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Evaluation of Ecological Environment Quality in Tianjin Based on Remote Rensing Ecological Indices

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Abstract:

With the accelerating process of urbanization, ecological and environmental degradation is escalating at an alarming pace. Remote sensing ecological index can be utilized to monitor and assess regional environmental conditions efficiently and rapidly. In this research, we select Tianjin as the object of this study, and four periods of Landsat TM/OLI image data in 2009, 2014, 2019, and 2024 were selected. The images were used to generate four important ecological indicators, namely, greenness, humidity, dryness, and heat, and then combined with principal component analysis to construct the Remote Sensing Eco-Environmental Quality Index evaluation model of Tianjin. In this way, the transformation in Tianjin were analyzed. The results show that the ecological environment quality of Tianjin firstly increases, then decreases, and then increases, and the overall trend is upward. The maximum value of RSEI is 0.65, and the minimum value is 0.42. In addition, the areas with poor ecological quality are distributed in the central urban area as well as the southwestern part. The share of regions with poor ecological quality is decreasing, and the proportion of areas with excellent quality is increasing, and the overall tendency is in the direction of positive development. In future research, we will optimize the RSEI algorithm and combine the land use data and GEE platform to make the ecological environment assessment more scientific and reasonable.

Keywords: Remote sensing ecological index; ecological environment; principal component analysis; dynamic change monitoring.

1 Introduction

With the dynamic evolution of the social environment and the robust growth of the economy, urbanization has experienced a significant acceleration, thus leading to great variations in the ecological environment [1]. In the context of sustainable development, the assessment and improvement of urban ecosystem quality has become a global concern [2]. To better support the construction of urban ecosystems, it is particularly important to accurately assess the quality of urban ecosystems [3]. In monitoring, macroscopic, dynamic, and rapid access to surface information is the focus of ecological environment assessment, and traditional monitoring methods have limited the scope of the study area, and the generalization of the regional ecological environment is not clear and concise [4].

In recent years, the applied research of the Remote Sensing Ecological Index has been expanding and deepening globally, becoming an important tool in the field. Shen Ra et al. (2020) emphasized the key role of remote sensing technology in ecological monitoring, pointing out its unique advantages in data acquisition and dynamic monitoring [5].

In the international research field, Sun et al. investigated the ecological security evolution of the Loess Plateau plateau region with RSEI and found that it has significant advantages in long-time series analysis [6]. Zhang Jing et al. combined the Google Earth engine and improved RSEI to monitor the ecological quality of Xi'an City dynamically, which further verified the scientific and practicality of the method [7]. For their part, Wei-Heng Xu et al. reviewed the current status of the application of remote sensing technology in ecological environment quality monitoring, pointing out that multi-source data fusion and algorithm optimization are important directions for future research [8].

As a key node of Beijing-Tianjin-Hebei synergistic development, Tianjin has seen the growth of green industries and the rise of eco-tourism and carbon trading, etc. However, along with the acceleration of urbanization and other human activities that have seriously affected the stability of urban ecosystems, relatively few studies have been conducted on the quantitative analysis of environmental quality in Tianjin. The above research results provide important references and lessons for the accurate assessment and effective management of ecological environment quality in Tianjin, and help Tianjin make greater progress in ecological protection and sustainable development [9].

In this study, based on relevant research results, Landsat 5 and Landsat 8 images are used as data sources to monitor the ecological status of Tianjin from 2009 to 2024. This study reveals the progress patterns and the Elements exerting influence on the ecological environment in the spatial and temporal dimensions [10]. In practice, it is very practical for Tianjin in order to formulate scientific and reasonable ecological protection policies and promote sustainable urban development.

2 The sources of data and relative analytical method

2.1 Overview of the study area

Located in the northeastern part of the North China Plain, Tianjin lies downstream of the Haihe River Basin, with the Bohai Sea to its east and the Yanshan Mountains to its north.with geographic coordinates ranging from 38°34′ to 40°15′ north latitude and 116°43′ to 118°4′ east longitude (see Fig. 1).Tianjin is significantly influenced by the monsoon circulation and the sea and has 4 seasons. The Bohai Sea regulates the regional climate, making the temperature difference in the coastal area smaller than inland and the humidity relatively high, forming unique coastal climate characteristics. Owing to its advantageous geographical position, Tianjin has an important strategic position in ecological environmental protection and regional synergistic governance.

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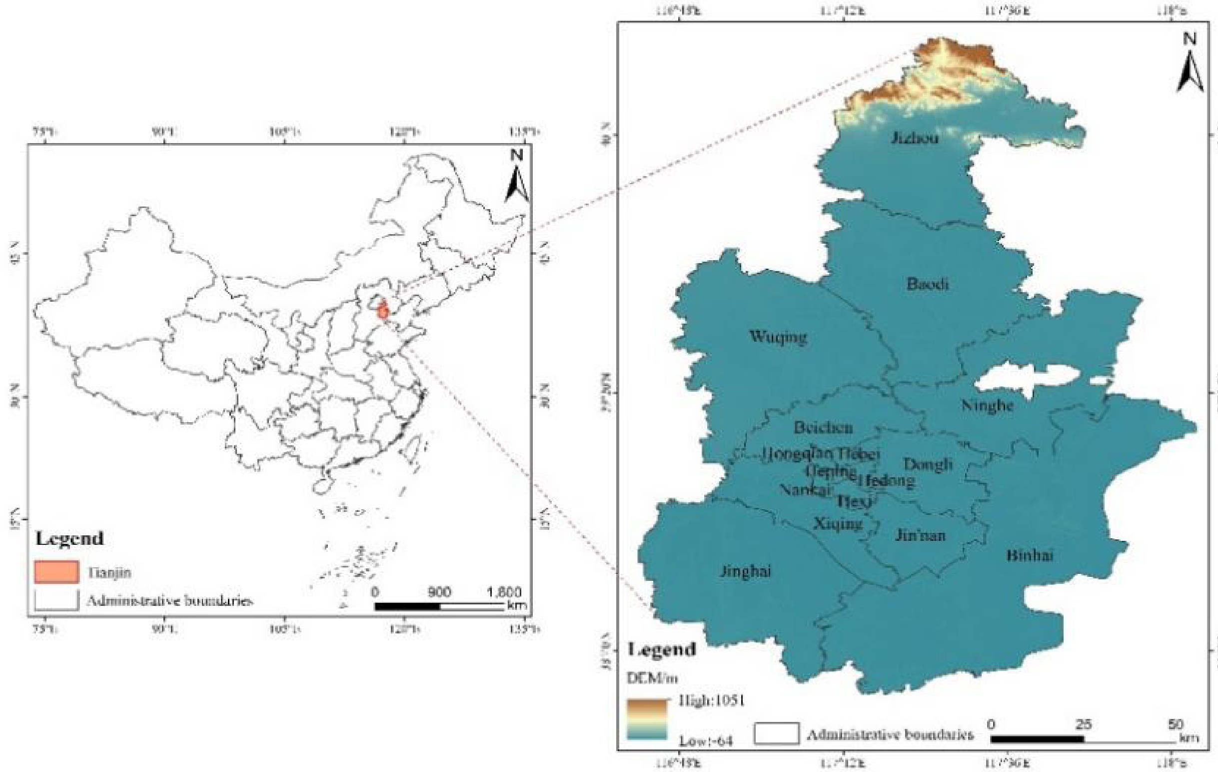

Fig. 1 Overview map of Tianjin

2.2 Data sources

In this study, Landsat5 TM and Landsat8 OLI images of Tianjin were selected as data for 4 periods of 2009, 2014, 2019, and 2025 imagery data at 5-year intervals. The selected data cloud is low, and the study area requires 3 images for complete coverage. The relative sources are listed in Table 1. The acquired image data were preprocessed with geometric correction, atmospheric correction, cropping, and stitching.

Table 1 Sources of remote sensing imagery and selected parameters for the period 2009-2024

particular year	satellite	Sensor type	spatial resolution /m
2009	Landsat5	TM	30
2014	Landsat5	TM	30
2019	Landsat8	OLI	30
2025	Landsat8	OLI	30

2.3 The methodology of research

The evaluation about ecological environment quality is realized by means of constructing the Remote Sensing Ecological Index and calculating 4 Signifiers, namely, greenness, humidity, dryness, and heat in this research. Based on the calculation of the indicators, principal component interpretation was conducted to classify the ecological grade and analyze Tianjin's environment quality,which can be observed in Fig. 2. Remote sensing ecological index construction mainly includes component index selection and principal component analysis.

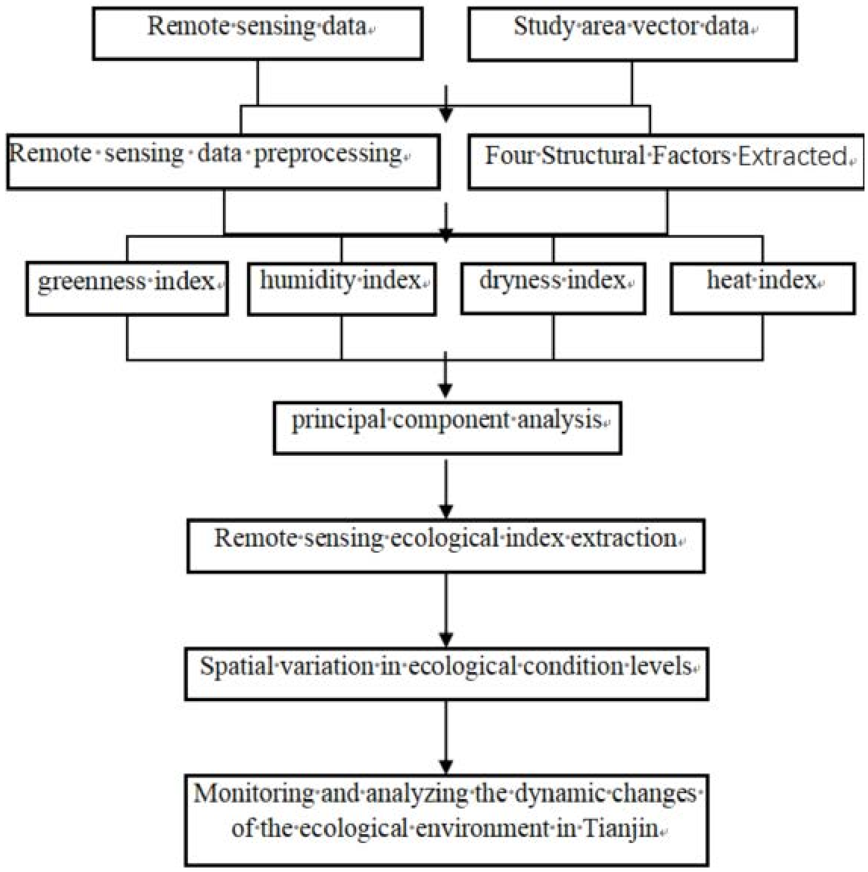

Fig. 2 Technical Processing Flow

2.2.1 Selection of Component Indicators

① Greenness index, normalized vegetation index (NDVI) can reflect the vegetation growth condition well, so the greenness index was NDVI in this study, and its relative formula is as follows:

$$\mathrm{NDVI}=(\rho_{\mathrm{nir}}-\rho_{\mathrm{r}})/(\rho_{\mathrm{nir}}+\rho_{\mathrm{r}}) \quad (1)$$

Where: ρ_{nir} stands for near-infrared reflectance; ρ_{r} stands for the infrared reflectance.

② Moisture indicator, the humidity component (WET) can reflect the humidity condition, and monitor the growth of plants and land degradation, which is conducive to the assessment of ecological environment quality, therefore, the humidity component was selected as the humidity indicator in this study, and its calculation formula is as follows:

$$\mathrm{WET_{TM}}=0.0315\rho_{\mathrm{B}}+0.2021\rho_{\mathrm{G}}+0.3102\rho_{\mathrm{R}}+0.1594\rho_{\mathrm{NIR}}-0.6806\rho_{\mathrm{SWIR_1}}-0.6109\rho_{\mathrm{SWIR2}} \quad (2)$$

$$\mathrm{WET_{OLI}}=0.1511\rho_{\mathrm{B}}+0.1973\rho_{\mathrm{G}}+0.3283\rho_{\mathrm{R}}+0.3407\rho_{\mathrm{NIR}}-0.7117\rho_{\mathrm{SWIR_1}}-0.4559\rho_{\mathrm{SWIR2}} \quad (3)$$

Where: $\rho_{\mathrm{B}},\rho_{\mathrm{G}},\rho_{\mathrm{R}},\rho_{\mathrm{NIR}},\rho_{\mathrm{SWIR_1}}和\rho_{\mathrm{SWIR_2}}$ denotes the reflectance of the blue band, green band, red band, near-infrared band, short-wave infrared 1 band, and short-wave infrared 2 band, respectively.

③ The heat index, land surface temperature (LST) can reflect the impacts related to vegetation growth, water vapor circulation, and urbanization on the ecological environment, so the heat component was calculated in this study with the following formula:

$$\mathrm{L}=gain\times\mathrm{DN}+bias \quad (4)$$

$$\mathrm{T}=\mathrm{K_2}/\mathrm{In}(\mathrm{K_1}/\mathrm{L}+1)\mathrm{T}=\mathrm{K_2}/\mathrm{In}(\mathrm{K_1}/\mathrm{L}+1) \quad (5)$$

$$\mathrm{LST}=\mathrm{T}/[(1+\lambda\mathrm{T}/\rho)\,\mathrm{In}\,\varepsilon] \quad (6)$$

L indicates the radiance value of the sensor, DN indicates the value of pixel gray, while gain and bias denote the values of gain and bias. t denotes the temperature value of the sensor; K1 and K2 denote the calibration coefficients, respectively, and LST denotes the surface temperature; λ denotes the dominant wavelength of the thermal emission-band; ρ denotes the Boltzmann constant, and ε denotes the specific emissivity of the surface.

④ Dryness index, the dryness index (NDBSI) of this

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study is selected from the bare soil index (SI) and the construction index (IBI) together, reflecting the degree of drying about the urban surface, the followings are the relations:

$$SI=\frac{\left(\rho_{SWIR_1}+\rho_R\right)-\left(\rho_{NIR}+\rho_B\right)}{\left(\rho_{SWIR_1}+\rho_R\right)+\left(\rho_{NIR}+\rho_B\right)} \tag{7}$$

$$IBI=\frac{\frac{2\rho_{SWIR_1}}{\rho_{SWIR_1}+\rho_{NIR}}-\frac{\rho_{NIR}}{\rho_{NIR}+\rho_R}-\frac{\rho_G}{\rho_G+\rho_{SWIR_1}}}{\frac{2\rho_{SWIR_1}}{\rho_{SWIR_1}+\rho_{NIR}}+\frac{\rho_{NIR}}{\rho_{NIR}+\rho_R}+\frac{\rho_G}{\rho_G+\rho_{SWIR_1}}} \tag{8}$$

$$NDBSI=\frac{SI+IBI}{2} \tag{9}$$

2.2.2 Principal Component Analysis

Principal component analysis is to compress the information of multiple variables into the first 1 or 2 principal components and assign the weights independently according to the contribution of each indicator to the principal components to avoid the bias caused by human intervention [11]. By normalizing the magnitude of the four indicators before performing principal component analysis.

$$IN=I-I_{min}/I_{max}+I_{min} \tag{10}$$

Where IN stands for the normalized value; I stands for the index value; and are the maximum and minimum values, respectively.

Using the above method to extract the annual RSEI value of Tianjin based on each index, and further investigate the temporal and spatial variation of RSEI of this district.

3 Results and analysis

3.1 Tianjin RSEI Analysis

The feature ratio of the first primary component in all four images is greater than 60.8%, indicating that PC1 contains most of information of 4 component indicators, and PC1 can be used to represent the comprehensive ecological environment status in the region.

According to Table 2, the values of heat and dryness Signifiers are pessimistic, showing that heat and dryness harm the ecological environment, but the greenness and humidity indicators are positive, suggesting that the metrics contribute to the better ecological environment. The absolute values of the loadings of heat index, greenness index and dryness index reach the highest value of each index alternately as 0.619, 0.529, 0.595, 0.624 respectively, indicating that the main factors affecting the ecological environment of Tianjin are heat, greenness and dryness index.

Table 2 Results of principal component (PC1) analysis for each component indicator

PC1	2009	2014	2019	2024
NDVI	0.356	0.385	0.595	0.199
WET	0.549	0.589	0.451	0.602
NDBSI	-0.619	-0.392	-0.468	-0.457
LST	-0.434	-0.638	-0.473	-0.624
Eigenvalue	0.132	0.112	0.176	0.092
Contribution rate/%	63.67	62.69	73.04	60.78

3.2 Analysis of Spatial Changes of RSEI in Tianjin City

Using ArcGIS, the RSEI of Tianjin in each year was reclassified into five ecological grades according to the equal period of 0.2, which were worse, just, great, and satisfied, according to the distribution map of the RSEI of Tianjin for 4 periods about 2009-2024 as shown in (see Fig. 3). According to the figure, it is apparent that the ecological environment of Tianjin City in the past 15 years generally shows an upward trend, and the ecological and environmental quality of some areas has been boosted significantly.

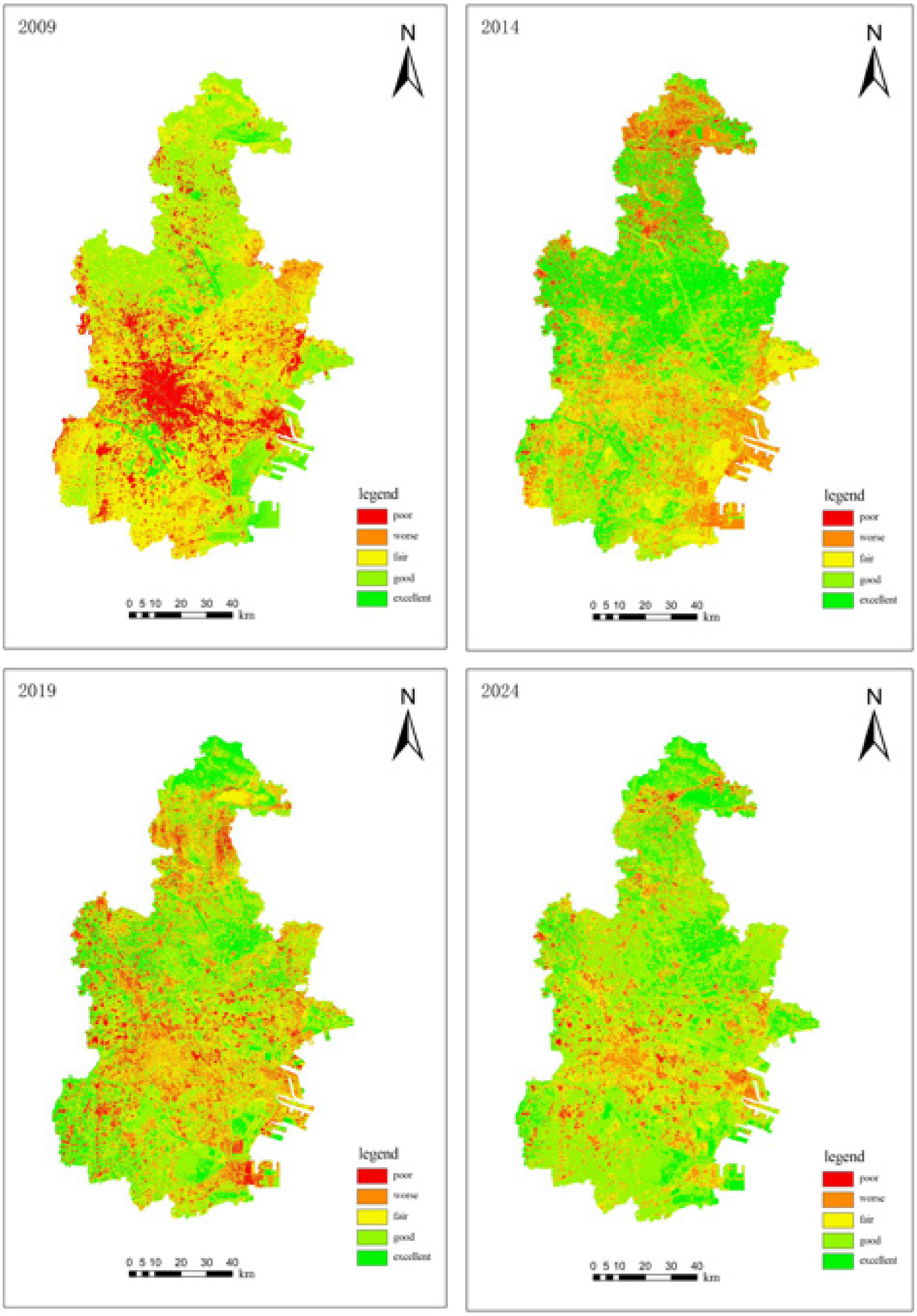

Fig. 3 Distribution of RSEI index levels in Tianjin, 2009-2024

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According to the statistics in Fig. 4, it is clear that the average value of RSEI rose from 0.41 to 0.64 in 2009-2014, decreased from 0.64 to 0.56 in 2014-2019 RSEI, and increased from 0.56 to 0.63 in 2019-2024 RSEI. The overall RSEI ecological index continues to show an upward trend, with ndvi reaching a maximum value of 0.69, wet a maximum value of 0.58, ndbsi reaching a maximum value of 0.79, and lst a maximum value of 0.64. This shows that in the past decade or so, although Tianjin city construction and others have had a profound effect with the ecological environment, relative implementation of various policies of Tianjin has led to the rapid increase of its ecological environment and overall trend.

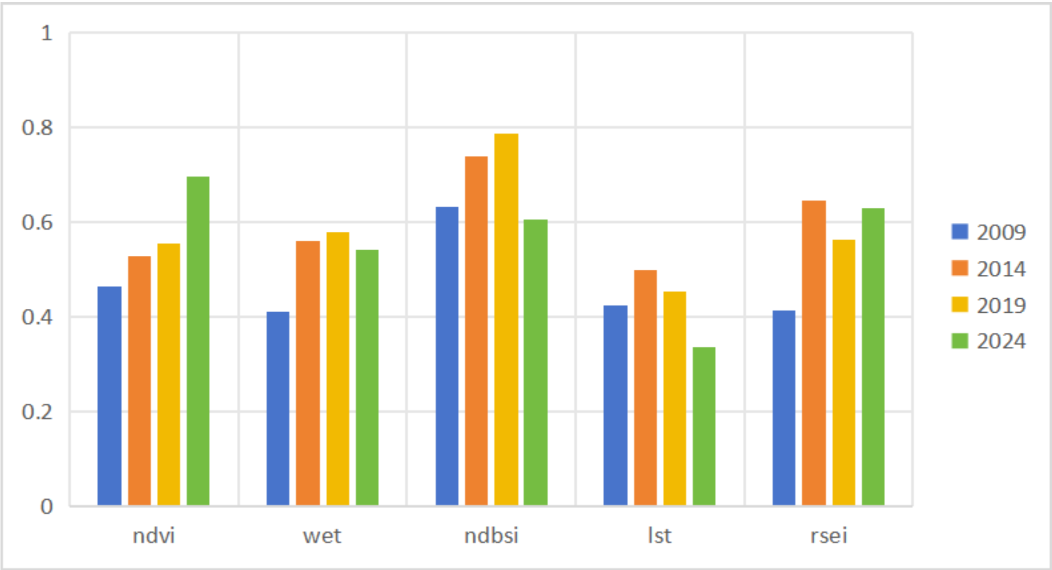

Fig. 4 Tianjin Municipal Ecological Environment Component Indicators and RSEI Statistics, 2009-2024

As can be concluded from Table 3, the area with excellent ecological quality in 2014 has multiplied several times compared to previous years, accounting for 19.71% of the total area. As is evident from Fig. 3, the regions with poor ecological environment in Tianjin are allocated in the central and southwestern regionalization, where human activities are frequent and industrial zones are concentrated, causing greater impact on the environment. The relative decrease in environmental quality in 2019 compared to 2014 is related to increasing urbanization and the Tianjin Port explosion, as ecological protection measures continue to be strengthened. The city's area of poor ecological quality decreased each year after 2019, with an overall upward trend in ecological quality.

Table 3 Area and percentage of RSEI grades

Hierarchy	*2009*		*2014*		*2019*		*2024*	
	Area /km²	*Percentage*	*Area /km²*	*Percentage*	*Area /km²*	*Percentage*	*Area /km²*	*Percentage*
Poor	*1291.02*	*10.82*	*3 36.87*	*2.82*	*809.43*	*6.79*	*269.29*	*2.26*
worse	*1807.56*	*15.15*	*2383.30*	*19.98*	*2207.93*	*18.51*	*1493.76*	*12.52*
fair	*4797.79*	*40.23*	*3214.62*	*26.95*	*3109.55*	*26.07*	*2506.6*	*21.02*
good	*3591.02*	*30.11*	*3642.04*	*30.53*	*4206.56*	*35.27*	*5996.73*	*50.28*
excellent	*439.83*	*3.69*	*2350.72*	*19.71*	*1593.72*	*13.36*	*1660.84*	*13.92*

The remote sensing images selected for this study have some limitations in terms of resolution, and the imaging time is not completely consistent, which may lead to some objective bias in the ecological quality evaluation results [12]. Secondly, this study analyzes the city of Tianjin, and the results are more targeted, but the lack of comparison and analysis of the ecological quality of adjacent areas may limit the generalizability of the outcomings.

In the future, the research will pay more attention to green development and sustainable development. Optimizing the RSEI algorithm and combining it with the GEE platform to make the assessment findings more academic and reasonable, it will help the ecological environment construction in Tianjin [13].

4 Conclusion

In this study, the RSEI index evaluation model was constructed using Landsat series remote sensing data in Tianjin.Meanwhile,the primary component analysis was performed on the index of greeness, the index of humidity,the index of dryness index and the index of heat to dynamically monitor and assess the ecological environment quality of Tianjin from 2009 to 2024, analyze the spatial and temporal changes of its ecological environment quality, and draw the following conclusions. The results are as follows:

(1) By analyzing 2009-2024 remote sensing image data of Tianjin through important component analysis, it is evident the highest value of RSEI is 0.64, and the main factors affecting the ecological environment of Tianjin are heat, greenness, and dryness indexes, with the highest values of 0.64, 0.69 and 0.79, respectively.

(2) The ecological environment about Tianjin is generally great from 2009 to 2024, and the area of this with quality boosted the most from 2009 to 2014, with an increase of 1,910.89 km2 Since 2019, Tianjin has vigorously promoted ecological protection projects and adhered to the concept of sustainable development, and the area of this of with excellent quality is increasing, and the area of this with poorer quality is decreasing. area is increasing, and the area of poorer area is decreasing.

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