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Preliminary communication

Evaluation of the Ecological Quality of the Taishan Region Based on Landsat Series of Satellite Images

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Abstract: The deterioration of ecological environment has seriously restricted regional sustainable development. Taishan region is one of the ecological protection and restoration of life community of mountains-rivers-forests-farmlands-lakes-grasslands in China. Its ecological quality changes are directly related to the overall layout of ecological restoration and protection projects. In this study, the Taishan region of China was taken as study area, and the grade change, spatial distribution, and spatial temporal fluctuation of the ecological environment quality were quantified. Based on the ENVI platform, the Landsat series of three images of the Taishan region in 2005, 2013, and 2017 serve as the data source, and the remote sensing ecological index model (RSEI) was used. According to the change characteristics of land use types, the driving factors of ecological environmental quality change were analyzed. The results showed that: (1) The area ratio of the ecological environment quality above the middle level was in order from large to small: 2005 (97.37%) > 2017 (91.46%) > 2013 (84.64%). (2) The overall quality of the ecological environment declined during the period of 2005-2013. (3) The overall change ranges from 2013 to 2017 are smaller than those from 2005 to 2013. The area of the deteriorating area decreased by 44.90%, and the area of the constant area and the area of the area that improved increased by 16.17% and 28.72%, respectively. During 2013-2017, the general trend is getting better and better. The improved areas were mainly concentrated in the main urban areas (Taishan District, Daiyue District), eastern Ningyang County, and western Xintai City. The research results can provide a scientific basis for the scientific evaluation of the ecological environment quality during the development and construction of the region, and have important value in the design and application of the ecological environment quality optimization path.

Keywords: ecological quality; RSEI; spatial-temporal evolution; Taishan

1 INTRODUCTION

Urban space expansion, land-use type, and contradictions between humans and land are increasingly prominent [1-3]. Environmental problems, such as water pollution, agricultural land, are decreasing, and along with insufficient urban green space, have led to deterioration in overall ecological quality, a decline in the quality of human settlements, and frequent food safety issues 1. These problems have become the focus of attention of experts and scholars at home and abroad, but no consensus has been reached on the relevant research methods of regional ecological quality assessment [2]. In particular, there are few reports on the monitoring and evaluation of regional ecological environment quality on a large-scale area [4].

At present, remote sensing ground observation systems rely on advantages, such as real-time, fast, and cyclical collection, to quantitatively evaluate and dynamically monitor ecological environment elements, such as forest carbon storage and soil organic carbon [5, 6], agricultural landscape evaluation [7], mines Geological survey [8], land use dynamics [9], and grassland use intensity [10] are widely used and have achieved good results. They all reflect the quality of certain aspects of the ecosystem through a single index, and then characterize the value of ecosystem use. However, this method can only evaluate one aspect of the ecosystem. The ecosystem is a complex system that is affected by multiple factors and cannot be accurately and comprehensively reflected by a single indicator. The HJ 192-2015 "Technical Specifications for Eco-Environmental Status Evaluation" issued in 2006 proposed the Ecological Index (EI) [11], which integrates multiple eco-environmental elements as an index for evaluating regional eco-environmental conditions. Due to the influence of regional differences, the index has a series of problems, such as irrational weighting in the application process. Moreover, the index can only represent the ecological status of the region, in general; it cannot be visualized, and it is highly subjective [4]. Xu [12] proposed a comprehensive index based on satellite remote sensing information, that is, the Remote Sensing Ecological Index (RSEI), and used this index to evaluate the ecological changes of soil and water loss areas in Changting County, Fujian Province. The RSEI is easy to obtain, and the calculation process is realized on the remote sensing information processing platform without manual intervention, so the calculation results are more objective and comparable. At present, the index is widely used in the red soil region in the south, the arid region in the northwest, and the black soil region in the northeast [13-15]. In fact, there are also many ecological fragile areas in the rocky mountain area in northern China. Among them, the Taishan area is typical and representative as the pilot area of the second group of ecological protection and restoration of the life Community of mountains, rivers, forests, fields, lakes and grasses in China. It has a strong applicability, but there are few reports on the study of the rocky mountain area in northern China.

Therefore, the Taishan region in the rocky mountain area in northern China is taken as the research area in this study. The RSEI remote sensing ecological index model composed of natural factors is used; three years of Landsat satellite imagery serve as the data source (2005, 2013, and 2017). Based on the ENVI image analysis software platform (Harris Geospatial Solutions, Inc., Boulder, CO, USA) and the ArcGIS platform (Esri, Redlands, CA, USA), the analysis is performed. The characteristics of the quality of the ecological environment in the development of the city fluctuated in time and space, and its driving factors were explored in order to provide scientific decision-making basis for the urban pattern planning, ecological protection, and governance of the Taishan regional government.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Study Area

The Taishan region was selected as the research area (35°38′N - 36°28′N, 116°20′E - 117°59′E), which mainly consists of Tai'an City, which is located at the southern foot of Mount Tai (Fig. 1). As it is located in the monsoon climate zone, the average annual temperature is 12.9 °C. The precipitation is unevenly distributed throughout the year, and the average annual rainfall is 697 mm. At the same time, the overall precipitation trend is affected by the terrain, and it decreases from northeast to southwest. The average total natural water resource for many years is 1.697 billion m^3. The main vegetation type is deciduous broad-leaved forest.

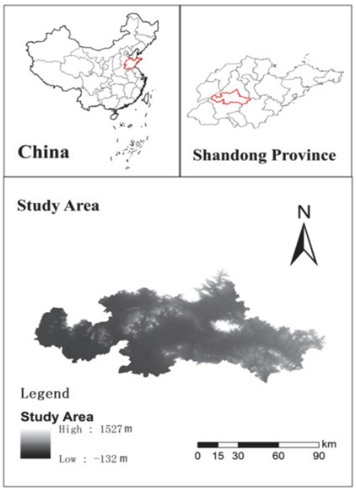

Figure 1 Tai'an city image location map

2.1.2 Data sources

The Landsat series of satellite images (Landsat 7, ETM, (slc-off), 2005; Landsat 8, OIL, 2013, 2017) provided by the geospatial data cloud website are uniformly selected in this study. The selected three phases of the images have basically the same seasonal phase to avoid the impact caused by seasonal differences. At the same time, the quality is good, and the Image cloud volume is less than 2%, and covering up the waters of the study area, the comparability and accuracy of the results is ensured.

2.1.3 Image Pre-processing

The pre-processing of remote sensing data mainly includes three steps: first, the radiation is calibrated so that the DN value of the band is converted into the reflectance at the sensor; then the Flash atmospheric correction is performed to reduce the impact of the atmosphere on the surface reflectance. Second, the corresponding index images are stitched, and the images are cropped with the vector boundary of the study area.

2.2 Methods

This study mainly focuses on the use of the new remote sensing lased ecology index (RSEI) [12] to evaluate the quality of the ecological environment in the Taishan region. The index is not a traditional subjective weighted summation given by people, but a principal component transformation method, which uses mathematical operations to objectively integrate each index component.

Table 1 Formulas needed to build the model

Indexes	Formula
NDVI	$NDVI=\left(\rho_{NIR}-\rho_{red}\right)/\left(\rho_{NIR}+\rho_{red}\right)$
NDBSI	$NDBSI=\left(SI+IBUI\right)/2$ $SI=\left[\left(\rho_{SWIR1}+\rho_{red}\right)-\left(\rho_{biue}+\rho_{NIR}\right)/\left(\rho_{SWIR1}+\rho_{red}\right)+\left(\rho_{biue}-\rho_{NIR}\right)\right]$ $IBI=\frac{\left\{\left(2\rho_{SWIR1}\right)/\left(\rho_{SWIR1}+\rho_{NIR}\right)+\left[\rho_{NIR}/\left(\rho_{NIR}+\rho_{red}\right)+\rho_{green}/\left(\rho_{green}+\rho_{SWIR1}\right)\right]\right\}}{\left\{\left(2\rho_{SWIR1}\right)/\left(\rho_{SWIR1}+\rho_{NIR}\right)+\left[\rho_{NIR}/\left(\rho_{NIR}+\rho_{red}\right)+\rho_{green}/\left(\rho_{green}+\rho_{SWIR1}\right)\right]\right\}}$
WET	Landsat ETM+: $Wet=0.2626\rho_{blue}+0.2141\rho_{green}+0.0926\rho_{red}+0.0656\rho_{NIR}-0.7629\rho_{SWIR1}-0.5388\rho_{SWIR2}$ Landsat OIL: $Wet=0.1511\rho_{blue}+0.1972\rho_{green}+0.3282\rho_{red}+0.3407\rho_{NIR}-0.7117\rho_{SWIR1}-0.4559\rho_{SWIR2}$
LST	$L_{\lambda}=\left[\varepsilon B\left(T_S\right)+\left(1-\varepsilon\right)L_{\downarrow}\right]\tau+L_{\uparrow}$ $B\left(T_S\right)=\frac{\left[L_{\lambda}-L_{\uparrow}-\tau\left(1-\varepsilon\right)L_{\downarrow}\right]}{\tau\varepsilon}$ $T_S=\frac{K_2}{ln\left[\frac{K_1}{B\left(T_S\right)}+1\right]}-273.15$ $\varepsilon=0.004P_v+0.986$ $P_v=\left(NDVI-NDVI_{soil}\right)/\left(NDVI_{veg}-NDVI_{soil}\right)$
RSEI	$NI_i=\left(Index_i-Index_{\min}\right)/\left(Index_{\max}-Index_{\min}\right)$ $RSEI_0=1-\left\{PC1\left[\int\left(NDVI,\ Wet,\ LSR,\ NDBSI\right)\right]\right\}$ $RESI=\left(RSEI_0-RSEI_{0\_\min}\right)/\left(RSEI_{0\_\max}-RSEI_{0\_\min}\right)$

At the same time, the vegetation coverage component (the normalized difference vegetation index, *NDVI*), humidity component (wetness, *WET*), surface temperature (the land surface temperature, *LST*), and bare soil and building composite index (the normalized difference impervious surface index, *NDBSI*) represent the dryness, humidity, heat, and greenness respectively in the principal component analysis. These indicators are highly representative and coupled by principal component analysis (PCA) [12]. Finally, the weights of four indicators involved in *RSEI* are determined.

This study mainly uses a more suitable and mature atmospheric correction method to retrieve the surface temperature [16, 17], the land surface temperature (*LST*). The extraction of humidity has different formulas for different satellite sensors [18, 19]. Because the study area is a city, the factors that cause the surface to "dry out" include bare soil and building land [12], that is, the dryness index is synthesized from the bare soil index and the building index [20]. Before the principal component analysis, the four indexes are normalized separately to make the data range the same [21]. The formulas involved are shown in Tab. 1.

In the formula, L_λ: the thermal infrared radiation brightness value received by each satellite sensor (Band 61 of the ETM satellite image and Band 10 of the OIL satellite image); ε: specific surface emissivity, value references [22]; T_S: real surface temperature (unit: °C); B (*TS*): blackbody thermal radiation brightness; τ: atmospheric transmittance in the thermal infrared band. For OIL band 10, K_1 = 774.89 W/(m^2·μm·sr) and K_2 = 1321.08 K, for ETM band 61, K_1 = 666.09 W/(m^2·μm·sr), K_2 = 1282.71 K. *NDVI* soil: *NDVI* value of the area without vegetation coverage; *NDVI* veg: *NDVI* value of the pixels completely covered by vegetation; NI_i: a normalized index, Index *i*: the corresponding value of the index at pixel *i*, $Index_{min}$: the index $Index_{max}$ represents the maximum value of this index; *RSEI*: a new type of remote sensing ecological index constructed [0, 1].

3 RESULTS

3.1 Principal Component Analysis of Ecological Quality Index

It is known from Tab. 2 that (1) the contribution rates of the three indicators to PC1 in the three phases are greater than 90%, indicating that PC1 is integrated. Most of the information of the four indicators, and the contribution of the four indicators to PC1 is relatively stable, so PC1 is selected. (2) In PC1 in 2005, 2013, and 2017, the humidity index (*Wet*) and greenness index (*NDVI*) are positive values, which indicates that they have a positive impact on the quality of the ecological environment, and the thermal index (*LST*) and the dryness index (*NDBSI*) have a negative impact, which is consistent with the actual ecological environment.

Table 2 Principal component analysis of each indicator

Index	2005				2013				2017			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Wet	0.814	0.028	-0.466	-0.347	0.835	0.024	0.001	-0.550	0.540	0.547	0.540	0.343
NDVI	0.278	0.855	-0.437	0.003	0.272	-0.866	0.026	0.374	0.223	-0.798	0.277	0.486
NDBSI	-0.022	-0.317	-0.602	0.732	-0.251	-0.216	0.860	-0.389	-0.554	0.249	-0.188	0.772
LST	-0.510	0.409	0.479	0.586	-0.407	-0.409	-0.510	-0.638	-0.593	-0.035	0.772	0.226
Eigenvalues	0.4390	0.0063	0.0011	0.0002	0.2663	0.0062	0.0030	0.0010	0.3218	0.0069	0.0021	0.0016
Percent eigenvalue / %	98.31	1.41	0.24	0.04	96.32	2.23	1.08	0.37	96.80	2.08	0.64	0.48

3.2 Analysis of the Characteristics of Ecological Environment Quality Grade Changes

In order to improve the *RSEI* results obtained by the principal component transformation, refer to the classification standard [4], and further classify the *RSEI* index. The values are divided into five levels of ranges, 0 - 0.2, 0.2 - 0.4, 0.4 - 0.6, 0.6 - 0.8, and 0.8 - 1, which, respectively, represent five ecological quality evaluation levels of extremely bad, bad, medium, good, and excellent.

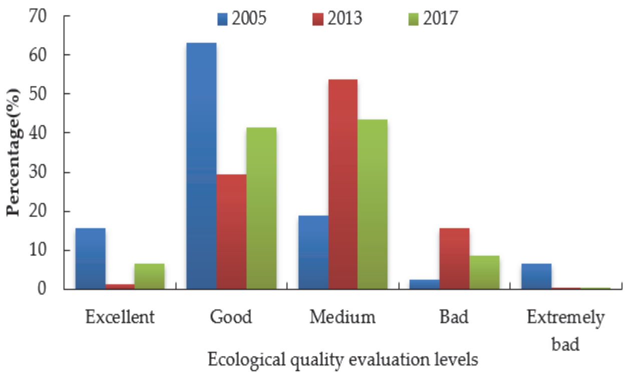

Figure 2 Classification and statistics of remote sensing ecological environment quality in the Tai'an region in different years

On the whole, the proportion of the area of the middle and higher grades in 2005, 2013 and 2017 was more than 84% (Fig. 2); the order of the ecological quality of the medium and higher grades was in the following order: 2005 (97.37%) > 2017 (91.46%) > 2013 (84.64%). In 2005, the quality of the ecological environment in the Taishan region was mainly good, accounting for 63.06% (Fig. 3a). The ecological and environmental quality of the Taishan region in 2013 and 2017 was mainly of medium grade, accounting for 54.73% and 43.54%, respectively (Fig. 3b, Fig. 3c).

Therefore, the ecological quality in 2005 was dominated by good grade, and the distribution of other grades was basically the same. In 2017, the ecological quality was mainly good and medium grades, and there was no extremely bad grade. The overall development trend of ecological quality was good. However, 2013 was dominated by medium grade, followed by good grade. It showed that the overall level of ecological quality was improved in 2017, and the overall level of ecological quality decreased most obviously in 2013.

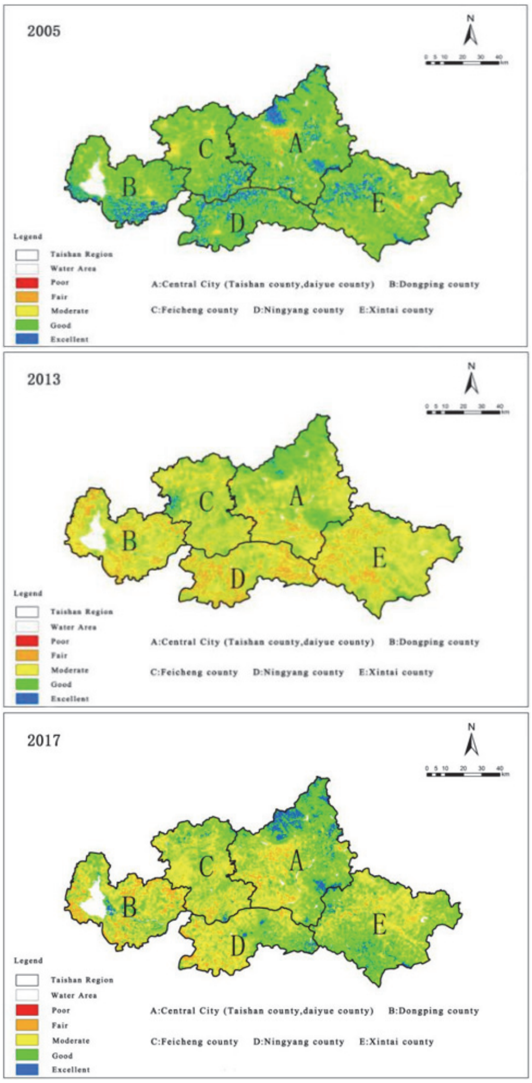

Figure 3 Classification of ecological quality in the Tai'an region
Note: a:2005; b:2013; c:2017

3.3 Spatiotemporal Fluctuation Intensity Analysis of Ecological Quality

From the perspective of inter-annual changes (Fig. 2), from 2005 to 2017, the change in the area occupied by each grade showed a "two increase and three decrease" phenomenon, with a large increase of 24.64% for the middle grade and a 5.96 for the worse grade. Excellent grades and good grades decreased by 8.89% and 21.67% respectively; poor grades decreased by 0.03%, and the decrease was small.

The proportion of variation areas (41.69%) from 2005 to 2017 was relatively large. During 2005 - 2017, the overall change trend was worse, yet the overall ecological and environmental quality has gradually improved since 2013; the proportions of variation areas from 2005 to 2013 and 2013 to 2017 were 56.72% and 11.83%, respectively. The overall change ranges from 2013 to 2017 is smaller than that from 2005 to 2013. The area of the deteriorating area decreased by 44.90%, and the area of the constant area and the area of the area that improved increased by 16.17% and 28.72%, respectively. During 2013 - 2017, the general trend was getting better and better.

In order to more intuitively and quantitatively analyze the changes in the temporal and spatial differences of ecological quality in the Taishan region over the past 13 years, based on the *RSEI* values obtained from the principal component transformation, the difference changes in *RSEI* values in 2005 and 2017 were detected to change the ecological environment quality. The amplitude was divided into three levels: no change (0), better (1 - 4), worse (-1 - -4). Areas with good ecological environment quality are indicated by green, areas with bad ecological environment quality are shown in red, and the unchanged area is shown in yellow (Fig. 4). Combined with the statistical results (Tab. 3), the following points were observed.

Table 3 Ecological Quality Fluctuation Detection in Tai'an City from 2005 to 2017

Class	Level	2005-2017			2005-2013			2013-2017		
		Level area / km^2	Class area / km^2	Proportion / %	Level area / km^2	Class area / km^2	Proportion / %	Level area / km^2	Class area / km^2	Proportion / %
Degraded	−5	0.009	3232.270	41.69	0.002	4397.945	56.73	0.003	917.724	11.83
	−4	0.164			0.121			0.013		
	−3	191.163			299.759			2.803		
	−2	765.244			1247.817			66.475		
	−1	2275.691			2850.247			848.431		
No change	0	3612.086	3612.086	46.59	2841.802	2841.802	36.65	4095.468	4095.468	52.82
Improved	1	858.866	908.691	11.72	475.132	513.300	6.62	2269.339	2739.856	35.34
	2	45.752			32.306			420.092		
	3	3.644			5.839			50.418		
	4	0.420			0.023			0.006		
	5	0.008			0.000			0.000		

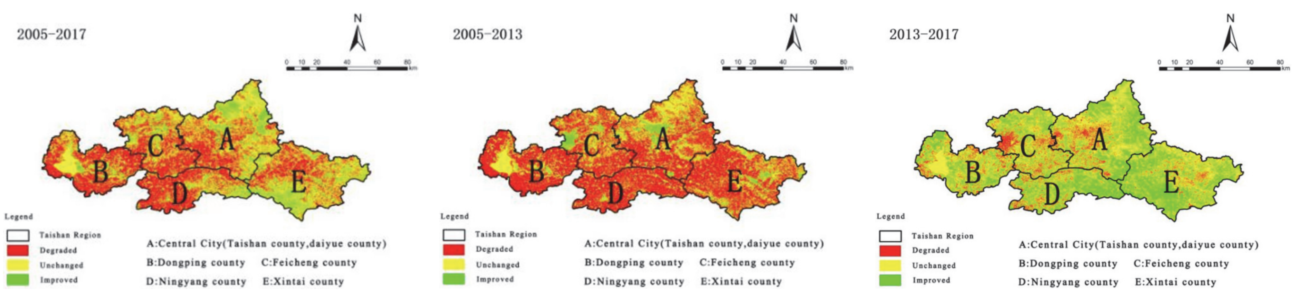

Figure 4 Changes in the ecological quality of Tai'an region
Note: green: good ecological environment quality; red: bad ecological environment quality; yellow: unchanged area

Spatially, in the past 13 years, the quality of the ecological environment in the eastern part of the Taishan region has improved, and the western region has declined. The overall ecological environment declined in 2005 - 2013, but the ecological environmental quality in the central urban area, western Feicheng City, and parts of Xintai City improved, whereas the ecological environment quality of the Taishan Scenic Area remained basically unchanged. From 2013 to 2017, the overall ecological environment quality improved, and the areas that improved are concentrated in the southeast of the main urban area, east of Ningyang County, and west of Xintai City (Fig. 4).

4 DISCUSSION

The factors that change the ecological quality can be roughly divided into natural factors and human factors. Some studies have shown that climate has become a driving factor for changes in the ecological environment [23]. Compared with the SPEI-based drought characteristics reported by Yan et al. [24] from 1958 to 2015, it has been found that the 2013 Mount Tai region was the worst drought in 13 years. It has a certain impact on the four indicators of RSEI, the RSEI value is low, this status is consistent with the worst ecological quality in 2013 shown by the results of this study, indicating that the results of this study have certain credibility.

Table 4 Tai'an City 2005-2017 land type area summary

Category	2005	2013	2005-2013	2017	2013-2017	2005-2017
Farmland	4046.22	3727.35	318.86 ↓	3025.45	701.90 ↓	1020.76 ↓
Vegetation	1849.87	1889.97	40.10 ↑	2204.52	314.55 ↑	354.65 ↑
Water body	276.92	306.69	29.77 ↑	250.10	56.59 ↓	26.82 ↓
Impervious surfaces	915.92	1652.64	736.72 ↑	2106.57	453.93 ↑	1190.65 ↑
Bare soil	664.29	183.24	481.05 ↓	174.40	8.84 ↓	489.89 ↓

The human factors affecting the quality of the ecological environment are mainly reflected in changes in land use [25]. Therefore, the types of land cover that affect the quality of the ecological environment roughly include impervious surfaces, vegetation, agricultural land, waters, and bare soil [26]. The ENVI supervision classification function is used to separately supervise and classify the three phases of images to extract the areas of impervious surface, vegetation, cultivated land, water, and bare soil (the supervision classification results are not shown in the article).

It can be seen from Tab. 4 that in the past 13 years in the Tai'an area, the increase in the area of impervious surfaces between 2005 and 2017 accounted for about 15% of the city's area. The area of bare soil and vegetation has mainly changed to the area of impervious surfaces. The economic development of Tai'an City has been rapid in the past 13 years, and the urbanization process has been significant. From 2005 to 2013, the area of vegetation and bare soil mainly changed to impervious surfaces. The increase in impervious surfaces will cause the surface to "dry out" and increase the quality of the ecological environment. The magnitude of change, during which the overall ecological environment declined, is consistent with the research by Xu et al. [26]. In 2013 - 2017, the increase in impervious area was larger than in 2005 - 2017, and the area of bare soil did not change significantly, but the area of increased vegetation accounted for 4.05% of the city's area. Compared with 2005 - 2013, the increase was larger, and the ecological environment quality improvement is consistent with the results of ecological quality changes during the period obtained by the new remote sensing ecological model.

5 CONCLUSIONS

This study uses Landsat 7/ETM and Landsat 8/OLI images combined with the new RSEI model and ENVI supervision classification proposed. Based on this, the classification and difference detection are cited. In 2017, the overall quality of the ecological environment in the Taishan region was improved, and the quality of ecological environment in the east was better than in the west. The vigorous advancement of drought and urbanization caused fluctuations in the quality of the ecological environment in 13 years. In 2017, there was some improvement. The areas that have become better are the main urban areas (Taishan District, Daiyue District) and Xintai City. Therefore, the ecological quality needs to be further improved by changing land use types in Dongping, Ningyang, and Feicheng regions. The results will provide a more accurate scientific basis for urban and rural planning and ecological environmental protection in the Taishan region.

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