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Assessment of Ecological Environment in Zhanjiang Based on RSEI and PCA

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Abstract— *This study uses Landsat-8 remote sensing images as the data source and selects four indicators that directly reflect the quality of the ecological environment, such as greenness (NDVI), wetness (WET), dryness (NDBSI), and heat (LST). Meanwhile, we use principal component analysis (PCA) to construct a remote sensing ecological index (RSEI) model for exploring the changes in the ecological environment quality of Zhanjiang from 2013 to 2021. The results indicate that RSEI can better reflect the ecological environment of the region. The study area is mainly affected by dryness, followed by greenness and humidity, with heat having the smallest impact. The average RSEI values in Zhanjiang City in 2013 and 2021 were 0.5339 and 0.5576, respectively, indicating a slight improvement in overall ecological environment quality. Among them, NVDI showed an increasing trend, NDBSI and WET decreased, but LST increased.*

Keywords— ***Remote Sensing Ecological Index (RSEI); Principal Components Analysis (PCA); Ecological Environment Quality; Normalized Difference Vegetation Index (NDVI), Normalized Difference Bare Soil Index (NDBSI), Land Surface Temperature (LST)***

I. INTRODUCTION

The quality of the ecological environment is a comprehensive characteristic of the elements, structure, and function exhibited by an ecosystem (Kong et al., 2019; Li et al., 2018). Which reflect the degree of superiority or inferiority of the ecological environment and speculate on the impact of human activities on the environment. The research on monitoring and evaluation of ecological environment quality is receiving increasing attention, and there are many methods and models for ecological quality evaluation, including Analytic Hierarchy Process (AHP) (Li et al., 2006), Ecological Environment Status Index (EI) (Yao et al., 2012), "Pressure State Response" PSR model (Wang et al., 2017), and the use of the InVEST model (Lu et al., 2018) and landscape pattern index (Liu et al., 2011) for ecological environment quality evaluation and analysis.

The factors adopted by the above model indicators are related to vegetation and human activities. There are differences in the suitability of human activity indicators in different regions, which has limitations for some areas where it is difficult to obtain human activity indicators. The Remote Sensing Ecological Index (RSEI) (Xu, 2013; Gao and Wang, 2023), which includes factors such as greenness, humidity, dryness, heat, etc., provides a more objective and comprehensive evaluation of the ecological environment of a region than traditional ecological quality index calculations. Moreover, this index is also applicable to soil erosion (Xu, 2013; Zhang et al., 2015) and urban areas (Yang et al., 2019).

In addition, some studies have added principal component analysis (PCA) to the RSEI model to evaluate and classify ecological indices. The method is a mathematical dimensionality reduction method that can convert multiple indicators into a few principal components, which are linear combinations of original variables and have no interrelationships with each other. They can reflect most of the information in the original data (Han et al., 2012), which is reasonable and feasible for evaluation. It has been applied in many practical fields and has the ability to classify and visualize a large amount of data.

In recent years, the regional economy in Zhanjiang has developed rapidly, with the industrial scale and total economic output continuously increasing (Liu et al., 2021; Yang and Li, 2022). Along with the advancement of urbanization and the expansion of urban land use, green development and ecological civilization construction are also important aspects of sustainable social and economic development. The use of RSEI science to monitor and evaluate the impact of human activities on cities has important theoretical and practical significance for protecting and promoting harmony between humans and nature and promoting sustainable social development. Thus, this study is based on the combination of RSEI and PCA to conduct a multi-indicator, large-scale, and multi-temporal ecological environment assessment. Analyze the changes in the ecological environment in the region from 2013 to 2021 and explore the key factors affecting urban environmental changes. The aim is to serve the ecological environment of Zhanjiang City and promote sustainable ecological development. Therefore, the main objectives of this paper include the following:

(1) By combining remote sensing technology with the current ecological environment situation in Zhanjiang, suitable ecological environment quality evaluation indicators are selected based on natural conditions, economic development, and other aspects. A suitable RSEI ecological environment quality evaluation system is selected, and relevant data and materials are searched based on the system.

(2) Utilize the ENVI software to extract information on greenness, humidity, dryness, and heat indicators required for experiments in remote sensing images.

(3) Assign the weight values of evaluation indicators through PCA, select the principal components with more information based on the results of PCA, and extract the RSEI index. Use ArcGIS software to comprehensively analyze the quality of the ecological environment.

(4) Based on the results of the comprehensive evaluation of the ecological environment quality in Zhanjiang, propose countermeasures and suggestions for the problems faced by the city's ecological environment.

II. STUDY AREA AND DATA SOURCES

2.1 Study Area

Zhanjiang City is located in the southernmost part of the Chinese Mainland, southwest of Guangdong Province, between 109 ° 40 ′ -110 ° 58 ′ E and 20 ° 13 ′ -21 ° 57 ′ N (Figure 1). Belonging to the tropical northern monsoon climate, it is year-round regulated by the marine climate, with no severe cold in winter and no scorching heat in summer. Subtropical crops and marine resources are abundant. The land of Zhanjiang is mostly composed of peninsulas and islands, with a terrain roughly high on the central axis, low on the east and west sides, high in the north and south, and low in the middle, with gentle undulations and mostly plains and plateaus. In the total land area of the city, plains account for 66%, hills account for 30.6%, and mountainous areas account for 3.4%. As of 2022, the permanent population of Zhanjiang City is 7.0354 million, with an urban permanent population of 3.3284 million. The proportion of the total population (urbanization rate) is 47.31%, and the total GPD ranks ninth in Guangdong Province. Zhanjiang mainly relies on the natural advantages of the port and plays a pivotal role in the economic development and foreign trade of its hinterland.

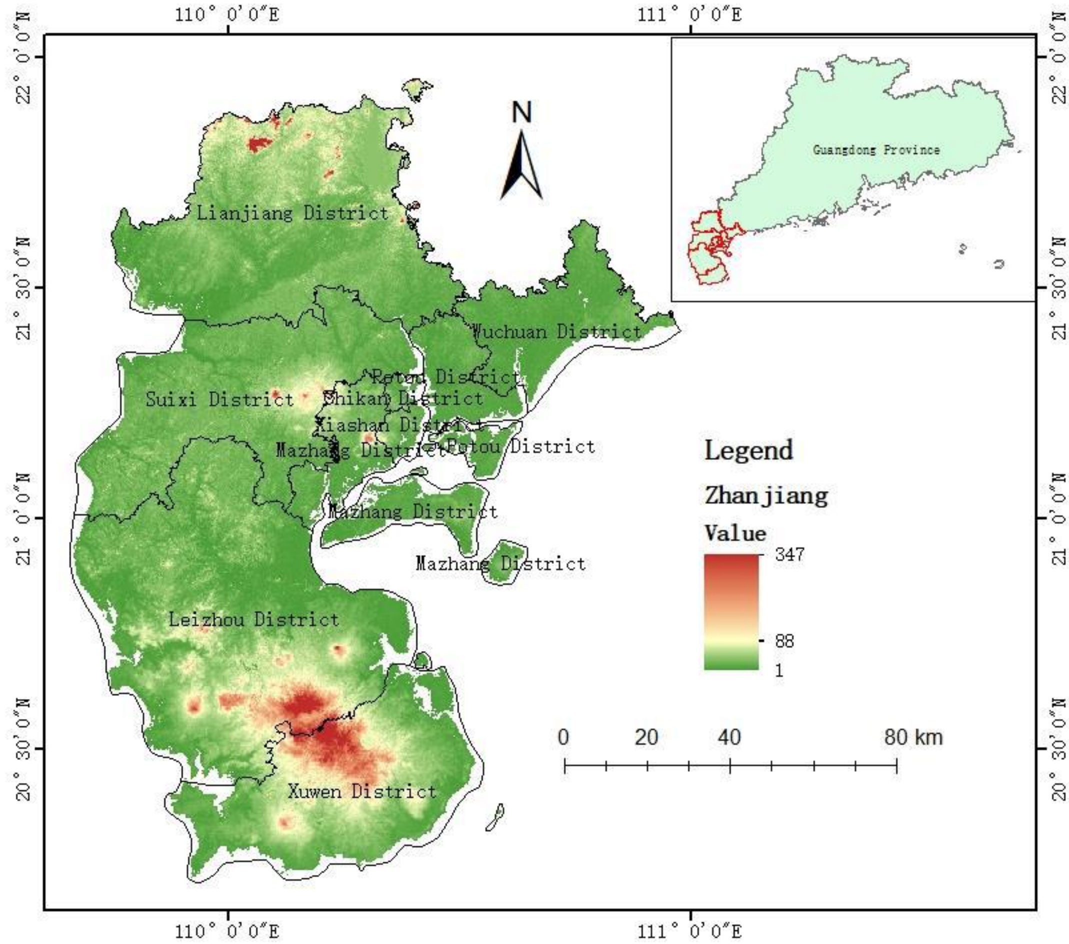

Fig.1 Map of Zhanjiang, Guangdong

2.2 Data Sources

The basic data used in this study is mainly Landsat-8 OLI remote sensing data (sourced from https://www.gscloud.cn/）. This includes two remote sensing images in 2013 and 2021, with the months concentrated in December, resulting in better image quality and data cloud coverage of less than 1% (Table 1). Vector data used in the research area (sourced from https://www.webmap.cn/) is mainly used for clipping and the production of remote sensing images. Terrain layer (from https://www.gscloud.cn/): the downloaded data is 30m DEM, which is used for the terrain's overview of the study area.

Table 1 Information of Remote Sensing Images

Satellite	Track Number	Resolution	Cloud cover	Imaging date
Landsat OLI	124/045	30m	0.01	2013/12/29
	124/046		0.09	2013/12/29
	124/046		0.08	2021/12/3
	124/045		0.03	2021/12/3

III. METHOD

The process of obtaining the remote sensing ecological index (RSEI) is shown in Figure 2. The technical route can be roughly divided into the following steps: remote sensing image preprocessing, RSEI index extraction, evaluation system construction and analysis, and production of thematic maps. Firstly, the selected images for the experiment were subjected to radiometric correction and mosaicism, and the study area images were clipped based on the vector data of the study area. Then, use relevant formulas to calculate four ecological indicators for each image, synthesize their images, and perform principal component transformation on the newly synthesized images; Next, calculate the numerical values based on the obtained ecological environment evaluation indicators, and conduct evaluation and analysis based on relevant data from the research area; Finally, create relevant thematic maps.

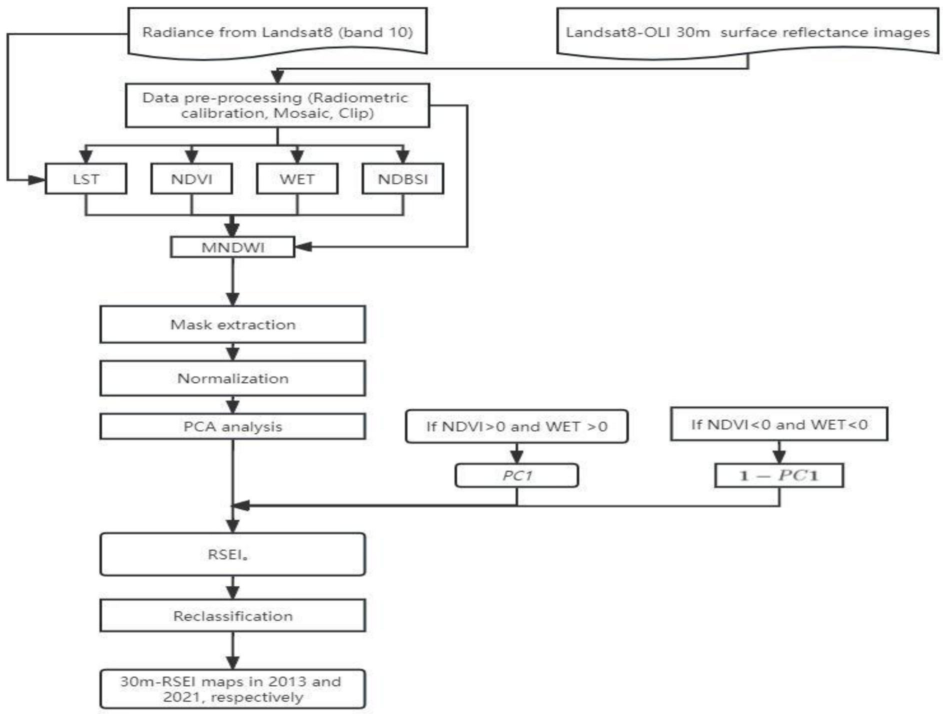

Fig.2 The Schema Flowchart of This Study

3.1 The Single Indicator of RSEI Model

（1）Greenness Index (NDVI): The Normalized Difference Vegetation Index (NDVI) is the most widely used vegetation index, which can accurately reflect vegetation greenness, regional land cover classification, and its changes (Song et al., 2011). Thus, NDVI is used to represent the greenness indicator:

$$\mathrm{NDVI} = (\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}}) - (\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}}) \quad (1)$$

In equation (1), ρ_{NIR} is in the near-infrared band; ρ_{Red} is the red band.

(2) Humidity Index (WET): Based on remote sensing data inversion, humidity is commonly used to reflect changes in soil moisture. If soil moisture is too low, it can cause plants to absorb less water, resulting in a decrease in plant moisture content. Thus, studying the humidity of the ecological environment is particularly important. The tassel-hat transformation is an empirical forward transformation of images based on the spatial information structure of soil, vegetation, etc. in multiple spectra (Zhou et al., 2006). One component is humidity, and the wavelength range of Landsat OLI data in the red band is 0.63-0.68 μm. The humidity indicators are represented as follows:

$$\mathrm{WET_{OLI}} = 0.1511\rho_1 + 0.19732\rho_2 + 0.32833\rho_3 + 0.34074\rho_4 - 0.71175\rho_5 - 0.45596\rho_6 \quad (2)$$

Equation (2) $\mathrm{WET_{OLI}}$ represents the humidity component of Landsat OLI remote sensing images, $\rho_1 - \rho_6$ represents the spectral reflectance of the blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2 bands, respectively.

(3) Dryness Index (NDBSI): With the acceleration of urbanization, land use types have shifted from agricultural land and forest land to impermeable construction land, while exposed soil and impermeable surfaces such as construction land will increase the degree of dryness. Thus, the study synthesized the soil index (SI) and intelligent building index (IBI) to obtain the dryness index (NDBSI) to reflect the changes in dryness:

$$\mathrm{SI} = [(\rho_5 + \rho_3) - (\rho_4 + \rho_1)]/[(\rho_5 + \rho_3) + (\rho_4 + \rho_1)] \quad (3)$$

$$\mathrm{IBI} = \{2\rho_5 + \rho_4) - [(\rho_4/\rho_4 + \rho_3) + \rho_2/(\rho_2 + \rho_5)]\}/\{2\rho_5/(\rho_5 + \rho_4) + [(\rho_4/\rho_4 + \rho_3) + \rho_2/(\rho_2 + \rho_5)]\} \quad (4)$$

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

In equations (3), (4), and (5), SI, IBI, and NDBSI represent soil index, building index, and dryness index, respectively, $\rho_1 - \rho_5$ represents the spectral reflectance of blue, green, red, near-infrared, and shortwave infrared bands.

(4) Heat Index (LST): The transformation of land cover leads to changes in thermal radiation and urban heat island effects, which affect ecological environment changes. For example, studying land surface temperature (LST) as one of the indicators to quantitatively evaluate urban land use and land use types (Yue et al., 2006). Thus, as an indicator of heat, LST has strong reliability. The variation of LST is inverted using atmospheric correction, and the specific formula is as follows:

$$L_\lambda = [\varepsilon B(LST) + (1-\varepsilon)L\downarrow]\tau + L\uparrow \quad (6)$$

$$\mathrm{B(LST)} = [\mathrm{L_\lambda} - \mathrm{L}\uparrow - \tau(1-\varepsilon)\mathrm{L}\downarrow]/\tau\varepsilon \quad (7)$$

$$\mathrm{LST} = \mathrm{K_2 2}/\ln(\mathrm{K_1}/\mathrm{B(LST)} + 1) \quad (8)$$

In equations (6), (7), and (8), L_λ is the brightness value of thermal infrared radiation, ε is the surface emissivity, LST is the true surface temperature, and B (LST) is the blackbody thermal radiance, τ for transmittance, L↑ and L↓represent the upward and downward radiance of the atmosphere, respectively. $K_1 = 774.84\,W/(m^2 \cdot \mu m \cdot sr)$, $K_2 = 1321.08K$。

3.2 Principal Components Analysis (PCA)

Let F1 be the PCA formed by the first linear combination of the original variable, $F_1=a_{11}X_1+a_{21}X_2+...+a_{p1}X_p$. According to mathematical knowledge, the amount of information extracted by each principal component can be measured by its variance. The larger the variance Var (F1), the more information F1 contains. It is often the first principal component (F1) that contains the largest amount of information, so F1 is selected as X1, X2,... in XP, the linear combination with the largest variance is called F1 as the first principal component (Xu and Deng, 2022).

3.2.1 Mathematical model of PCA method

From a geometric perspective, PCA is the process of rotating and transforming the original coordinates to obtain intersecting coordinate axes. The direction where all data points are scattered is the direction of the coordinate axes, and this new set of coordinate axes is arranged based on the size of the obtained eigenvalues. For n samples, X1，X2，...， the dataset X of Xp variables has a data matrix of:

$$\begin{bmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{bmatrix} = [x_1, x_2, \ldots, x_p] \quad (9)$$

wherein： $x_i = (x_{1i}, x_{2i}, .., x_i)T$, i=1,2,...,p

PCA is the transformation of the original P observation variables X1，X2， Xp, forming P new variables (comprehensive variables), Namely:

$$\begin{cases} F_1 = a_{11}x_p + a_{12}x_p + \cdots + a_{1p}x_p \\ F_2 = a_{21}x_p + a_{22}x_p + \cdots + a_{2p}x_p \\ F_3 = a_{31}x_p + a_{32}x_p + \cdots + a_{3p}x_p \\ \cdots \\ F_p = a_{p1}x_p + a_{p2}x_p + \cdots + a_{pp}x_p \end{cases}$$

(10)

In equations (9) and (10), x_i is an n-dimensional vector, F_i is also an n-dimensional vector. The above model needs to meet the following conditions:

F_i, F_j Uncorrelated（i≠j,I,j=1,2,3,…,p）

The variance of F_1 is greater than F_2. The variance of F_2 is greater than F_3, and so on.

Simultaneously satisfying the above three conditions, the transformed new random variables are independent of each other, and the variance gradually decreases, and F_1 is the first principal component, F_2 is the second principal component, and so on. Represent the above model in matrix form as: F=AX

$$F = \begin{bmatrix} F_1 \\ F_2 \\ \cdots \\ F_p \end{bmatrix} \quad X = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ x_P \end{bmatrix} \quad A = \begin{bmatrix} a_{11} & \cdots & a_{1p} \\ \vdots & \ddots & \vdots \\ a_{p1} & \cdots & a_{pp} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ \cdots \\ a_p \end{bmatrix} \quad (11)$$

Where, in equation (11), A is the main component coefficient matrix.

PCA can obtain multiple principal components, but their variance is decreasing. Therefore, in practical operations, it is generally determined based on the size of the contribution rate. The contribution rate reflects the amount of information in each principal component, and the first principal component accounts for the majority of the information in the principal component. The contribution rate calculation formula is:

$$F_1 = \lambda_1 / \sum_{i=1}^{p} \lambda_1 \quad (12)$$

In equation (12), F_1 is the number of main components with a contribution rate of p, λ is the characteristic values of the main components.

3.2.1 MRSEI model

MRSEI is the weighted value of the principal components in RSEI, which is:

$$\text{MRSEI} = \omega_1 PC1 + \omega_2 + PC2 + \omega_3 PC3 \quad (13)$$

The MRSEI index is a weighted sum calculation that adds the second and third principal components without ecological significance to the first principal component with clear ecological significance. When the characteristic value of PC1 accounts for a high proportion (contribution rate>80%), although the results of MRSEI are lower than those of RSEI, the difference is very small, so using MRSEI will only increase the computational workload and is completely unnecessary. When the characteristic value of PC1, i.e. contribution rate, is less than 80%, MRSEI will significantly reduce the value of RSEI, so it cannot be used (Xu and Deng, 2022). Therefore, in practical operation, PC1 is used as the initial value of RSEI.

3.3 Comprehensive Index Construction of RSEI Model

The RSEI model, composed of greenness, humidity, dryness, and heat, can be used to qualitatively and quantitatively evaluate the quality of the ecological environment, and the weight of the indicators can be determined through the principal components. This model is easily affected by water bodies, so when there is a large amount of water in the study area, such as reservoirs and lakes, the water body should be masked. The water body index model used here is WNDWI (Xu, 2005) to reflect the ecological status of the study area. In order to unify each single indicator, it is necessary to normalize the individual indicators (Equation 14), then perform principal component analysis and retain the first component with the highest variance, namely the initial value of RSEI (equation 15).

According to the research results of RSEI (normalized initial value RSEI) (equation 16), it is divided into five levels using the equal interval method: Poor (0-0.2), Inferior (0.2–0.4), Moderate (0.4–0.6), Good (0.6–0.8), and Excellent (0.8–1) to analyze the changes in ecological environment quality in Zhanjiang.

$$NI_i = (I_i - I_{min})/(I_{max} - I_{min}) \quad (14)$$

In equation (14) NI_i is the normalized value for the i-th year: taking NDVI as an example I_i is the i-th year NDVI, I_{min} is the minimum value of NDVI, I_{max} is the maximum NDVI value in the i-th year.

$$RSEI_0 = 1 - \{PC1[f(NDVI, WET, VDBSI, LST)]\} \quad (15)$$

$$\mathrm{RSEI} = (\mathrm{RSEI}_0 - \mathrm{RSEI}_{0\_min})/(\mathrm{RSEI}_{0\_max} - \mathrm{RSEI}_{0\_min}) \quad (16)$$

In equations (15) and (16), $RSEI_0$ is the initial value of the RSEI; PC1 is the first principal component obtained by principal component transformation of NDVI, WET, NDBSI, and LST; RSEI_{0_max} 、 RSEI_{0_min} are the maximum and minimum values of the initial RSEI values, respectively. The range of RSEI is between [0-1]. The larger the RSEI, the better the local ecological environment quality. Conversely, the worse the local environmental quality.

IV. ANALYSIS AND RESULTS

The results of the four principal component analyses in Zhanjiang in 2013 and 2021 are shown in Table 2, which shows that the proportion of PC1 is very large, indicating that most of the characteristic values of the four indicators have been concentrated. In PC1, NDVI which represents greenness, and WET, which represents humidity, exhibit positive values, indicating their positive impact on ecology. If it is negative, the "1-PC1" operation (equation 10) needs to be performed. If it is positive, this operation is not required.

Table 2 Principal component analysis of each index

Year	Index	PC1	PC2	PC3	PC4
2013	NDVI	0.65	0.47	-0.58	-0.14
	WET	0.08	0.04	-0.1	0.99
	NDBSI	-0.72	-0.64	0.28	-0.01
	LST	-0.25	0.61	0.75	0.03
	Eigenvalue	0.1556	0.0559	0.0292	0.0013
	Contribution rate /%	64.3	23.11	12.05	0.54
2021	NDVI	-0.63	0.01	0.74	0.24
	WET	-0.27	-0.06	0.08	-0.96
	NDBSI	0.70	0.23	0.65	-0.16
	LST	0.18	-0.97	0.16	0.02
	Eigenvalue	0.1616	0.0381	0.0091	0.003
	Contribution rate /%	76.29	18.01	4.3	1.4

4.1 RSEI Graded Evaluation

Analysis shows that the RSEI in 2013 and 2021 were 0.5339 and 0.5576, respectively (Table 3), showing a slight upward trend, indicating an improvement in the ecological environment of the study area.

Further, analyzing the changes in environmental quality and spatial pattern in Zhanjiang from 2013 to 2021 (Figure 3), the annual RSEI was divided into five levels:

Poor (0-0.2), Inferior (0.2–0.4), Moderate (0.4–0.6), Good (0.6–0.8), and Excellent (0.8–1). Table 4 shows the ecological grade area and proportion of Zhanjiang in different periods. In 2013, the total area of areas with excellent and good ecological environments in Zhanjiang was about 43.48%, distributed in the eastern part of Xuwen County, the southwestern part of Leizhou City, and the northern part of Lianjiang City; the total area of areas with poor and inferior is about 24.89%, distributed in urban areas such as the eastern part of Leizhou and Chikan District, as well as towns around the city; and the area with a moderate ecological grade is about 41.63%, with a relatively scattered distribution. The Suixi area has a relatively large range with a moderate ecological grade, indicating that the ecological quality and environment in Zhanjiang are relatively stable and good. By 2021, the RSEI level difference in Zhanjiang had increased by 3.79%, while the ecological environment quality level had increased to 14.18% and 28.07%, respectively. In areas such as Suixi and Lianjiang, the RSEI level has shifted from medium to excellent, indicating that Zhanjiang's ecology practices the concept of "environmental protection". Ecological issues have been taken seriously, and environmental protection work has been implemented.

Table 3 Changes of Mean Values of Four Indicators and RSEI

Year	Item	NDVI	WET	NDBSI	LST	RSEI
2013	Mean	0.5837	0.5904	0.5428	0.4913	0.5339
2021		0.6152	0.3804	0.4512	0.5410	0.5576

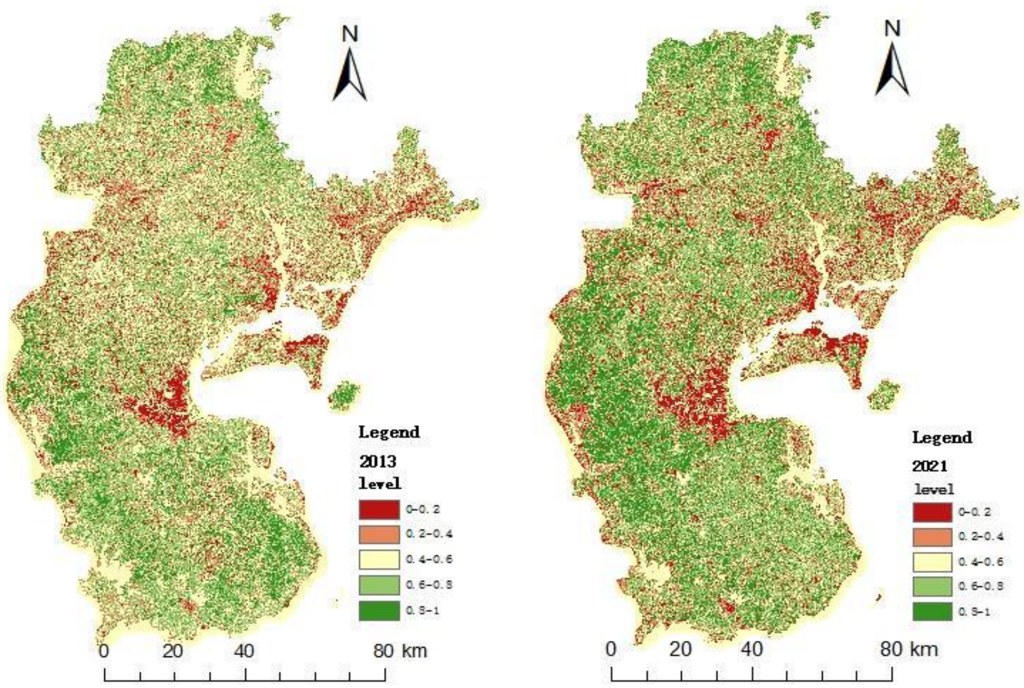

Fig.3 Changes of RSEI in Zhanjiang from 2013 to 2021

Table 4 Area and proportion of ecological grade in different periods of Zhanjiang

RSEI grade	2013 年		2021 年	
	Area/㎢	Rate/%	Area /㎢	Rate/%
Poor	858.19	6.71	1342.51	10.50
Inferior	2325.09	18.18	2139.22	16.73
Moderate	5324.34	41.63	3903.88	30.52
Good	2858.78	22.35	3590.63	28.07
Excellent	1423.64	11.13	1813.79	14.18
Total	12790.03	100.00	12790.03	100.00

4.2 Characteristics of Ecological Environment Changes

In Figure 4, the legends 1, 2, 3, 4, and 5, respectively, represent a significant change in RSEI level, with an obvious decrease, slight decrease, no change, slight improve, and significant improve. The statistical results of RSEI ecological level changes in Zhanjiang from 2013 to 2021 are shown in Table 5. Through ArcGIS and Excel statistical analysis, the area where the ecological level of Zhanjiang remains unchanged is 5769.85 km^3, accounting for approximately 42.77%. Mainly distributed in river and lake areas, the quality of the ecological environment in this area is relatively stable. About 26.29% of them have slightly or obvious decreased ecological levels, distributed in the eastern part of Xuwen County and Donghai Island. The proportion of slightly improved and significantly improved areas is about 30.94%, with the most significantly improvement being in the western part of Suixi County, indicating a gradual improvement in the environmental quality of the region.

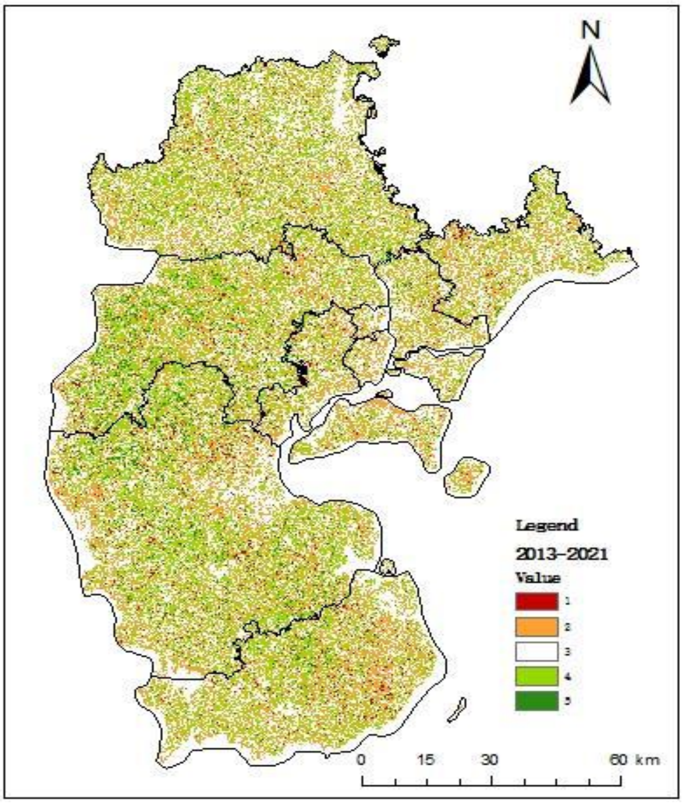

Fig.4 Change of RSEI in Zhanjiang between 2013 and 2021

Table 5 Area and Percentage Change of RSEI in Zhanjiang

Class	RSEI level transfer area/km^3	Change rate /%
Obvious decrease	250.19	1.85
Slight decrease	3296.78	24.44
No change	5769.85	42.77
Slight improve	3787.62	28.08
Significant improve	385.89	2.86
Total	13490.33	100.00

V. CONCLUSIONS

(1) Among the green index, humidity index, dryness index, and heat index, the dryness index has the highest contribution rate to RSEI, indicating that land use methods are closely related to the urban ecological environment. The increase in building land area caused by urban planning and layout will have a negative impact on the urban environment, while greening projects such as afforestation and the construction of landscape economic belts will improve the ecological environment of the area. Therefore, people should enhance their awareness of this aspect, effectively adapt to local conditions, and plan reasonably. The government should not only focus on urban economic development but also vigorously promote ecological environment construction, increase urban green area, and optimize urban and rural land use structures.

(2) Between 2013 and 2021, the RSEI value of Zhanjiang increased from 0.5339 to 0.5576, an increase of 2.37%, indicating that the ecological quality of Zhanjiang is developing towards a positive trend. According to the RSEI index grading table, the ecological environment quality of Zhanjiang is mostly in the "medium" and "good" stages, with a decrease in the proportion of "poor" and "Inferior", and an increase in the proportion of "excellent" and "good". This indicates that people's awareness of ecological protection has been continuously strengthened in recent years, and in recent years, Zhanjiang has vigorously developed the tourism industry, promoting the protection of tourism resources, including natural resources, which has to some extent protected the local ecological environment.

(3) The areas where the ecological environment level of Zhanjiang has decreased are mainly on Donghai Island and around towns. The towns may have been affected by comprehensive poverty alleviation policies in recent years, increased investment in infrastructure by the government, expansion of construction land, and the construction of hardened roads in villages, resulting in a certain degree of ecological damage along the way. Donghai Island may be due to the ecological environment decline caused by the large industrial group Baosteel. Thus, the expansion of urban land use, the increase in bare soil area, and environmental pollution will all be the main tasks of governance in Zhanjiang in the future. Therefore, in future development, Zhanjiang should focus on rational planning of land resources, increasing vegetation coverage in the urban area, reducing industrial pollution, encouraging green consumption among citizens, and promoting green living.

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