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Abstract: Nanling Mountain region is a typical southern hilly region, which plays an important ecological and environmental protection role in China's overall land protection pattern. Based on the remote sensing image data of Longnan City in Nanling Mountain in 2013, 2018 and 2023, this paper interpreted the land use type and analyzed the land use transfer situation by using Land use transfer flow, and Land use transfer matrix. At the same time, based on the remote sensing Ecological index (RSEI) model, the ecological environment quality of Longnan City from 2013 to 2023 was retrieved. The temporal and spatial response model of ecological environment quality to land use transfer in Longnan City from 2013 to 2023 was discussed based on Spatial autocorrelation and Geographic detector. The results show that from 2013 to 2023, the decrease of forest land (16.23km²) and the increase of construction land (13.25km²) were the main land use transfer in Longnan City. The ecological environment index of Longnan City in 2013, 2018 and 2023 was 0.789, 0.917 and 0.872, respectively, showing a trend of "first rising and then decreasing". The ecological environment quality in the north of Longnan City was significantly lower than that in the south, and the poor ecological quality area appeared in and around the northern main urban area, showing a trend of "inward contraction". Forest land, garden land, grassland, cultivated land and water area have a positive impact on ecological environment quality, while traffic land, construction land and other land have a negative impact on ecological environment quality. The response of ecological environment quality to different land use transfer modes is related to the change of the overall ecological environment quality. The interaction between LUCC and other factors had a great impact on the evolution of ecological environment quality in Longnan City.

Keywords: remote sensing ecological index; land use transfer flow; land use transfer matrix; spatial autocorrelation; geographic detector; nanling mountain

1. Introduction

In 2012, the Chinese government put forward a new type of national space development goal of "livable and moderate living space, intensive and efficient production space, and beautiful ecological space". All parts of the country responded positively, and the ecological environment quality in most areas has improved significantly. In this context, the influence of ecological protection on urban development and territorial spatial planning has gradually expanded and occupied an irreplaceable position [1–4]. On the one hand, the development and utilization of territorial space usually lead to the transformation of land use [5,6]. For example, agricultural land and ecological land are squeezed, resulting in the gradual deterioration of ecological environment quality. On the other hand, the land transfer caused by the implementation of measures such as returning farmland to forest (lake) will improve the quality of the local ecological environment. The effects of the two land use transfer processes on ecological environment change showed heterogeneity. Therefore, exploring the

response mode of ecological environment quality change to land use transfer is helpful to improve the local ecological environment quality. Relevant studies have shown that: land use benefit [7], land cover change and transformation [8,9] will have a direct impact on ecological benefit and ecological landscape, and urban expansion [10] will have a negative impact on ecological environment. Moreover, these effects are often two-way, and the ecological environment quality also has a counter-effect on the regional economy [11], crop quality [12,13], air quality [14], population distribution [15] and other social and economic conditions.

The most direct way to evaluate the regional ecological environment quality is to calculate the ecological index. For example, Ecological Index (EI)[16], Remote Sensing Ecological Index (RSEI)[17], City Ecological Index (CEI)[18] and other quantitative evaluation methods are used to calculate regional ecological environment quality. Methods such as analytic hierarchy process [19], geographic detector model [20], and improved remote sensing ecological index [21] are also widely used to evaluate ecological environment quality. Because of its objectivity [22], RSEI is widely used in the study of ecological environmental quality change. Zhang[23], Yuan[24] and Zhang[25] all used RSEI to study regional eco-environmental quality change and its potential influencing factors, and the results showed that land use, vegetation cover and urban construction would all affect the eco-environment. Pai Rihai · Heili [26] and Xu[27] used RSEI to evaluate urban ecological environment quality, and the research showed that impervious water surface would also have an impact on ecological environment quality.

Nanling Mountain is an important part of the hilly mountain belt in southern China, mainly developing subtropical evergreen broad-leaved forest and coniferous forest, with rich biodiversity. But its artificial forest species is single, forest quality is not good, urban construction and mining development lead to biodiversity damage, ecological environment quality deterioration. Therefore, exploring the response mode of ecological environment quality to land use transformation in Longnan City of Nanling Mountain region is helpful to find out the causes of ecological environment change in Longnan City, and provide references for ecological protection and restoration in Nanling Mountain region. However, most current studies take land use as a single factor to explore its impact model on ecological environment quality [27,35,36], and there are few reports on the response model of ecological environment quality to land use transformation.

In this study, the ecological environment quality of Longnan City was evaluated by obtaining three remote sensing images of Longnan City in 2013, 2018 and 2023, and calculating RSEI index. On this basis, the direction of land use types was divided into: positive land types that promote the ecological environment and negative land types that hinder the ecological environment. By calculating Pearson's correlation coefficient, the correlation degree between the evolution of ecological environment quality and land use transfer was explored. Combined with the results of field investigation, the temporal and spatial response model of ecological environment quality to land use transfer in Longnan City was further discussed. The research results provide an important perspective for understanding the relationship between ecological environment and land use, and also provide a scientific basis for mountain ecological protection and restoration.

2. Materials and Methods

2.1. Study Area

Longnan City is located in the southernmost part of Jiangxi Province (Figure 1), in the subtropical humid monsoon climate zone, covering an area of 1641km². The territory is rich in natural resources, the forest coverage rate of the whole area is as high as 81.42%, the soil is dominated by red soil, and there are five first-level tributaries of the Ganjiang River such as Taojiang and Lianjiang. Longnan City belongs to the soil and water conservation area of Nanling mountains and hills in Jiangxi Province, with excellent ecological environment. However, in recent years, the urban expansion of Longnan City inevitably occupied part of the ecological land around the town, which posed a potential threat to the quality of its ecological environment.
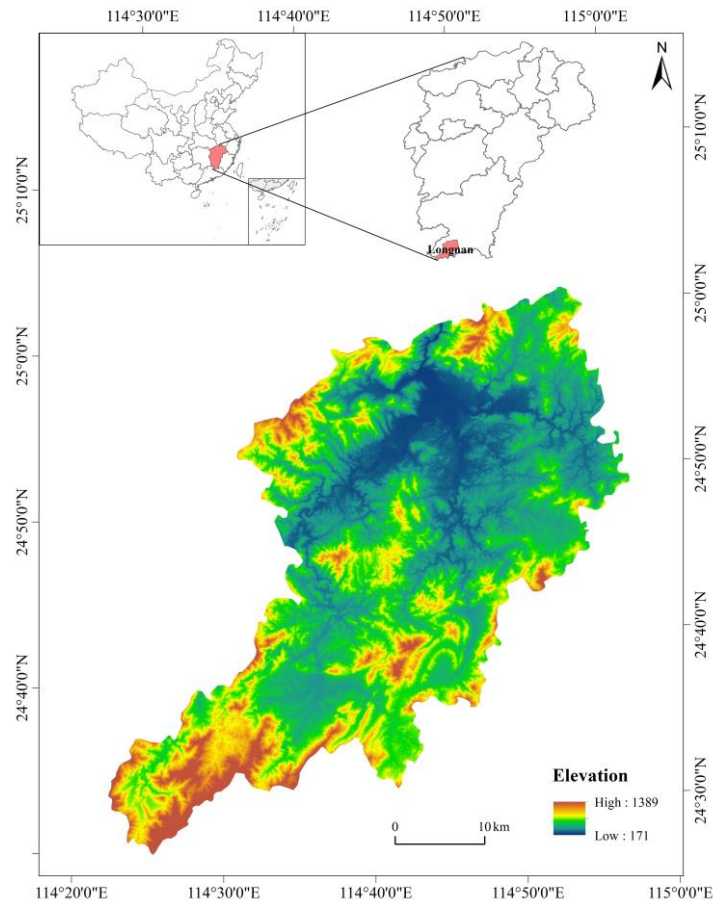
Figure 1. Schematic diagram of the research area.

2.2. Data Processing

2.2.1. Data

The remote sensing data obtained in this study came from the three phase Landsat 8 OLI/TIRS image data (March 10, 2013, March 9, 2018 and March 7, 2023) that had been pre-processed for atmospheric correction by Geospatial data Cloud and Alibaba Cloud AI Earth platform. Among them, 2013 and 2018 are C2 L1 level data, and 2023 is C2 L2 level data, with a spatial resolution of 30m. The land use data in 2023 were obtained from the National Soil and Water Conservation Survey project, and the land use data in 2018 and 2013 were visually interpreted by the authors.

2.2.2. Remote Sensing Ecological Index

Remote sensing ecological index (RSEI) is composed of four main indicators: greenness, humidity, dryness and heat [28]. The calculation process is as follows:

(1) Greenness index. In this study, normalized vegetation index (NDVI) was used to characterize the greenness index, as shown in formula 1:

$$NDVI = (B_5 - B_4)/(B_5 + B_4) \tag{1}$$

In formula (1), B_5 is the near-infrared band and B_4 is the red band.

(2) Humidity index. The humidity index was calculated using OLI image calculation method (obtained by referring to indexdatabase https://www.indexdatabase.de/), as shown in Formula 2.

$$WET = 0.1511 \times B_2 + 0.1973 \times B_3 + 0.3283 \times B_4 + 0.3407 \times B_5 - 0.7117 \times B_6 - 0.4559 \times B_7 \tag{2}$$

In formula (2), B_2, B_3, B_4, B_5, B_6 and B_7 are respectively blue band, green band, red band, near infrared band, short-wave infrared 1 and short-wave infrared 2.

(3) Dryness index. The dryness Index is represented by the average value of Soil Index (SI) and urban building Index (IBI) [29,30].

$$NDBSI = (SI + IBI)/2 \tag{3}$$

$$SI = [(B_6 + B_4) - (B_2 + B_5)]/[(B_6 + B_4) + (B_2 + B_5)) \tag{4}$$

$$IBI = [2B_6/(B_6 + B_5) - B_5/(B_5 + B_4) - B_3/(B_3 + B_6)]/[2B_6/(B_6 + B_5) + B_5/(B_5 + B_4) + B_3/(B_3 + B_6)] \tag{5}$$

In formula (4), B_2, B_4, B_5 and B_6 are respectively blue band, red band, near infrared band and short wave infrared. In formula (5), B_3, B_4, B_5 and B_6 are respectively green band, red band, near infrared band and short wave infrared.

(4) Heat index. According to the inverse function of Planck's formula, the heat index can be obtained by calculating vegetation coverage and radiative scaling [3], as shown in Equation 6:

$$LST = k_1/\ln(k_2/B_T + 1) - 273 \tag{6}$$

In the formula, B_T is the blackbody radiation brightness temperature, for OLI image, k_1 is 1321.08, k_2 is 774.89.

(5) Remote sensing ecological index. After calculating each indicator according to formula (1)-(6), resampling of each indicator is processed to 30m. In order to eliminate the influence of indicator direction, it is necessary to normalize the indicator.

$$NI_i = (I_i - I_{min})/(I_{max} - I_{min}) \tag{7}$$

In formula (7), NI_i is the index value after normalization, I_i is the value of this index at pixel i, I_{min} is the minimum value of this index, and I_{max} is the maximum value of this index.

In this study, the RSEI model proposed by Xu Hanqiu [4] was adopted to calculate the RSEI index.

$$RSEI_0 = 1 - \{PCI[f(NDVI, WET, NDBSI, LST)]\} \tag{8}$$

$$RSEI = (RSEI_0 - RSEI_{0min})/(RSEI_{0max} - RSEI_{0min}) \tag{9}$$

In formula (8) and (9), $RSEI_0$ is the initial RSEI value synthesized by the main component, and RSEI is the RSEI index after normalization treatment, ranging from 0 to 1. The higher RSEI index is, the better the ecological environment quality is. $RSEI_{0min}$ is the minimum value of $RSEI_0$, and $RSEI_{0max}$ is the maximum value of $RSEI_0$.

2.2.3. Pearson Correlation Coefficient

Pearson correlation coefficient is used to describe the degree of correlation between two variables. In this study, Pearson correlation coefficient was used to explore the correlation degree between four indicators (NDVI, WET, NDBSI and LST) and RSEI. The calculation method was referred to the explanation of Pearson correlation coefficient by Xu Jianhua [31].

$$r_{xy} = [\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})]/\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{10}$$

In equation (10), r_{xy} is the correlation index among the factors.

2.2.4. Land Use Change Analysis

(1) Land use transfer matrix

Land use transfer matrix is used to analyze the process of land use transfer [32]. In this study, the superposition analysis module of ArcGIS software was used to calculate the land use transfer matrix of Longnan City [33,34].

$$B = \begin{bmatrix} B_{11} B_{12} & \cdots & B_{1n} \\ B_{21} B_{22} & \cdots & B_{2n} \\ \vdots & \vdots & \vdots \\ B_{n1} B_{n2} & \cdots & B_{nn} \end{bmatrix} \tag{11}$$

In formula (11), B_{ij} is the area of land use type i transformed into land use type j; n is the number of land use types.

(2) Land use transfer flow

Land use transfer flow [37] is a vector attribute used to represent land use change, divided into "inflow flow" and "outflow flow", and the difference between inflow flow and outflow flow is the net

value of land transfer flow. When the net value is greater than 0, it means net inflow, and vice versa. The calculation is as follows:

$$L_f = L_{in} + L_{out} \tag{11}$$
$$L_{nf} = L_{in} - L_{out} \tag{12}$$

In formula (11) and (12), L_f is the land use transfer flow, L_{out} is the transfer flow, L_{in} is the transfer flow, and L_{nf} is the net value of land transfer flow.

(3) Single land use dynamic attitude

By calculating the dynamic attitude of single land use, it can reflect the change of the quantity of certain land use type in a certain time in the study area. See the following formula:

$$K = \frac{L_{nf}}{U_{ai}} \times \frac{1}{T} \times 100\% \tag{13}$$

In equation (13), K is the dynamic attitude of single land use, U_{ai} is the land use area of a certain type in year A, and T is the time period of land use change. In this study, T value is 5.

2.2.5. Spatial Autocorrelation Analysis

(1) Global spatial autocorrelation

The global Moran's I is used to reflect the similarity of the attribute values of the unit in the space region [31]. -1 < Moran's I < 1, when Moran's I is less than 0, indicating a negative correlation; A value equal to 0 indicates no correlation; A positive correlation greater than 0.

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{n \sum_{i=1}^n \sum_{j=1}^n w_{ij}(x_i - \bar{x})^2} \tag{15}$$

(2) Local spatial autocorrelation

The local Moran's I describes the degree of correlation between local spatial units in a region. As follows:

$$I_i = \frac{n(x_i - \bar{x}) \sum_j w_{ij}(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \tag{16}$$

In equations (15) and (16), w_{ij} is the space weight, n is the total number of space units, x_i and x_j are the observed values of region i and region j, and $\bar{x}$ is the average value of attributes of all space units.

2.2.5. Geographic Detector

Geodetector is a statistical method to explore spatial differentiation and explain the driving factors behind it [38]. In this study, factor detector and interactive detector were used to explore the relationship between the evolution trend of ecological environment quality and land use transfer in Longnan City. The value of q indicates the extent to which attribute X_i explains the spatial differentiation of attribute Y [39]. The larger the value of q, the more obvious the spatial differentiation of Y. Its calculation is shown in the following formula:

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N_{\sigma^2}} = 1 - \frac{SSW}{SST} \tag{17}$$

In formula (17), $q \in [0,1]$; SSW and SST are the sum of intra-layer variance and the total variance of the whole region, respectively. $h=1,\cdots$ L is the number of layers of influence factor X in the study area; N_h is the number of units in layer h, and N is the number of units in the whole area. σ_h^2 is the variance of Y in layer h, and σ^2 is the variance of Y in the study area.

3. Results

3.1. Temporal and Spatial Changes of Ecological Environment Quality

3.1.1. Interannual Change of Ecological Environment Quality

According to the ecological environment quality classification standard issued by the National Environmental Protection Standard (HJ192-2015), the ecological environment quality of Longnan City is divided into five levels, as shown in Table 1:

Table 1. Ecological Environment Quality Classification in Longnan City.

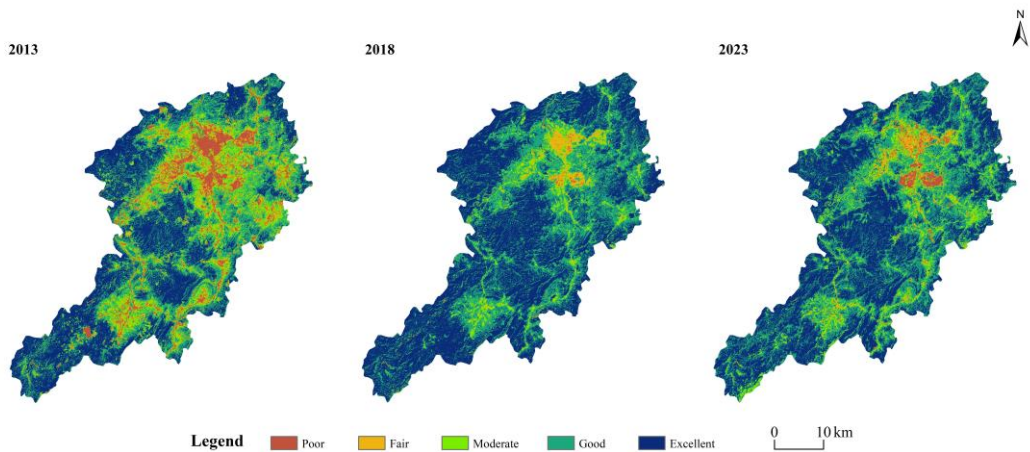| Ecological environment quality	Ecological index	Ecological environment quality grade
Poor	r<0.2	V
Fair	0.2≤r<0.35	IV
Moderate	0.35≤r<0.55	III
Good	0.55≤r<0.75	II
Excellent	r≥0.75	I

According to the classification standard, the ecological environment quality of Longnan City was classified and counted, and the results were shown in Table 2. The mean values of remote sensing ecological index of Longnan City in 2013, 2018 and 2023 were 0.789, 0.917 and 0.872, respectively, and the ecological environment quality showed a trend of "first rising and then decreasing". In general, from 2013 to 2023, the poor ecological environment area, poor ecological environment area and general ecological environment area of Longnan City showed a downward trend. The area of good ecological environment and excellent ecological environment showed an increasing trend. The peak values of the area with poor ecological environment quality and the area with excellent ecological environment quality appeared in 2013 and 2018 respectively.

Table 2. Statistics on Ecological Environment Quality Grade of Longnan City from 2013 to 2023.

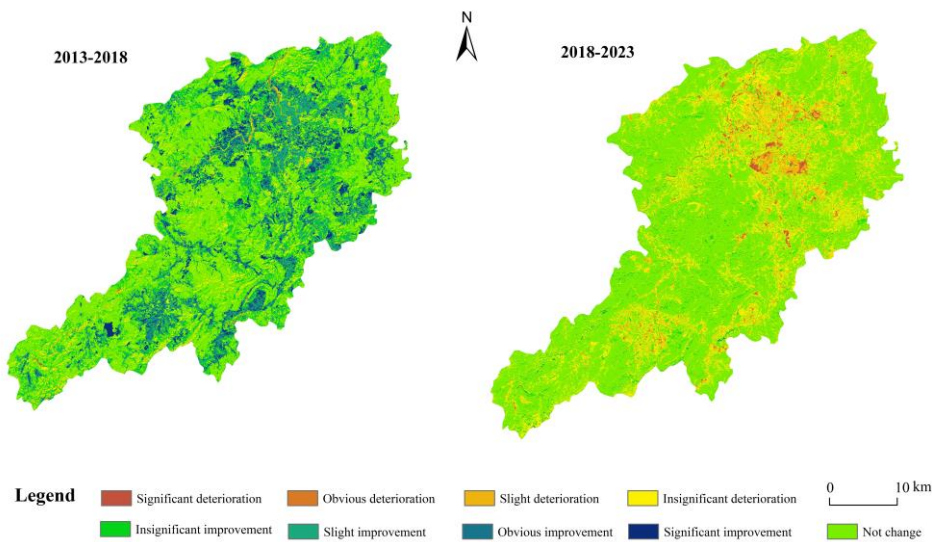| Ecological environment quality grade	2013		2018		2023	
	Area(km²)	Proportion(%)	Area(km²)	Proportion(%)	Area(km²)	Proportion(%)
V	144.181	8.759	6.815	0.414	18.48	1.123
IV	73.1	4.441	31.223	1.897	49.46	3.005
III	221.634	13.464	79.431	4.825	130.89	7.951
II	498.371	30.274	403.883	24.535	570.077	34.63
I	708.894	43.063	1124.827	68.330	877.273	53.291

3.1.2. Temporal and Spatial Evolution of Ecological Environmental Quality

The spatial distribution of ecological and environmental quality in Longnan City from 2013 to 2023 is shown in Figure 2. The ecological and environmental quality in the northern part of Longnan City is significantly lower than that in the southern part in the three periods. The area of poor ecological environment quality is concentrated in the main urban area and its surrounding area. From 2013 to 2023, the scope of this area shows the characteristics of "inward contraction". The regions with good ecological environment quality are distributed in the southwest and central regions with wide forest cover, but the ecological environment quality of the two regions increases first and then decreases due to the influence of human activities.

Figure 2. Spatial distribution of ecological environment quality in Longnan.

In order to explore the change of ecological environment quality in Longnan City, this study processed the difference between the two periods of data before and after, and obtained the spatial-temporal differentiation of ecological environment change in the two periods (from 2013 to 2018 and from 2018 to 2023), as shown in Figure 3. As can be seen from Figure 3, the change of ecological environment quality in Longnan City showed a strong spatial difference between the two periods. The change of ecological environment quality in the north was significantly greater than that in the south, and the change was mainly distributed in the main urban area of Longnan City and its surrounding areas. From 2013 to 2018, the ecological environment quality of Longnan City showed an overall trend of improvement, and there were two obvious improvement areas in the southern and northern regions respectively. From 2018 to 2023, the ecological environment quality of Longnan City remained unchanged on the whole, but the ecological environment quality of the northern main urban area showed obvious deterioration, which may be related to the expansion of the main urban area and the occupation of ecological land.

**Figure 3.** Types of spatial and temporal evolution of ecological environment quality in Longnan.

It is not difficult to see from the global Moran's I index of Longnan City (Table 3) and the local spatial autocorrelation LISA clustering diagram (Figure 4) in the two time periods calculated by spatial autocorrelation: (1) The $RSEI_i$ global Moran's I index of Longnan City in the two periods was -0.13 and 0.28, respectively, and both passed the $P < 0.05$ test. The results showed that the change pattern of ecological environment quality in Longnan City showed negative spatial correlation from

2013 to 2018, and positive spatial correlation from 2018 to 2023. The global Moran's I index increased significantly, indicating that from 2013 to 2023, the spatial agglomeration of ecological environment quality in Longnan City increased significantly. (2) From 2013 to 2018, the changes of ecological environment quality in Longnan City were mainly high-high clustering (ecological environment quality improved) and low-low clustering (ecological environment quality did not change significantly). The high-high cluster area is concentrated in and around the northern main urban area, and the low-low cluster area is distributed in most forest covered areas of Longnan City. (3) From 2018 to 2023, the changes of ecological environment quality in Longnan City are mainly high-high clustering (ecological environment quality becomes better), low-low clustering (ecological environment quality becomes worse) and not significant (no significant changes). Low-low cluster areas are concentrated in and around the main urban area, while high-high cluster areas are distributed in a few areas in the north, east and south of Longnan City. The non-obvious area is almost all over the whole area of Longnan City, and the area is mostly forest covered area.

Table 3. Global Moran's I Index of Changes in Ecological Quality in Longnan.

Period	Moran's I	Z	P
2013-2018	-0.13	-2.60	0.009
2018-2023	0.28	3.95	0.000
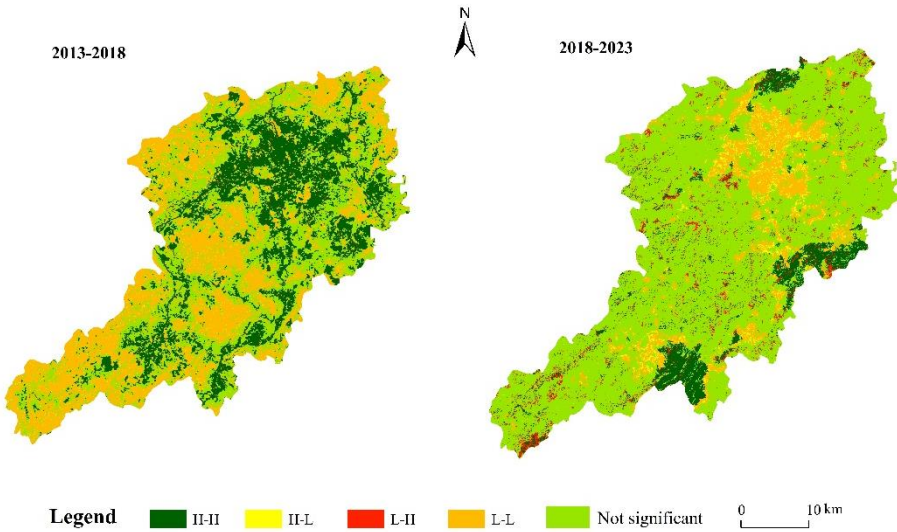
Figure 4. LISA cluster diagram of changes in ecological quality in Longnan.

3.2. Land Use Transfer Characteristics

According to the national land classification standard, the land use type of Longnan City is divided into 8 types: cultivated land, garden land, forest land, grassland, construction land, traffic land, water body and other land (mainly man-made disturbance land). The following results are obtained by calculating the land use transfer matrix (Tables 4 and 5 and Figure 5) of the two periods.

Table 4. Statistics on Land Use in Longnan Ciyt from 2013 to 2023.

Land-use type	2013		2018		2023	
	Area(km²)	Proportion(%)	Area (km²)	Proportion (%)	Area (km²)	Proportion (%)
Cultivated land	147.84	8.981	146.31	8.888	142.12	8.633
Crop land	80.14	4.868	86.36	5.246	85.77	5.210
Frostland	1308.32	79.476	1296.87	78.781	1292.29	78.502
Grassland	4.57	0.277	3.98	0.242	3.08	0.187

Built-up land	43.83	2.662	46.36	2.816	57.08	3.467
Traffic land	16.16	0.982	18.00	1.093	22.4	1.361
Water area	19.02	1.155	19.14	1.163	19.33	1.174
Other land	26.31	1.598	29.15	1.771	24.10	1.464

Table 5. Land Use Transfer Matrix in Longnan City from 2013 to 2018 (unit:km²).

2013 \ 2018		Positive land use type					Negative land use type			
		Cultivated land	Crop land	Forestland	Grassland	Water area	Traffic land	Built-up land	Other land	All
Positive land use type	Cultivated land	143.20	0.61	0.79	0.26	0.72	0.59	0.07	1.58	147.84
	Crop land	0.19	79.18	0.15	0	0.05	0.06	0	0.51	80.14
	Forestland	1.23	5.07	1291.56	0.15	1.17	2.54	0.03	6.56	1308.32
	Grassland	0	0	0.06	2.96	0.20	0.26	0	1.09	4.57
	Water area	0.32	0.00	0.35	0.31	39.27	0.06	0.05	3.46	43.83
Negative land use type	Traffic land	0.35	0.17	1.68	0	0.01	13.91	0	0.04	16.16
	Built-up land	0.15	0.09	0.02	0	0.01	0.01	18.73	0.01	19.02
	Other land	0.86	1.24	2.26	0.30	4.92	0.57	0.25	15.90	26.31
	All	146.31	86.36	1296.88	3.98	46.36	18.00	19.14	29.15	1646.18
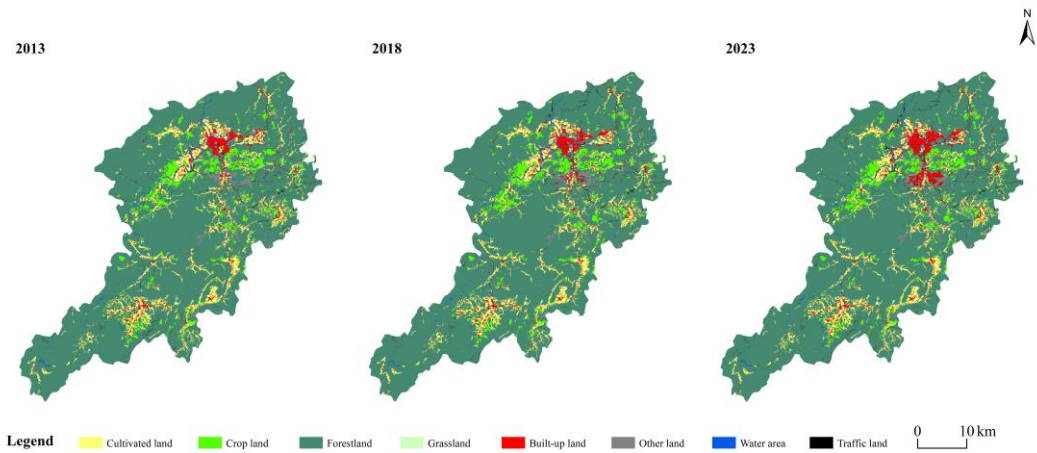
Figure 5. Spatial distribution of land use in Longnan City.

The transfer of the above 8 types of land use types in the 10 years from 2013 to 2023 is as follows:

(1) A total of 5.72km² of cultivated land was transferred in Longnan City, of which 4.64km²(mainly transferred to other land) was transferred from 2013 to 2018, and 3.11km²(mainly transferred to grassland) was transferred from 2013 to 2018; From 2018 to 2023, a total of 4.64km² is transferred out (mainly to other land), and a total of 0.45km² is transferred in (mainly to other land).

(2) A total of 5.64km² of garden land in Longnan City was transferred, of which 7.18km²(mainly transferred from forest land) and 0.96km²(mainly transferred to other land) from 2013 to 2018; From 2018 to 2023, a total of 0.6km² will be transferred (mainly from other land) and a total of 1.19km² will be transferred (mainly from other land).

(3) A total of 16.03km² of forest land was transferred out of Longnan City, of which 16.76km²(mainly transferred out of garden land and other land) and 5.32km²(mainly transferred into other land) from 2013 to 2018; From 2018 to 2023, a total of 6.7km² of forest land will be transferred (mainly to other land), and a total of 2.12km² will be transferred (mainly from cultivated land).

(4) A total of 1.49km² of grassland in Longnan City was transferred, of which 1.61km²(mainly transferred to other land) and 1.02km²(mainly transferred to building land and other land) from 2013 to 2018; From 2018 to 2023, grassland will be transferred to 1.11km²(mainly transferred to other land) and 0.21km²(mainly transferred to other land).

(5) The building land of Longnan City increased by 13.25km², of which 7.09km² was transferred from 2013 to 2018 (mainly transferred from other land) and 4.56km² was transferred from 2018 to 2023 (mainly transferred from other land). A total of 11.07km² of building land was transferred (mainly from other land), and a total of 0.35km² was transferred (mainly from other land).

(6) The transportation land of Longnan City increased by 6.24km², of which from 2013 to 2018, the transportation land was transferred to 4.09km²(mainly transferred to forest land) and 2.25km²(mainly transferred to forest land); From 2018 to 2023, a total of 4.53km² of transportation land will be transferred (mainly from forest land), and a total of 0.13km² will be transferred (to other land).

(7) The water area of Longnan City has increased by 0.21km². From 2013 to 2018, the water area has been transferred to 0.41km²(mainly transferred from other land) and 0.29km²(mainly transferred from cultivated land). From 2018 to 2023, the water area has been transferred to 0.22km²(mainly transferred from cultivated land). A total of 0.03km² is transferred out (transferred out to other land).

(8) Other land use in Longnan City decreased by 2.21km², of which 10.41km² was transferred from 2013 to 2018 (mainly transferred from construction land) to 13.25km²(mainly transferred from forest land). From 2018 to 2023, A total of 11.99km² of other land is transferred out (mainly for building land), and a total of 6.94km² is transferred into (mainly from forest land).

Table 6. Land Use Transfer Matrix in Longnan City from 2018 to 2023 (unit:km²).

| 2023 / 2018		Positive land use type					Negative land use type			
		Cultivated land	Crop land	Forestland	Grassland	Water area	Traffic land	Built-up land	Other land	All
Positive land use type	Cultivated land	141.67	0.17	1.09	0	0.65	1.00	0	1.73	146.31
	Crop land	0	85.17	0.03	0	0.05	0.32	0	0.79	86.36
	Forestland	0.03	0	1290.17	0.02	0.64	2.72	0	3.30	1296.87
	Grassland	0	0	0	2.87	0	0.02	0.45	0.65	3.98
	Water area	0	0	0	0	19.11	0.00	0	0.03	19.14
Negative land use type	Traffic land	0	0	0	0	0	17.87	0	0.13	18.00
	Built-up land	0.03	0	0.01	0	0.01	0.01	46.01	0.31	46.36
	Other land	0.40	0.43	0.99	0.20	0.00	0.47	9.50	17.16	29.15
	All	142.12	85.77	1292.29	3.08	20.46	22.40	55.96	24.10	1646.18

3.3. Temporal and Spatial Response of Ecological Environment Quality Evolution to Land Use Transfer

3.3.1. Correlation between Ecological Environment Quality Evolution and Land Use Type

In order to explore the correlation degree between ecological environment quality and land use in Longnan City, this study conducted a field investigation of Longnan City, and selected 114 points containing eight typical land classes (Figure 6) to calculate their ecological index. The results are shown in Table 7.

Table 7. Ecological Environment Quality Grade of Field Study Sites.

Land-use type	Cultivated land	Crop land	Forest land	Grass land	Built-up land	Traffic land	Water area	Other land
RSEI	0.6	0.725	0.724	0.6	0.4	0.25	0.567	0.235
Ecological environment quality grade	Good	Good	Good	Good	moderate	Fair	Good	Fair
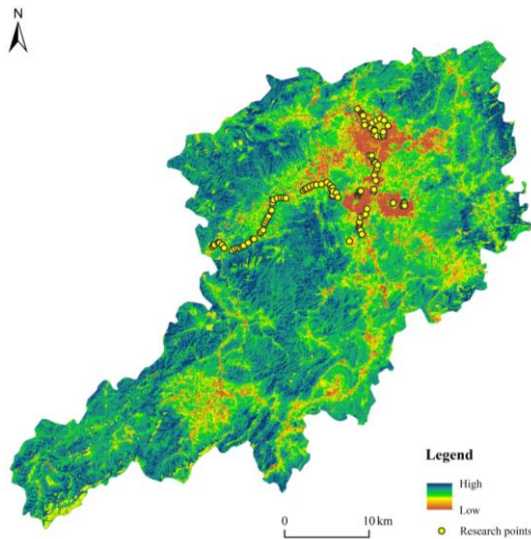
Figure 6. The route of field trip.

In order to explore the spatiotemporal response mode of ecological environment evolution to land use transfer in Longnan City, based on Table 7, the study divided five land types (forest land, garden land, water area and cultivated land) with good ecological environment quality into positive factors, and three land types (construction land, transportation land and other land) with average and poor ecological environment quality into negative factors. According to whether the land use type is a positive factor or a negative factor before and after the change, land use transfer is divided into four transfer modes: "positive" (from positive factor to positive factor), "positive" (from positive factor to negative factor), "negative" (from negative factor to negative factor), and "negative" (from negative factor to positive factor). On this basis, the temporal and spatial response model of ecological environment quality to land use transfer in Longnan City was explored. Among the four indexes of NDVI, WET, NDBSI and LST, NDVI and WET have a positive impact on ecological environment quality, while NDBSI and LST have a negative impact on ecological environment quality [4].

Based on this, on the basis of land use transfer mode, this study determined the correlation coefficient between RSEI and NDVI, WET, NDBSI and LST by creating fishing nets (extracting 6586 sets of data points in the study area), and explored the response mode of ecological environment quality to different land use transfer modes. The measurement results are shown in Table 8.

Table 8. Correlation Between RSEI and The Four Factors under Different Land Use Transfer Patterns.

Factors / Land-use transition type	NDVI	WET	NDBSI	LST
positive-positive	0.523	0.408	-0.268	-0.241
positive-negative	0.767	0.337	-0.479	-0.528
negative-positive	0.741	0.521	-0.121	-0.472
negative-negative	0.561	0.5	-0.523	-0.511

On the whole, NDVI, WET and RSEI were positively correlated, while NDBSI and LST were negatively correlated. The correlation coefficient changes with the change of land transfer type, which is manifested in: (1) The correlation coefficients of positive indicators NDVI, WET and RSEI increased with the difference of land use transfer mode. In other words, the correlation coefficient is small when the land use transfer mode is "homotropic", while the correlation coefficient is large when the land use transfer mode is "heterotropic". The results showed that the land types representing the positive indicators (forest land, garden land, cultivated land, grassland and water area) had a positive impact

on the ecological environment quality. (2) The correlation coefficients of negative indicators NDBSI, LST and RSEI change with the change of land use transfer results, that is, when the land use transfer results are positive, the correlation coefficient is small, and when the land use transfer results are negative, the correlation coefficient is large. It shows that the land types (construction land, transportation land and other land) representing negative indicators have negative effects on ecological environment quality.

3.3.2. Temporal and Spatial Response Model of Ecological Environment Quality Evolution to Land use Transfer

In this study, the changes of ecological environment quality under different land use transfer modes were divided into two periods, and the changes of ecological environment quality were classified according to national standards, as shown in Table 9. On this basis, the response of ecological environment quality to the four land use transfer modes was further explored, and the statistical results were shown in Figure 7 and Table 10.

Table 9. Grading degree of Ecological Environment Quality Change.

| Change degree	No significant change	Slight change	Obvious change	Significant change
Changing value	$\|\Delta EI\|<1$	$1\leq\|\Delta EI\|<3$	$3\leq\|\Delta EI\|<8$	$\|\Delta EI\|\geq8$
Description	No significant change in ecological environment quality	Slightly better or worse in ecological environment quality	Obviously better or worse in ecological environment quality	Significantly better or worse in ecological environment quality
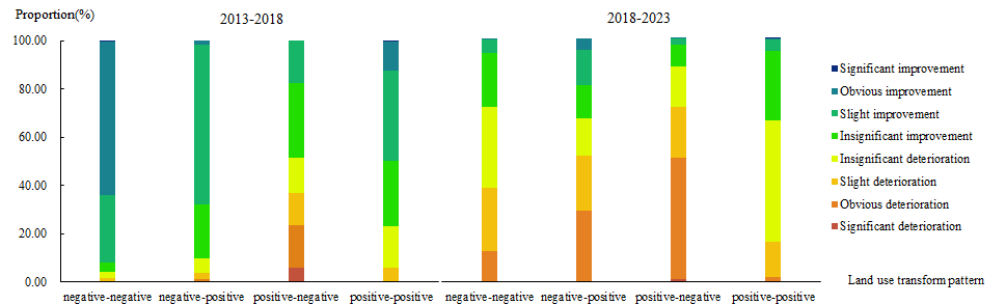
Figure 7. Statistics on changes in the quality of the ecological environment.

Table 10. Statistics on Changes in Ecological Quality Qnder Different Land Use Transfer Patterns.

Land-use transfer pattern	negative-negative		negative-positive		positive-negative		positive-positive	
Proportion(%)	2013-2018	2018-2023	2013-2018	2018-2023	2013-2018	2018-2023	2013-2018	2018-2023
Change trend								
Significant deterioration	0.002	0.517	0.061	0.028	6.079	1.024	0.024	0.043
Obvious deterioration	0.331	12.073	1.029	29.097	17.444	50.101	0.415	1.821
Slight deterioration	1.435	26.202	2.892	22.714	13.284	20.746	5.535	14.809

Insignificant deterioration	2.257	33.268	5.696	15.303	14.588	16.612	17.100	49.690
Insignificant improvement	3.908	22.001	22.449	13.554	30.921	8.791	27.129	28.514
Slight improvement	27.905	5.636	66.091	14.799	17.652	2.509	37.442	4.790
Obvious improvement	63.962	0.304	1.782	4.505	0.033	0.219	11.883	0.318
Significant improvement	0.202	0.000	0.000	0.000	0.000	0.000	0.472	0.015

From 2013 to 2018: (1) The response of ecological environment quality change to the "negative-negative" land use transfer pattern is as follows: The area of obvious improvement of ecological environment quality is relatively large, followed by the slightly improved area, there are a small number of areas with no obvious deterioration, no obvious improvement and slight deterioration, there are very few areas with obvious deterioration and significant improvement, and almost no significant deterioration. (2) The response of the change of ecological environment quality to the "negation-positive" land use transfer mode is as follows: the area of slightly improved ecological environment quality is relatively large, followed by the area of not obviously improved, with a few areas of obvious improvement, not obviously worse, slightly worse and obviously worse, with a few areas of significant deterioration and no significant improvement. (3) The response of the change of ecological environment quality to the "position-negative" land use transfer mode is as follows: the area of the ecological environment quality is not significantly improved, and the area of the ecological environment quality is slightly improved, not significantly deteriorated, slightly deteriorated and significantly deteriorated is equal in proportion. There are a few areas of significant deterioration, a few areas of significant improvement, and no areas of significant improvement. (4) The response of the change of ecological environment quality to the "positive-positive" land use transfer mode is as follows: The area of the ecological environment quality is significantly improved, followed by the area of not significantly improved, and then the area of obviously improved and not significantly deteriorated. There are a few areas of slight deterioration, a few areas of significantly improved and significantly deteriorated, and almost no significant deterioration.

From 2018 to 2023: (1) The response of the change of ecological environment quality to the "negative-negative" land use transfer pattern is as follows: The proportion of areas with slightly worse, not obviously worse and slightly better ecological environment quality is the same, followed by the obvious worse area, there are a few slightly better areas, there are a few significant worse and significantly better areas, and there are no significant better areas. (2) The response of the change of ecological environment quality to the "negative-positive" land use transfer mode is as follows: The area of obvious deterioration of ecological environment quality is relatively large, followed by the slightly deterioration area, the area of no obvious deterioration, no obvious improvement and slightly improvement is the same, there are a few obvious improvement areas, almost no significant deterioration area, no significant improvement area. (3) The response of the change of ecological environment quality to the "position-negative" land use transfer mode is as follows: the area with obvious deterioration of ecological environment quality accounts for a large proportion, the area with no obvious deterioration and the area with slight deterioration accounts for the same proportion, there are a few areas with slight improvement and significant deterioration, a few areas with obvious improvement and no significant improvement. (4) The response of the change of ecological environment quality to the "positive-positive" land use transfer mode is as follows: The area of the ecological environment quality is not significantly worse, followed by the area of not significantly better, and the area of slightly worse again, there are a small number of significantly worse and slightly better areas, there are very few significantly better areas, and almost no significantly better and significantly worse areas.

3.4. Analysis of Temporal and Spatial Evolution Factors of Ecological Environment Quality in Longnan City

The geographic detector was used to analyze the driving factors for the spatial heterogeneity of the evolution of ecological environment quality in Longnan City. The inter-annual changes of NDVI, WET, NDBSI, LST and LUCC (reflected by a single dynamic attitude of land use) were taken as X_1, X_2, X_3, X_4 and X_5, and the inter-annual changes of RSEI were taken as Y for detection. As shown in Table 11 and Figure 8.

(a) 2013-2018   (b) 2018-2023
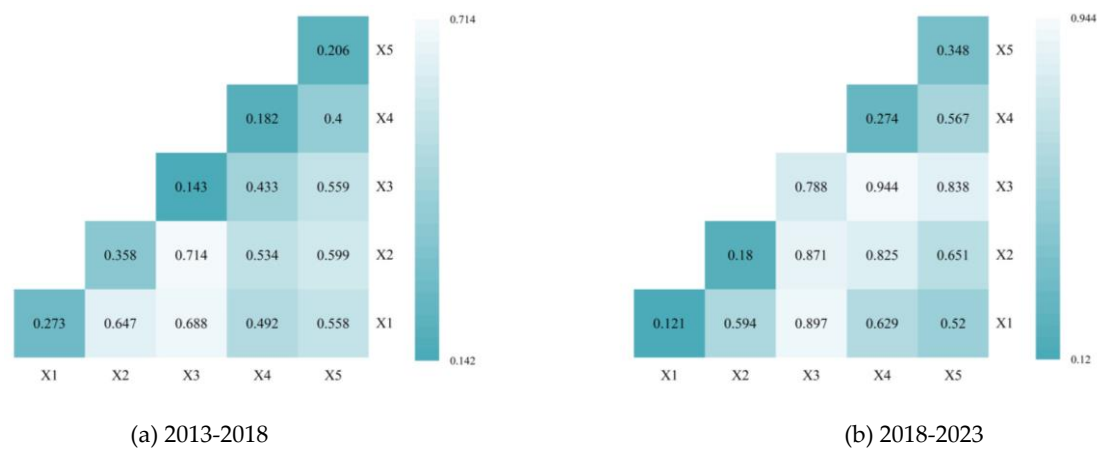
Figure 8. Driving factors for the ecological environment quality in Longnan for each phase using the interaction detector.

Table 11. Results of Ecological Environment Euality Evolution Factor Detrction in Longnan City.

Driving factors	Period	
	2013-2018	2018-2023
X_1	0.27*	0.12*
X_2	0.36**	0.18*
X_3	0.14*	0.79**
X_4	0.18*	0.27*
X_5	0.21*	0.35**

* means $P < 0.05$, ** means $P < 0.01$.

The results of interaction detection are both double factor enhancement or nonlinear enhancement, indicating that the impact of interaction between factors on ecological environment quality in Longnan City is stronger than that of single factor. From 2013 to 2018, the combination of X_4, X_2 and X_5 was the main factor affecting the change of ecological environment quality in Longnan City during this period. From 2018 to 2023, the four combinations of X_3 and X_1, X_2, X_4 and X_5 and the combination of X_4 and X_5 are the main factors affecting the change of ecological environment quality in Longnan City during this period.

4. Discussion

In this study, spring images were selected to calculate the RSEI index of Longnan City to reflect the ecological environment quality of Longnan City. (1) Due to the influence of seasons, some cultivated land is in a state of "barren species", which will lead to a low RSEI index of this land type. In this study, cultivated land is classified into land types that are beneficial to ecological environment quality, which may have little interference with the measurement results. (2) In this study, only some data points were selected for the detection of Pearson correlation coefficient, which may lead to differences between the calculated results and the actual results. (3) Due to equipment limitations, most of the land classes investigated in this study were distributed along roads and did not enter the land class center for sampling. The calculated RSEI index may be affected by the road RSEI index,

and the solution to such problems will be improved in the future research. (4) The size of the fishing net sampled in the study area is 500×500, and only 6586 sets of data are extracted. The sampling points are not comprehensive enough, which may cause errors in the detection results.
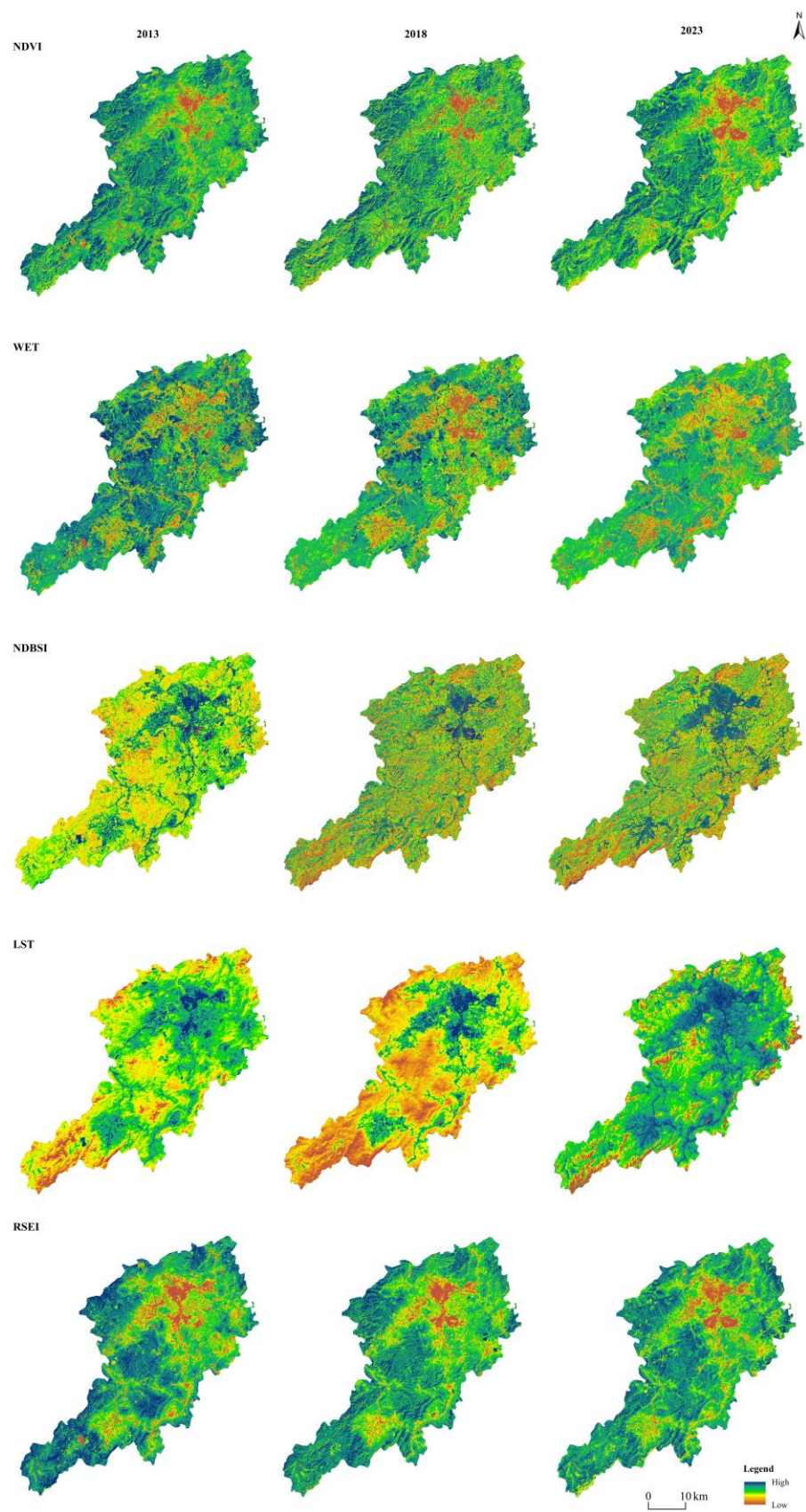
Figure 8. RSEI and its main indicators.

5. Conclusions

1. The RSEI index retrieved from remote sensing images can comprehensively reflect the ecological environment quality of Longnan City. The ecological environment index of Longnan City in 2013 was 0.789. In 2018, the ecological environment index was 0.917; The ecological environment index in 2023 is 0.872, and the results of the three phases all show that the ecological environment quality of Longnan City is higher.

2. From 2013 to 2018, the transfer of forest land (16.67km²) and the transfer of other land (13.25km²) dominated Longnan City; From 2018 to 2023, Yongnam City will mainly transfer other land (11.99km²) and transfer construction land (11.07km²). Over the past 10 years, Yongnam has been dominated by the transfer of forest land (16.03km²) and construction land (13.25km²). Combined with Figure 2, it can be clearly observed that the ecological environment quality in the main urban area gradually deteriorates and shows an "inward contraction" trend.

3. By measuring the correlation coefficient between ecological environment quality and land use transition mode in Longnan City, it is indicated that the proposed method is more accurate to characterize the land types that positively and negatively affect ecological environment quality; Combined with the results of field investigation, it is proved once again that the two types of land types have different effects on ecological environment.

4. The temporal and spatial responses of ecological environment quality to different land use transition modes are highly correlated with the changes of overall ecological environment quality. The results showed that from 2013 to 2018, under different land use transfer modes, the area of ecological environment quality improvement was always larger than that of ecological environment quality deterioration. From 2018 to 2023, under different land use transfer modes, the area of ecological environment quality deterioration is always larger than the area of ecological environment quality improvement.

5. Through the exploration of the driving factors of the temporal and spatial evolution of ecological environment quality in Longnan City, it is not difficult to find that LUCC always exerts a heavy influence on the ecological environment quality of Longnan City in two periods. Specifically, from 2013 to 2018, the interaction between LUCC and LST had a greater impact on the change of ecological environment quality than the interaction between other factors. From 2018 to 2023, the impact of LUCC interaction with NDBSI and LST on the change of ecological environment quality during this period is also stronger than the interaction between other factors.

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