Spatiotemporal Characteristics and Trend Analysis of Remote Sensing Ecological Quality in Liaoning Province

Abstract: Liaoning Province's economy is highly dependent on heavy industry, thus facing severe challenges between industrial development and ecological balance. Evaluating ecological changes is crucial for formulating effective protection policies. Based on the GEE platform, the Remote Sensing Ecological Index (RSEI) was calculated from 2000 to 2023. The ecological changes were assessed using Theil-Sen and Mann-Kendall analysis, trend stability was evaluated using the coefficient of variation, and the mutation years were identified using Pettitt and Mann-Kendall tests to reveal spatiotemporal distribution patterns. Partial correlation analysis was used to identify significant influencing factors, and the Hurst index was employed to predict future trends in ecological quality. The study shows that:①The overall ecological environment quality in Liaoning Province is on the rise, with an average annual RSEI of 0.53, fluctuating between 0.48 and 0.58, peaking in 2017, and 2009 being a significant mutation year.② The spatial difference in the average ecological environment quality over the years in Liaoning Province is significant, with a polarization phenomenon, deteriorating gradually from southeast to northwest. ③ Vegetation coverage and cumulative precipitation are important factors affecting remote sensing ecological quality.④ It is expected that about 63.98% of Liaoning Province's area will face the risk of ecological degradation in the future. The results provide important data support for Liaoning Province to achieve sustainable development and ecological civilization construction.

Keywords: GEE;RSEI, Spatiotemporal Analysis, Trend Analysis, Liaoning Province.

The ecological environment constitutes the comprehensive system of all living organisms and their habitats on Earth. It is not only the foundation for human survival and development but also a critical element in maintaining the ecological balance of the planet. As we humans do more, the environment's importance really stands out. Sustainable development of the ecological environment can only be achieved through scientific management and rational utilization.

Several methods exist for monitoring ecological environment quality, such as AHP [1], Ecological Footprint [2], Ecological Risk Assessment [3], and the Integrated Ecological Index [4]. In 2013, Xu Hanqiu [5] introduced the Remote Sensing Ecological Index (RSEI), using remote sensing to measure regional ecological quality. The RSEI index is an evaluation metric entirely based on natural factors, featuring no human-set weights, simple indicator acquisition, and visualized results. Due to the absence of human interference, it ensures the objectivity and rationality of the evaluation results[4,5]. It has been widely applied in evaluating the ecological environment quality of the Yellow River Basin[6], urban areas[7], islands[8], and other regions. For long-term RSEI analysis, Google Earth Engine (GEE) solves data acquisition problems with its powerful computing, enabling fast remote sensing data

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processing[9]. That's why it's widely used in ecological environment quality studies.

Liaoning Province is located in the northeastern part of China, bordered by the Yellow Sea to the east, the Bohai Sea to the south, Jilin Province to the west, and Inner Mongolia Autonomous Region to the north. It covers a total area of approximately 148,000 square kilometers and has a population exceeding 43 million. The province's economic structure is centered on heavy industry, particularly in the sectors of steel, chemicals, machinery manufacturing, and electronics. However, in terms of environmental protection, Liaoning Province is facing severe challenges, especially in balancing industrial development with ecological equilibrium. Consequently, a precise grasp of Liaoning Province's ecological environment's spatiotemporal dynamics and projected future is crucial, holding significant research and strategic value for its conservation and development.

1 Materials and Methods

1.1 Data Sources and Processing

Based on the GEE remote sensing data cloud platform, MOD13A1-Vegetation Index, MOD11A2-LST, and MOD09A1-Surface Reflectance data from the vegetation growing season (June-September) from 2000 to 2023 were selected. The data were processed for cloud removal and water body masking to improve the accuracy of the RSEI. The Theil-Sen and Mann-Kendall trend analysis methods, CV coefficient of variation method, Pettitt and Mann-Kendall tests, partial correlation analysis, and Hurst index method were used to analyze the spatiotemporal variation characteristics and influencing factors of remote sensing ecological quality.

Based on previous studies, three influencing factors (temperature, precipitation, and vegetation coverage) were selected from natural factors to analyze the relationship with remote sensing ecological quality. The data are shown in Table 1.

Table 1 Data sources and pre-processing

Data Name	Data Source	Temporal Resolution	Spatial Resolution	Pre-processing Method
MOD13A1-NDVI	NASA （https://modis.gsfc.nasa.gov/）	16d	500m	Water body masking; Cloud removal
MOD11A2-LST	NASA （https://modis.gsfc.nasa.gov/）	8d	1000m	Water body masking; Cloud removal; Resampling to 500m
MOD09A1-SSR	NASA （https://modis.gsfc.nasa.gov/）	8d	500m	Water body masking; Cloud removal
Average Temperature	TPDC （https://data.tpdc.ac.cn）	1a	1000m	Mask extraction; Resampling to 500m
Total Precipitation	TPDC （https://data.tpdc.ac.cn）	1a	1000m	Mask extraction; Resampling to 500m

FVC	TPDC (https://data.tpdc.ac.cn)	1a	1000m	Mask extraction; Resampling to 500m

1.2 Research Methods

1.2.1Construction of the RSEI Model

(1) Greenness

$$\mathrm{NDVI} = (p_2 - p_1)/(p_2 + p_1) \tag{1}$$

(2) Humidity

$$\mathrm{WET} = 0.1147p_1 + 0.2489p_2 + 0.2408p_3 + 0.3122p_4 - 0.3122p_5 - 0.6416p_6 - 0.5087p_7 \tag{2}$$

(3) Heat

$$\mathrm{LST} = 0.02\mathrm{DN} - 273.15 \tag{3}$$

In this context, DN represents the pixel grayscale value (K), and LST represents the land surface temperature value (°C).

(4) Dryness

$$\mathrm{SI} = \frac{(\rho_6+\rho_1)-(\rho_2+\rho_3)}{(\rho_6+\rho_1)+(\rho_2+\rho_3)} \tag{4}$$

$$\mathrm{IBI} = \frac{2\rho_6/(\rho_6+\rho_2)-[\rho_2/(\rho_1+\rho_2)+\rho_4/(\rho_4+\rho_6)]}{2\rho_6/(\rho_6+\rho_2)+[\rho_2/(\rho_1+\rho_2)+\rho_4/(\rho_4+\rho_6)]} \tag{5}$$

$$\mathrm{NDBSI} = \frac{\mathrm{SI} + \mathrm{IBI}}{2} \tag{6}$$

ρ1-ρ7 represent the bands of the MOD09A1 surface reflectance product.

(5) Scores between 0 and 1 represent ecological environmental quality, with 1 being high and 0 being low.

1.2.2 Mann-Kendall and Pettitt Mutation

(1) Unaffected by outliers, a non-parametric method is the Mann-Kendall mutation test[10] . In this study, the RSEI of Liaoning Province from 2000 to 2023 was tested for mutation points in the time series to capture the t moment of notable shift in RSEI.

First, for n sample sizes (x_1,..., x_n), construct S_k:

$$S_k = \sum_{i=1}^{k} r_i = (k = 2,3,\ldots,n) \tag{7}$$

$$ri = \begin{cases} 1 & x_i > x_j \\ 0 & x_i < x_j \end{cases} (j = 1,2,\ldots,i) \tag{8}$$

x_i represents the mean RSEI value at time i, and S_k represents the cumulative value of time i being greater than time j. Assuming random independence in the time series, one has

$$\mathrm{UF_k} = \frac{S_k - E(S_k)}{\sqrt{\mathrm{var}(S_k)}} (k = 1,2,\ldots,n) \tag{9}$$

Where $\mathrm{var}(S_k)$ and $E(S_k)$ are the variance and mean of S_k, respectively. When $UF_k>0$, it shows an upward trend in the time series; when $UF_k<0$, this indicates a decreasing trend in the time series; when UB_k and UF_k intersect and are within the critical line, this time point is the beginning of the mutation.

(2)Pettitt Mutation Test

The Pettitt mutation test can effectively determine the temporal mutation situation of RSEI to test whether the mutation is significant in mathematical statistics. The rank sequence r_i is defined in three situations:

$$ri = \begin{cases} +1 & x_i > x_j \\ 0 & x_i = x_j \quad (j = 1, 2, ..., i) \\ -1 & x_i < x_j \end{cases} \tag{10}$$

r_i, the rank sequence, records the cumulative counts of values at time i relative to those at times j. Pettitt's method detects mutation points using this sequence. If the moment t0 satisfies:

$$k_{t0} = \max \; kt_0 = \max|S_k| \qquad (k = 2,3,...n) \tag{11}$$

Then the point t0 is a mutation point.

$$P = 2\exp[-6k_{to}^2\,(n^3 + n^2)] \tag{12}$$

If P⩽0.5, the mutation point is considered statistically significant.

1.2.3 Theil-Sen/Mann-Kendall Trend Analysis

The Mann-Kendall significance test can be used to perform a significance test on Sen's slope estimator [12].

$$Q_{\mathrm{RSEI}} = \mathrm{mean}\,\frac{\mathrm{RSEI}_j - \mathrm{RSEI}_i}{j-i} \tag{13}$$

Q_{RSEI} shows the trend change. We get it from the average RSEI of periods i and j with $1<i<j<n$. Q_{RSEI} values exceeding 0.0005 suggest an upward trend, a value of 0.0005 indicates stability, and values below 0.0005 indicate a downward trend.

The formula for the test statistic is

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sign}(\mathrm{RSEI}_j - \mathrm{RSEI}_i) \tag{14}$$

$$\mathrm{sign}(\mathrm{RSEI}_j - \mathrm{RSEI}_i) = \begin{cases} +1 & \mathrm{RSEI}_j - \mathrm{RSEI}_i > 0 \\ 0 & \mathrm{RSEI}_j - \mathrm{RSEI}_i > 0 \\ -1 & \mathrm{RSEI}_j - \mathrm{RSEI}_i < 0 \end{cases} \tag{15}$$

For $n \geqslant 10$, S approximates a standard normal distribution, and Z is used for trend testing. The formula is:

$$Z = \begin{cases} S-1/\sqrt{\mathrm{var}(s)} & S>0 \\ S+1/\sqrt{\mathrm{var}(s)} & S<0 \end{cases} \tag{16}$$

where var represents variance. A significance level of α=0.05 is used for the significance test. When $|Z| \geqslant 1.96$, the sequence change is significant; when $|Z|<1.96$, the sequence change is not significant.

1.2.4 Coefficient of Variation

To evaluate ecological environment quality disturbance, this study uses pixel-scale raster data and the coefficient of variation (CV). The CV quantifies the degree of change; lower values signify a stable environment, while higher values indicate instability[13]. The computational formula is provided:

$$\mathrm{CV} = \frac{1}{T_{\text{mean}}} \times \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(T_i - T_{\text{mean}})^2} \tag{18}$$

where n is the total number of time series, T_{mean} is the multi-year mean of RESI, and T_i is the RESI value at time series i.

1.2.5 Partial Correlation Analysis

This statistical method, partial correlation analysis, evaluates the linear relationship between two variables while adjusting for other variables. For four variables X、Y、Z and W, the calculation method is:

$$\gamma_{XYZW} = \frac{\gamma_{XY} - \gamma_{XZ}\gamma_{YW}}{\sqrt{(1-\gamma_{XZ}^2)(1-\gamma_{YW}^2)}} \tag{19}$$

where γ_{XYZW} is the partial correlation of X and Y, controlling for Z and W. γ_{XZ} and γ_{YW} are the correlations of X with Z and Y with W, respectively. Partial correlation coefficients range from -1 to 1, with values nearing 1 or -1 indicating strong linear relationships between two variables after controlling for others, and values near 0 indicating weak relationships.

1.2.6 Hurst Exponent

The Hurst exponent shows if the RSEI data's trend will continue. It helps predict the future pattern. Here's how to figure it out.

For the time series {Index(t)}, 1,2,3,…,n, the mean sequence Index(T) and cumulative deviation X(t,T) are defined as:

$$\mathrm{Index}(T) = \frac{1}{T}\sum_{t=1}^{T}\mathrm{Index}_{(t)} \tag{21}$$

$$X_{(t,T)} = \sum_{t=1}^{T}(\mathrm{Index}_{(t)} - \mathrm{Index}_{(T)}) \tag{22}$$

If there exists H, and the range of cumulative deviation R and the standard deviation of the time series S satisfy $R/S \propto T^H$. If 0.5<H<1, it indicates positive correlation, with values closer to 1 indicating more significant positive correlation; if 0<H<0.5, it indicates negative correlation, with values closer to 0 indicating more significant negative correlation; if H is close to 0.5, the autocorrelation of the time series is not significant. Therefore, the results of the Hurst exponent and Theil-Sen slope can be used to determine the persistence of RSEI changes.

2 Results and Analysis

2.1 Temporal and Spatial Characteristics of Ecological Environment Quality

The inter-annual variation of ecological environment quality in Liaoning Province over several years is shown in Figure 1. The RSEI exhibits a fluctuating upward trend (P > 0.05), with a range of 0.48-0.58 and an average value of 0.53. The highest RSEI was observed in 2017, while the lowest was in 2000. This indicates that under the environmental protection policies and ecological management measures, the ecological environment quality in Liaoning Province has significantly improved and is expected to continue improving in the future.

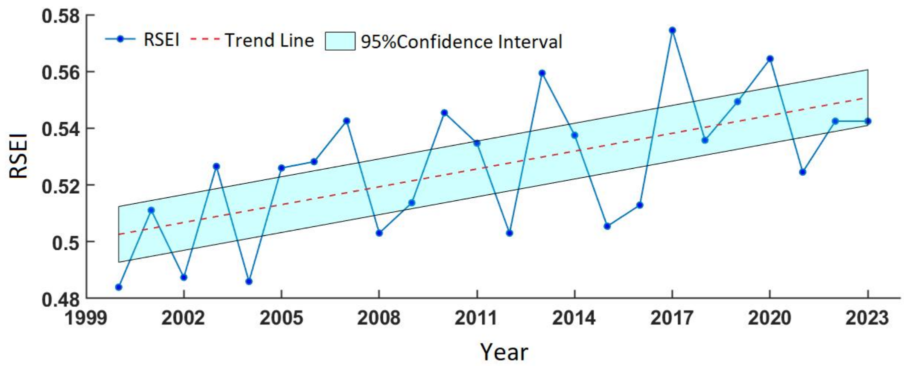


Fig.1 Inter-annual variation in ecological environment quality

The results of the M-K and Pettitt mutation tests for the ecological environment quality in Liaoning Province are illustrated in Figure 2. The M-K test shows that the UF curve continuously rises, indicating an improvement in environmental quality. The RSEI intersects in 2006 and 2008, located between the critical lines. The Pettitt mutation test shows abrupt changes in environmental quality in 2010, 2013, and 2007. Based on the comprehensive test results, the mutation point of environmental quality in Liaoning Province from 2000 to 2023 is determined to be 2009.

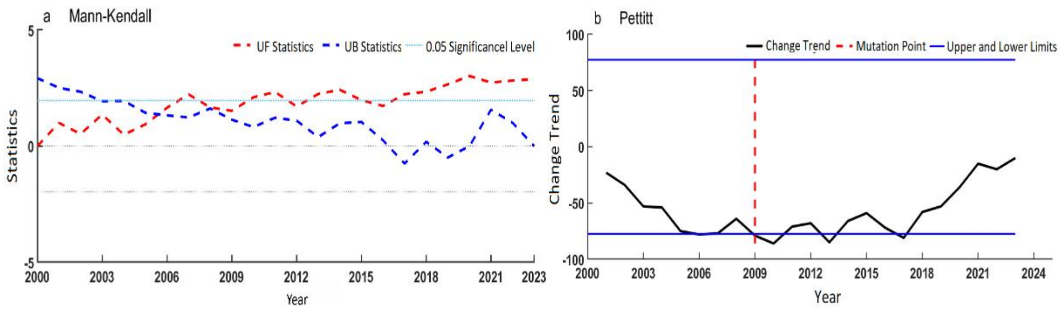


Fig.2 Mann-Kendall（a）and Pettitt mutation tests（b）for ecological environment quality

To reveal the spatial distribution characteristics of ecological environment quality in Liaoning Province, the existing ecological environment quality grading standard was referenced. The RSEI was divided into five value intervals: [0, 0.2), [0.2, 0.4), [0.4, 0.6), [0.6, 0.8), and [0.8, 1], representing five grades of ecological environment quality: "poor," "fair," "moderate," "good," and "excellent." Based on this, the spatial distribution maps of the annual ecological environment quality and the multi-year average ecological environment quality in Liaoning Province were drawn, as shown in Figure 3.

The "excellent" grade of ecological environment quality is mainly distributed in the eastern region of Liaoning Province, while the "fair" grade is concentrated in the northwest and southern regions. Overall, the ecological environment quality shows a gradual decline from east to west.

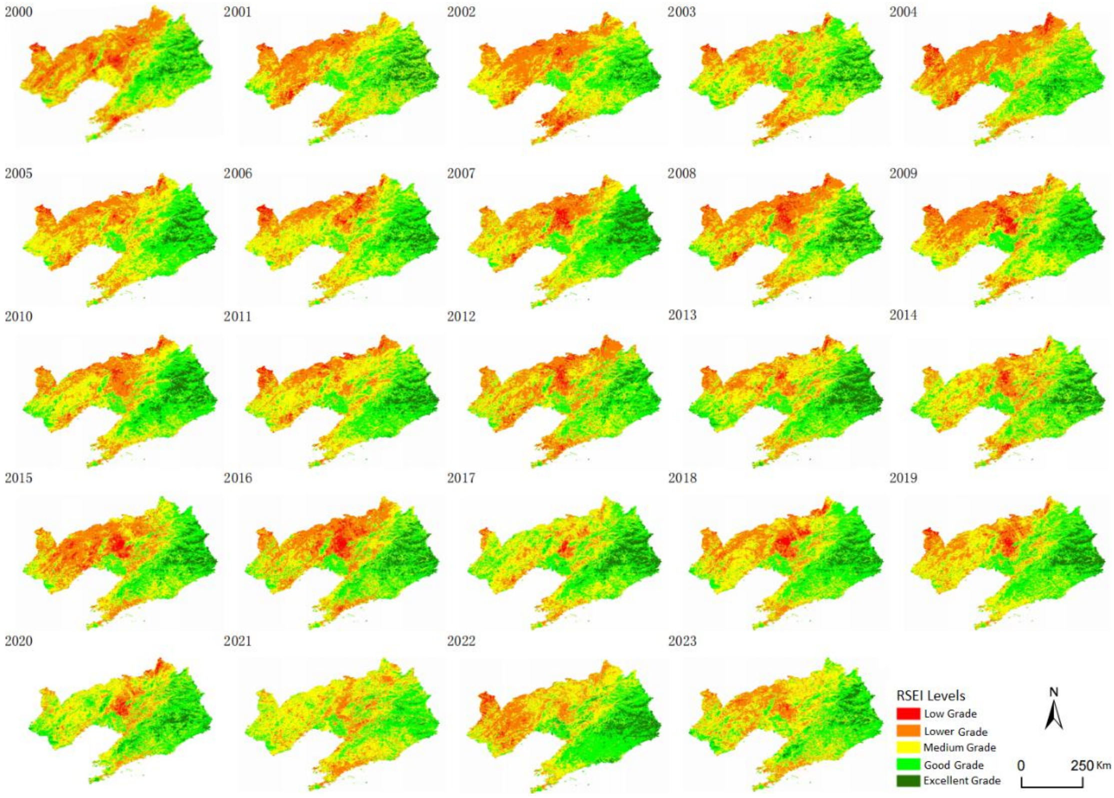


Fig.3 Year-by-year spatial distribution of ecological environment quality

The spatial distribution characteristics of the multi-year average ecological environment quality in Liaoning Province exhibit significant regional differences, showing a decreasing trend from southeast to northwest. The area rated as "excellent" grade covers 0.72 thousand km² (4.89%), mainly distributed in the eastern part of Liaoning Province. These areas have high vegetation coverage, diverse vegetation types, minimal human disturbance, and play an important role in climate stability, soil and water conservation, and ecosystem security. The "good" grade area covers 4.06 thousand km² (27.50%), mainly concentrated in the southeastern mountainous area of Liaoning Province. This region has high vegetation coverage, good water conservation function, high precipitation, and the combined effect of vegetation and climate results in better ecological environment quality. The "moderate" grade area covers 6.52 thousand km² (44.16%), mainly distributed in the central, northwest, and southern regions of Liaoning. The "fair" grade area covers 3.44 thousand km² (23.31%), mainly located in the northwest region of Liaoning Province. The "poor" grade area covers 0.02 thousand km² (0.13%), located at the edge of the sandy land in the north of Jianping. This area is widely covered by desert and gobi, with very low vegetation coverage, strong wind erosion, dry climate, and evapotranspiration far exceeding precipitation, leading to extremely harsh and fragile ecological environments.

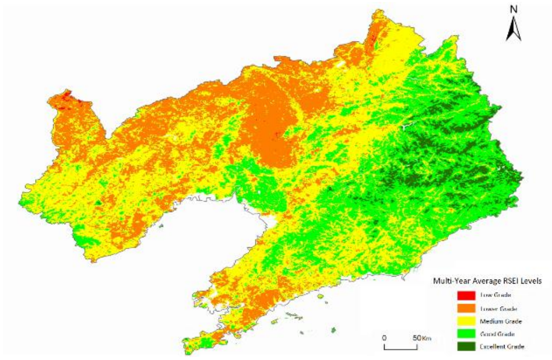


Fig.4 Spatial distribution of multi-year average ecological environment quality

2.2 Trends and Stability of Ecological Environment Quality

The spatial differences in the trends of ecological environment quality in Liaoning Province are quite significant, as shown in Fig. 5(a). Areas with an increasing trend account for 55.90% of the total area of Liaoning Province. Regions with a highly significant increase comprise 4.26%, mainly distributed in the Yingkou and Dalian areas. Conversely, 42.93% of the regions show a declining trend in ecological quality, covering an area of 63,800 km². Overall, from 2000 to 2023, the trend in ecological environment quality in Liaoning Province has been predominantly upward, with the largest proportion being areas with a non-significant increase, followed by areas with a non-significant decrease, and the smallest proportion being areas with no change.

The spatial stability was analyzed based on the coefficient of variation (CV) method, as shown in Fig. 5(b) and Table 2. The results indicate that areas with high stability account for 53.49%, mainly in the eastern part of Liaoning; areas with moderate stability account for 19.20%, distributed in the northwestern and southern parts of Liaoning; and areas with low stability account for 27.30%, primarily in the eastern part of Dalian, Fuxin, and Chaoyang.

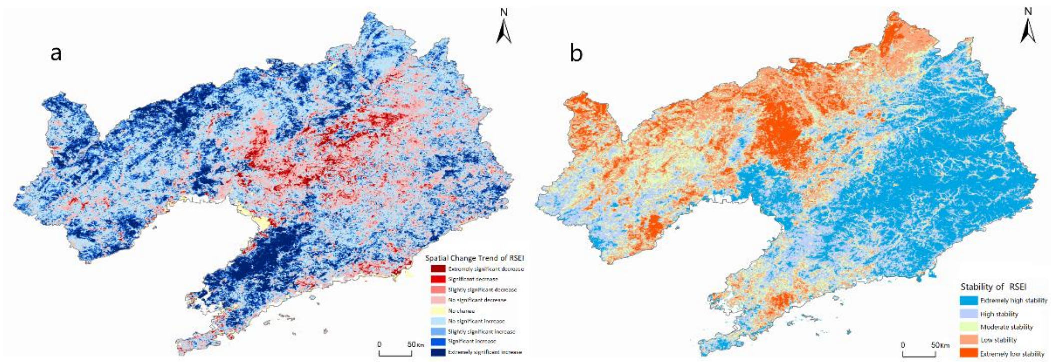


Fig5 Spatial distribution of trends and stability of changes in ecological environment quality

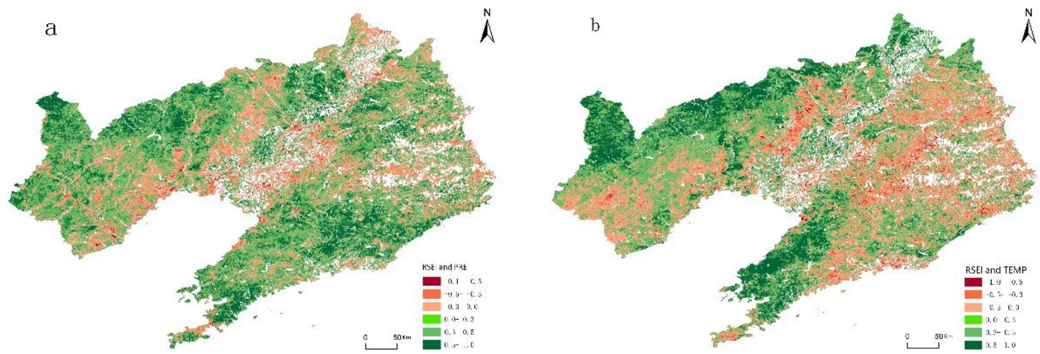
Table2 Trends and stabilization area statistics in ecological environment quality

Change Trend			Stability		
Level	Area（10,000 km²）	Proportion (%)	Level	Area（10,000 km²）	Proportion (%)
Highly significant decrease	0.59	3.97	Very high stability	4.06	27.40
Significant decrease	0.61	4.14	High stability	3.86	26.09

Significant decrease	0.53	3.56	High stability	2.84	19.20
Non-significant decrease	4.65	31.26	Low stability	2.94	19.87
No change	0.18	1.20	Low stability	1.10	7.43
Non-significant increase	6.01	40.45			
Slight significant increase	0.78	5.27			
Significant increase	0.88	5.93			
Highly significant increase	0.63	4.26			

2.3 The Impact of Precipitation, Temperature, and Vegetation Coverage on Ecological Environment Quality

The relationship between temperature, precipitation, vegetation coverage, and RSEI was analyzed based on raster data. Partial correlation analysis was performed using Matlab software. During the analysis, partial correlation coefficients were calculated to assess the relationships between variables, as shown in Figure 6. So, we looked at how precipitation, temperature, and vegetation coverage affect RSEI, and we controlled for the other factors each time. Turns out, when we focused on precipitation's effect, it had a partial correlation of 0.096, with a t-value of 0.50. Temperature's effect was lower, at 0.057 with a t-value of 0.31. Vegetation coverage, though, showed a correlation of 0.098, with a t-value of 0.56. Basically, vegetation and precipitation had a bigger impact than temperature, and they both had a positive effect. So, to keep our ecosystems healthy, we really need to pay attention to changes in precipitation and vegetation when we plan ecological management. That way, we can make sure things stay sustainable.



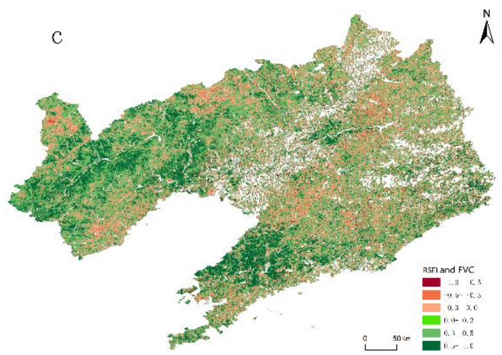


Fig6 RSEI and partial correlation coefficient with natural factors

Note: Partial correlation coefficient between RSEI and precipitation (a), partial correlation coefficient between RSEI and temperature (b), partial correlation coefficient between RSEI and vegetation coverage (c).

2.4 Future Trends in Ecological Environmental Quality

The Hurst index in Liaoning Province ranges from 0.127 to 0.824, as shown in Figure 7(a) and Table 3. The area with a Hurst index greater than 0.5 is 20,800 km², accounting for 14.17% of the total area of Liaoning Province. This indicates that these regions exhibit a general trend of continuous development in the same direction. Conversely, the area with a Hurst index less than 0.5 is 141,700 km², accounting for 85.77% of the total area, suggesting that these regions are likely to exhibit a trend of anti-persistent changes in the future. Overall, the regions with sustainable trends are scattered throughout Liaoning Province, while the spatial distribution of regions with anti-persistent trends is the opposite.

The future trends in the ecological environmental quality of Liaoning Province, as shown in Figure 7(b) and Table 3, indicate that the overall trend may be one of degradation (accounting for 63.98%). The area where ecological quality is expected to shift from improvement to degradation in the future is approximately 88,300 km² (accounting for 59.83% of the province), while the area with continuous degradation is about 6,100 km² (accounting for 4.2% of the province). The area where ecological quality is expected to shift from degradation to improvement in the future is approximately 26,400 km² (accounting for 17.87% of the province), while the area with continuous improvement is about 12,700 km² (accounting for 8.63% of the province).

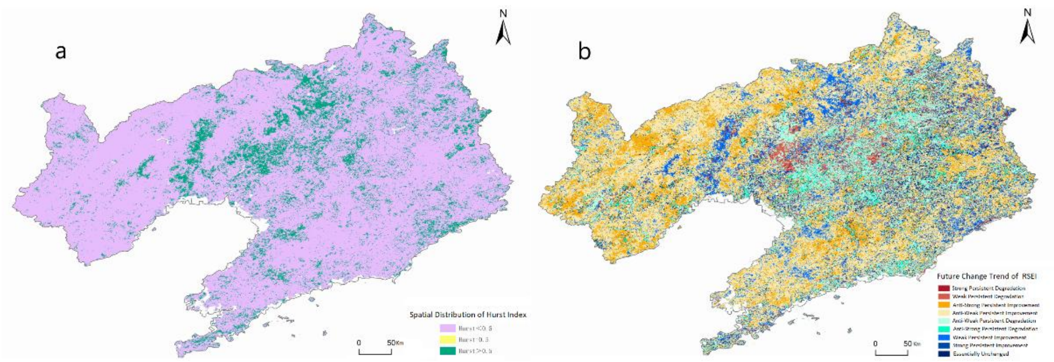


Fig7 Hurst index of RSEI and future trend in Liaoning Province

Table3 Future change trend of ecological environment quality in Liaoning Province

Development Direction	Future Trend	Area (10,000 km²)	Percentage (%)
Continuous Degradation	Strong Persistent	0.02	0.13

	Degradation		
	Weak Persistent Degradation	0.59	4.02
Past Improvement but Future Degradation	Anti-Strong Persistent Improvement	2.21	14.99
	Anti-Weak Persistent Improvement	6.62	44.84
Past Degradation but Future Improvement	Anti-Weak Persistent Degradation	2.10	14.21
	Anti-Strong Persistent Degradation	0.54	3.66
Continuous Improvement	Weak Persistent Improvement	1.25	8.47
	Strong Persistent Improvement	0.02	0.16
Essentially Unchanged	Essentially Unchanged	1.40	9.49

3 Discussion

3.1 Exploring the Dynamic Changes of Ecological Environment Quality Over Time and Space.

The overall ecological environment quality in Liaoning Province shows an upward trend. The annual average RSEI is 0.53, with a fluctuation range from 0.48 to 0.58, reaching its peak in 2017. The year 2009 marks a significant turning point, indicating the effectiveness of government environmental policies and management measures. Spatially, the ecological quality decreases gradually from east to west, with the eastern mountainous areas generally having better ecological quality, while the northwest and southern regions have relatively poorer ecological quality. This phenomenon emphasizes the need to consider regional differences in ecological management, providing important reference for future ecological management strategies.

3.2 Discussion on the Trend and Stability of Ecological Environment Quality

The ecological environment quality in Liaoning Province exhibits significant spatial differences, with more than half of the regions showing improvement, particularly in Yingkou and Dalian. However, approximately 43% of the regions show a declining trend in ecological quality, mainly concentrated in the southern part of Shenyang and the northern part of Anshan. Through the analysis of the coefficient of variation method, we found that more than half of the regions maintain stable ecological quality, especially in the eastern and southern areas. Regions with medium stability account for 19.20%, while regions with low stability account for 27.30%, mainly distributed in the eastern part of Dalian and Shenyang areas. Overall, most regions in Liaoning Province have small fluctuations in ecological quality and high stability, particularly in the eastern areas, fully demonstrating the effectiveness and sustainability of ecological management measures.

3.3 Effects of Natural Factors on Ecological Environment Quality

The partial correlation coefficients between ecological environment quality and temperature, precipitation, and vegetation coverage are 0.057, 0.096, and 0.098, respectively. The partial correlation coefficient between vegetation coverage and precipitation is higher than that of temperature, indicating that vegetation coverage and precipitation have a greater impact on ecological environment quality than temperature, and both show a positive correlation. This is important for ecological management, climate change response, and maintaining ecosystem health. Future ecological management strategies should consider changes in precipitation and vegetation coverage to advance the ecological environment's sustainable development.

3.4 Ecological Environment Quality Outlook in Liaoning Province

The Hurst index in Liaoning Province ranges from 0.127 to 0.824, with most areas (approximately 85.77%) likely to exhibit anti-persistent changes in the future, while only 14.17% of the areas show a consistent development trend. It is expected that the ecological environment quality will face degradation risks, with 63.98% of the areas likely to deteriorate. Although 8.63% of the areas, such as eastern Chaoyang County, Yixian County in Jinzhou, and Pulandian in Dalian, have improvement potential, 59.83% of the areas currently on an upward trend may turn into a downward trend. Therefore, priority should be given to implementing ecological restoration and protection measures in areas that may degrade, while encouraging areas with improvement potential to strengthen ecological protection strategies to ensure continuous improvement in environmental quality.

4 Conclusion

The study reveals that the ecological environment quality in Liaoning Province has shown a significant upward trend with fluctuations. The annual average remote sensing ecological index is 0.53, with a fluctuation range between 0.48 and 0.58. The peak of the index was reached in 2017, while 2009 was identified as a significant mutation year.

The spatial distribution of ecological environment quality exhibits notable regional differences, with the eastern regions generally having higher ecological quality than the western regions. Approximately 55.90% of the areas have seen an improvement in ecological quality, primarily concentrated in the Yingkou and Dalian areas. However, 42.93% of the areas have experienced a decline in ecological quality, particularly evident in the southern part of Shenyang and the northern part of Anshan.

Precipitation and vegetation cover are crucial factors influencing ecological environment quality, playing an important role in ecological management, climate change response, and maintaining ecosystem health.

In the future, most areas of Liaoning Province are expected to exhibit a trend of non-sustained changes, with 63.98% of the regions facing the risk of ecological degradation.

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