the last link of the Yellow River into the sea, the Yellow River Delta is an important ecological defense line in our country, so it is very necessary to evaluate the ecological environment in this region.

Remote sensing satellite observation system is widely used by researchers in the study of ecological environment because of their wide coverage, instant update of information, and stable measurement period. The research on ecological quality has gradually developed from relying on a single index to comprehensively considering multiple indexes. For example, considering the evolution of land use type, vegetation evolution, water quality adjustment, and other factors, the researchers will conduct a comprehensive evaluation of land cover and ecosystem service functions. Liu et al. (2005) analyzed the spatial and temporal patterns of farmland in China with remote sensing data [8], which provided important references for land cover change and ecosystem service assessment. Yang et al. used remote sensing data, various ecological indexes of the wetland ecosystem in the Pearl River Delta were calculated from the perspective of a multi-factor combination, and the local ecological environment level was measured [9], demonstrating the ability of comprehensive remote sensing data to assess the wetland's environmental quality. Li et al. (2015) studied the relationship between biodiversity and habitat change [10], It is emphasized that remote sensing data has gradually become an indispensable part of ecological quality measurement. These studies provide concrete

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cases and scientific support for ecological environmental quality assessment emphasizing the combination of multiple factors.

This study used remote sensing data from 2013 to 2021 to evaluate the ecological health status of the Yellow River Delta region. It is found that the ecological environment quality in the Yellow River Delta region has significant spatial heterogeneity and temporal fluctuation trend, which highlights the easy imbalance of the region, further emphasizes the necessity of adopting a comprehensive strategy to balance ecological protection and economic growth, and provides information support for sustainable development policies in the region.

2. Data and method

2.1 Study area

Located in eastern China along the Yellow Sea, the Yellow River Delta is an important part of the estuary and alluvial plain of the Yellow River. This terrain is mainly plain and floodplain, and the surface fluctuation is small, belonging to a typical warm temperate estuarine wetland [11]. The Yellow River Delta region shows obvious monsoon climate characteristics, hot and humid in summer, and cold and dry in winter, forming an obvious seasonal climate, temperature changes significantly, and annual precipitation is relatively abundant. At the same time, it is influenced by the Yellow River and its tributaries, the surface water bodies are abundant and the wetland area is extensive, this will profoundly affect the natural ecological environment and water distribution in the Yellow River Delta [12]. Rich land and water resources in this region also provide great convenience for agriculture, animal husbandry, and industry [13].

Considering that the modern Yellow River Delta region is basically located in Dongying City, Shandong Province, Dongying City is chosen as the land boundary of the target area (Fig. 1).

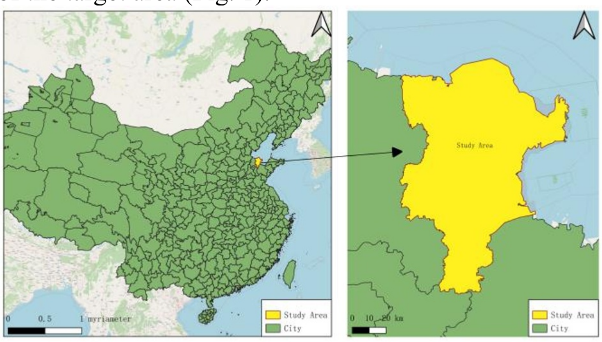

Fig.1. Dongying city(Photo/Picture credit : Original)

2.2 Data resource

Details of the data used are shown in table 1. The vector data includes Landsat 8 OLI_TIRS satellite digital product (five-time nodes in 2013, 2015, 2017, 2019, and 2021) and the administrative region (2018). All the selected influences were from May to June. During this period, the Yellow River Delta region will affected by the warm temperate monsoon climate, the climate conditions were good, the vegetation was in the growing season, and the spectral information was rich, which was convenient for remote sensing translation.

Table 1. Research data details

Satellite type	Imaging time	Column number	Resolution ratio	Cloud cover	Data sources
Landsat 8 OLI_TIRS/TIRS C2 L2	2013/5/30	121/34	30m	0.16	USGS
Landsat 8 OLI_TIRS/TIRS C2 L2	2015/6/5	121/34	30m	0.44	USGS
Landsat 8 OLI_TIRS/TIRS C2 L2	2017/5/25	121/34	30m	0.2	USGS
Landsat 8 OLI_TIRS/TIRS C2 L2	2019/5/31	121/34	30m	0.49	USGS
Landsat 8 OLI_TIRS/TIRS C2 L2	2021/6/5	121/34	30m	3.71	USGS

2.3 Methodology

2.3.1 Research method

In this study, based on the remote sensing Ecological index (RSEI) proposed by Xu Hanqiu [14], Landsat data will be used to calculate greenness, humidity, and dry heat. The ecological environment quality of the Yellow River Delta was evaluated by principal component analysis. In order to reduce the influence of large areas of water on inversion results, normalized differential water index NDWI was used instead of normalized Vegetation index (NDVI) to measure greenness in the study area because of dense river networks and interleaved water systems.

The relevant information and calculation formula of specific indicators are as follows:

Greenness indicator NDWI. The calculation is based on the difference in reflectance between the green and short-wave infrared bands, with values ranging from -1 to 1. In theory, When the NDWI is greater than 0, it means that the land is covered by water or snow. When NDWI is equal to 0, the land surface is covered by rocks or bare soil. When NDWI is less than 0, it means that the land surface is covered by vegetation. The formula is as follows:

$$\mathrm{NDWI} = (\rho_G - \rho_{SWIR1})/(\rho_G + \rho_{SWIR1}) \qquad (1)$$

Whereρ_G and ρ_{SWIR1} represent the reflectance of the green band and short-wave infrared band respectively.

Humidity indicator WET. Using the moisture component in cap and hat transformation instead of the moisture index [15] can reflect the dry moisture of soil and vegetation growth status. The calculation formula based on Landsat OLI image data in this paper is as follows:

$$\mathrm{WET_{OLI}} = 0.1511_{\rho_B} + 0.1972_{\rho_G} + 0.3283_{\rho_R} + 0.3407_{\rho_{NIR}} - 0.7117_{\rho_{SWIR1}} - 0.4559_{\rho_{SWIR2}} \qquad (2)$$

Where, ρ_B、ρ_G、ρ_{NIR}、ρ_{SWIR1}、ρ_{SWIR2}为 are the reflection data of OLI's blue, green, red, red near-outside, shortwave infrared 1, and shortwave infrared 2 bands.

Dryness index NDBSI. Construction index IBI[16] and bare soil index SI[17] are used to calculate the dryness index representing the degree of soil drying. Both IBI and SI are calculated by the ratio of band reflectance, which is usually between 0 and 1, so NDBSI is usually between 0 and 1. In practical application, the closer the value of NDBSI is to 0, the more the value of NDBSI is to 0. It indicates that the less buildings and bare soil cover in the area, on the contrary, it means that the quality of the ecological environment is worse, the worse the ecological condition.

$$\mathrm{IBI} = \{2\rho_{SWIR1}/(\rho_{SWIR1} + \rho_{NIR}) - [\rho_{NIR}/(\rho_{NIR} + \rho_R) + \rho_G/(\rho_G + \rho_{SWIR})]\}/\{2\rho_{SWIR1}/(\rho_{SWIR1} + \rho_{NIR}) + [\rho_{NIR}/(\rho_{NIR} + \rho_R) + \rho_G/(\rho_G + \rho_{SWIR1})]\} \quad (3)$$

$$\mathrm{SI} = [(\rho_{SWIR1} + \rho_R) - (\rho_B + \rho_{NIR})]/[(\rho_{swir1} + \rho_R) + (\rho_B + \rho_{NIR})] \quad (4)$$

$$\mathrm{NDBSI} = (\mathrm{IBI} + \mathrm{SI})/2 \quad (5)$$

Heat indicator LST. The land surface temperature was represented by the thermal infrared index and calculated by the Landsat user manual model [18], and the expression is as follows:

$$\mathrm{LST} = T_b/[1 + ((\lambda T_b)/\rho)\ln\varepsilon] - 273.15 \quad (6)$$

$$T_b = K_2/\ln\ (K_1/L_{10} + 1) \quad (7)$$

$$L_{10} = \mathrm{gain} \times \mathrm{DN} + \mathrm{bias} \quad (8)$$

T_b is sensor temperature, L_{10} is rthe adiation level at sensor in band 10 of OLI image, λ is a wavelength path in the center of the thermal infrared band, $\rho = 1.438 \times 10^{-2}$ m. K_1 and K_2 indicates the sensor calibration parameter, ε is the surface-specific emissivity, DN is the gray value of the image element, and gain and bias are the gain and bias values of the band.

2.3.2 Construct remote sensing ecological index

Principal component analysis (PCA), a multidimensional data compression technique that can effectively prevent correlations between different indicators and the influence of subjective weights on the results, it can reflect the ecological status of the study area in all aspects. Principal component analysis transforms the original variable into a new set of linear independent variables through a linear space rotation transformation and concentrates the main information on 1-2 principal components to improve the objectivity and accuracy of ecological status assessment. In principal component analysis, The first principal component is a linear combination of the original variables that captures the greatest variance of the data. The second principal component then captures the largest portion of the remaining variance and is orthogonal (i.e. uncorrelated) to the first principal component. The process continues until all variances are captured or a predetermined number of principal components is reached.

It should be noted that due to different index units, normalization should be performed before principal component analysis. The normalization formula is as follows:

$$\mathrm{NI_i} = (\mathrm{I_i} - \mathrm{I_{min}})/(\mathrm{I_{max}} - \mathrm{I_{min}}) \quad (9)$$

Where $\mathrm{NI_i}$ is the normalization result, $\mathrm{I_i}$ represents the value of the i th pixel, $\mathrm{I_{min}}$ is minimum and $\mathrm{I_{max}}$ is the maximum value.

After the PCA which carried by ENVI software, PC1 ratio was checked if it exceeded 80%, and it was determined to meet the statistical requirements. After the normalization process of positive and negative transposition, RSEI was obtained.

3 Result

ENVI software was used for principal component analysis of the four research indicators, and the PC1 contribution rate of the five study years reached 90%, which could concentrate most of the features of the indicators. In order to better analyze the ecological level of the study area, RSEI should be graded. In this paper, RSEI will be divided into 0.2 intervals, and the ecological quality of the study area will be analyzed according to the results of the division, the division is as follows: very poor [0 ~ 0.2], poor [0.2 ~ 0.4], medium [0.4 ~ 0.6], good [0.6 ~ 0.8], excellent [0.8 ~ 1]. After observing and analyzing the results of the 5-year study, it can be found that there is significant spatial heterogeneity of ecological environment quality in Dongying City. In Dongying City from 2013 to 2021, low-quality ecological environment blocks (RSEI≦0.4, graded as poor and very poor) mainly appeared in the northern and eastern coastal areas, while high-quality ecological environment blocks (RSEI≧0.6, graded as good and excellent) in the western, southern and some central areas. The time series analysis reveals the dynamic change of ecological environment quality. In 2013, the overall ecological environment quality of Dongying City was poor, as shown in Fig. 2. The regions rated as poor were widely distributed in Dongying City, the areas with the worst ecological quality are distributed along the banks of the Yellow River estuary, and some RSEI≦0.2 zones were scattered in the mainland. Areas with RSEI ≥ 0.8 also distributed in a fragmented manner within Dongying City, with the most concentrated in the northeast direction, followed by the central and southern parts. In 2015, we can see in Fig. 3 that the poor rated areas disappeared from the inland areas along the river, concentrated to the northeast along the Yellow River estuary, and showed a trend of diffusion. Meanwhile, the number of very poor areas increased, showing a trend of concentration in coastal areas. At the same time, the high-quality ecological area has a large scope of expansion, and the area area of RSEI≧0.8 has increased, which is more close to the low-quality area. In this year, both high quality and low quality ecological environment areas showed a distribution from east to west from dense to sparse. In 2017, the ecological environment quality of Dongying City has deteriorated significantly, RSEI rating greater than or equal to 0.8 almost disappeared, and the area with RSEI ≤ 0.2 expanded rapidly from the western coastal area along the Yellow River, It basically occupies the eastern part of Dongying City, as shown in Fig. 4. In the southern region, the area rated poor has proliferated and eroded inward from the east-west boundary. In 2019, the ecological environment quality of Dongying City returned to a level similar to that of 2015, the ecological Environment in the northern part of the city deteriorated, and the ecological quality of the study area was restored. In addition, high-quality ecological areas appeared in a large range and became the best period of overall ecological Environment in the five research periods. However, this trend has not been sustained, and there are still unstable factors in the quality of ecological Environment in this region. The ecological environment quality of the Yellow River estuary region deteriorated again in 2021 (Fig. 6), with most of the high-quality ecological areas in the west and south disappearing.

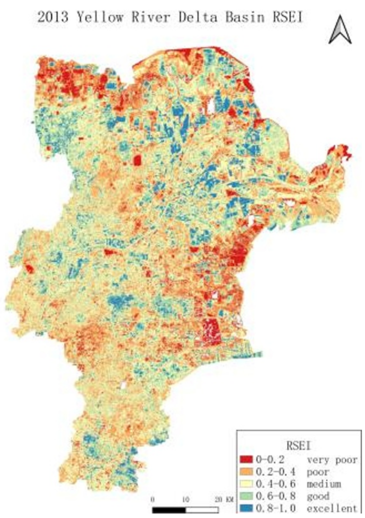

Fig.2. 2013RSEI(Photo/Picture credit : Original)

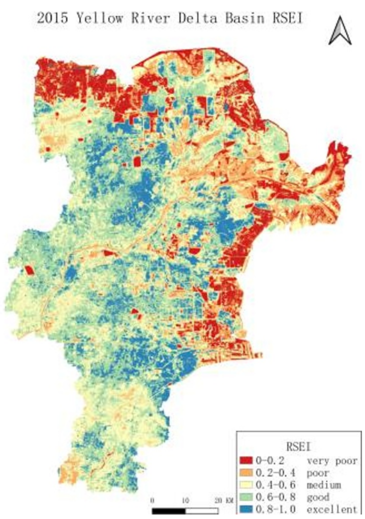

Fig.3. 2015RSEI(Photo/Picture credit : Original)

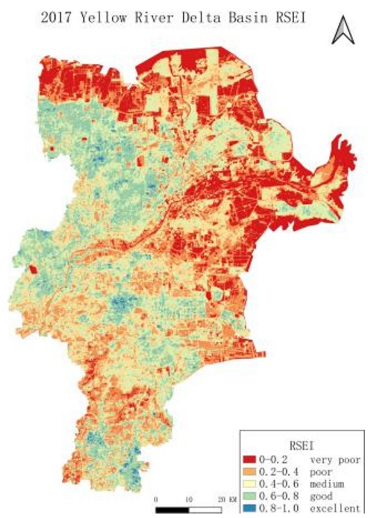

Fig.4. 2017RSEI(Photo/Picture credit : Original)

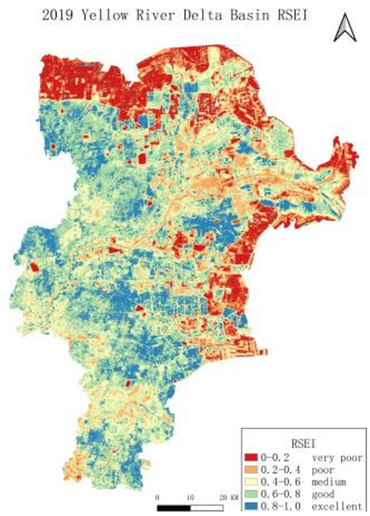

Fig.5. 2019RSEI(Photo/Picture credit : Original)

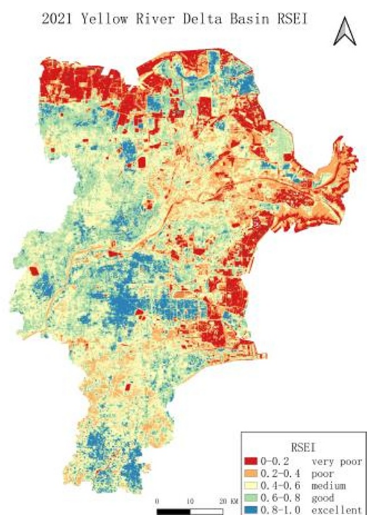

Fig. 6. 2021RSEI(Photo/Picture credit : Original)

4 Discussion

As a key ecological protection area and economic growth point in China, the evolution of ecological environment quality in the Yellow River Delta is influenced by many factors. The results showed that the ecological quality of the Yellow River Delta showed significant spatial heterogeneity during 2013-2021.

From the perspective of spatial distribution, the ecological environment quality of the Yellow River Delta is relatively low in the northern and eastern coastal areas, but relatively high in the western, southern, and some central areas. This may be related to the fact that coastal areas are more significantly affected by human activities, such as industrial development and urban expansion, which can lead to changes in land cover, vegetation destruction, and water quality deterioration. At the same time, the wetland ecosystem in the Yellow River estuary area may fluctuate due to the influence of sediment input and the change of hydrological conditions.

From the perspective of time series analysis, from 2013 to 2021, the ecological environment quality of the Yellow River Delta experienced a series of fluctuations, first from overall poor to local improvement, then deteriorated again, and then greatly improved, and a small ecological degradation occurred in the following two years. This fluctuating phenomenon may be influenced by a variety of factors such as climate change, the intensity of human activities, and the implementation of ecological protection policies. For example, the expansion of high-quality ecological areas after 2015 May benefit from strengthening ecological conservation measures, such as wetland conservation and restoration projects. On the other hand, the deterioration of ecological environment quality after 2017 May be intrinsically related to the increase of extreme weather events, excessive exploitation of water resources, environmental pollution, and other factors.

In addition, social and economic factors and policy orientation should also be considered in the ecological environment quality assessment of study area. With the development of the economy and the growth of the population, the demand for natural resources is rising, which puts pressure on the ecosystem. At the same time, the government's ecological protection policies and environmental management measures have played a key role in improving the quality of the ecological Environment. Therefore, future research endeavors should delve into strategies for harmonizing economic growth with ecological conservation, as well as explore administrative measures that are both scientifically sound and effective in preserving and enhancing the ecological integrity of the Yellow River Delta region.

In summary, the ecological environment quality assessment of the Yellow River Delta has not only unveiled the spatial temporal characteristics of the area's ecological conditions but also furnished a scientific foundation for the development of effective ecological protection and sustainable development policies. Subsequent research and management efforts should integrate the interplay of natural and anthropogenic factors, implementing a multifaceted approach to foster the health and sustainable progress of the regional ecosystem.

5 Conclusion

Through the application of remote sensing technology, the ecological environment quality of the Yellow River Delta region was evaluated in depth. This study adopted the remote sensing Ecological Index (RSEI) methodology based on Landsat 8 OLI_TIRS satellite data. Through the quantitative calculation of four key indicators, namely green vegetation, water status, drought degree, and surface temperature, and combined with principal component analysis technology, The ecological environment quality from 2013 to 2021 was systematically and quantitatively studied.

It was found that the eco-environmental quality of the Yellow River Delta region showed significant spatial heterogeneity. The eco-environmental quality of the northern and eastern coastal areas was low, while that of the western, southern, and some central regions was relatively high. Time series analysis shows that the ecological Environment quality in this area has experienced a process from overall poor to local improvement and then deterioration. The overall ecological environment quality was poor in 2013, the high-quality ecological area expanded in 2015, deteriorated significantly in 2017 and recovered in 2019. However, the ecological environment quality of the Yellow River estuary area deteriorated again in 2021, and the overall fluctuation changed

Future research can improve the accuracy and reliability of ecological environment quality assessment by introducing more types of remote sensing data and more advanced analytical methods, such as machine learning and deep learning techniques. At the same time, the research can be extended to the analysis of social and economic factors to explore the balance strategy between financial development and ecological protection. In addition, the significance of the study is to provide the scientific basis for environmental protection and sustainable development in the Yellow River Delta region and help formulate more effective environmental management policies to promote regional ecological health and coordinated economic development. Through continuous monitoring and assessment, ecological problems can be detected in time, providing data support for environmental restoration and protection measures and ensuring the long-term stability of the ecosystem and the protection of biodiversity in the Yellow River Delta region.

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