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Environmental Monitoring in Northern Aksu, China Based on Remote Sensing Ecological Index Model

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Abstract

In order to understand the development status of ecological environment quality in the Aksu region of China, to effectively adjust the ecological environment quality, so as to promote the sustainable development of its social economy and ecological environment protection. This paper selects the Landsat series remote sensing images of the northern Aksu region in 2013, 2016, and 2019, and uses the tools such as ENVI5.3 and ArcGIS 10.8.1 to process the image data accordingly. The principal component analysis method is used to calculate the Remote Sensing Ecological Index (RSEI) of the northern Aksu region. The data show that: 1) The ecological environment quality index in the northern Aksu region in 2013, 2016, and 2019 was 0.706087, 0.25243 and 0.362991 respectively; 2) The areas where the ecological environment quality declined significantly in the northern Aksu region were the human settlements and the Gobi, fan-shaped land and other special terrain areas; 3) The humidity index and the heat index are the two factors that have the greatest impact on the ecological environment quality in the northern Aksu area. The data as a whole show that the ecological environment in the northern part of the Aksu region has deteriorated seriously, and the severely deteriorated area is close to the human living area.

Keywords

Aksu, China, Ecological Environment Quality, Principal Component Analysis, Remote Sensing Ecological Index

1. Introduction

Economic development has caused a lot of damage to the ecological environment, and it has also gradually increased people's awareness of environmental protection. Dynamic monitoring of the change process of the regional ecological environment can comprehensively reflect the changes in its ecological quality, which is helpful to effectively adjust the quality of the regional ecological environment, thereby promoting the sustainable development of its social economy and ecological environment protection [1] [2] [3].

At present, remote sensing technology is widely used in dynamic monitoring and evaluation of ecological environment quality due to its rapid, real-time, and wide-coverage monitoring characteristics. The assessment of the ecological environment, it is generally divided into two types: single-index assessment and multi-index assessment. For example, Ni Ming *et al.* used the normalized vegetation index (NDVI) to analyze the response degree of vegetation to extreme climatic events in the southwestern region [4]. Hao Long *et al.* analyzed its effect on forest aboveground biomass according to surface temperature [5]. Although a single indicator can analyze the relationship between influencing factors and things to a certain extent, due to the diversity and variability of ecosystems, it often cannot fully reflect the objective causal relationship between things [6]. Xu Hanqiu proposed a new Remote Sensing Ecological Index (RSEI) in 2013, RSEI integrates four environmental factors of greenness, humidity, heat and dryness, which can comprehensively, quickly, and objectively reflect the quality of the regional ecological environment [7]. Zhou Quanping used the remote sensing ecological index RSEI to quantitatively analyze and evaluate the status and changes of the ecological environment in 11 provinces (cities) in the Yangtze River Economic Belt [8]. Zhang Hua *et al.* evaluated and analyzed the ecological environment quality of Qilian Mountain National Park from 1989 to 2019 based on the Remote Sensing Ecological Index (RSEI) [9]. It can be seen that the evaluation of regional environmental quality is mostly based on the multi-index remote sensing ecological index, and the remote sensing ecological index has been widely used in the evaluation of ecological environment quality.

With the help of remote sensing and GIS technology, this study calculated the remote sensing ecological index of northern Aksu in 2013, 2016, and 2019 by principal component analysis method, and quantitatively analyzed the status and changes of the ecological environment in northern Aksu. The temporal and spatial changes of the ecological environment over the years provide a reference for its ecological environment construction and policy formulation.

2. Study Area and Data Sources

2.1. Overview of the Study Area

Aksu region is located in northwestern China, the central part of Xinjiang Uygur Autonomous Region, the southern foot of the middle section of the Tianshan Mountains, and the northern part of the Tarim Basin. It is located at 78˚03' - 84˚07'E, 39˚30' - 42˚41'N, with a total area of 132,500 square kilometers. The whole district governs 2 county-level cities and 7 counties, with a total area of

132,500 square kilometers [10] [11]. According to the seventh census data, as of 00:00 on November 1, 2020, the resident population of the Aksu area was more than 27 million. Its terrain is high in the north and low in the south, sloping from northwest to southeast. The Tomur Peak with an altitude of 7435.3 meters is the highest point in the territory, and the banks of the Tarim River with an altitude of 945 - 1020 meters are the lowest points in the territory. The study area has a warm temperate arid climate, which has the remarkable characteristics of a continental climate [12]. This paper takes the northern part of the Aksu area as the main research area, which is located at 80˚00' - 83˚26'E and 40˚67' - 42˚79'N. An overview of the study area is shown in **Figure 1**.

2.2. Data Sources and Processing

This paper uses Landsat 8 OLI/TIRS C1 L1 remote sensing image data (30m resolution) from the USGS (United States Geological Survey). Three Landsat8 images with good vegetation growth, less than 5% cloud cover, short time intervals, and good data quality in 2013, 2016, and 2019 were selected. The data are preprocessed by radiometric calibration and atmospheric correction.

3. Research Methods

Remote Sensing Ecological Index

The remote sensing ecological index RSEI is proposed to evaluate and monitor the urban ecological environment from natural factors. It was proposed and standardized by Xu Hanqiu and other scholars [7]. The remote sensing ecological

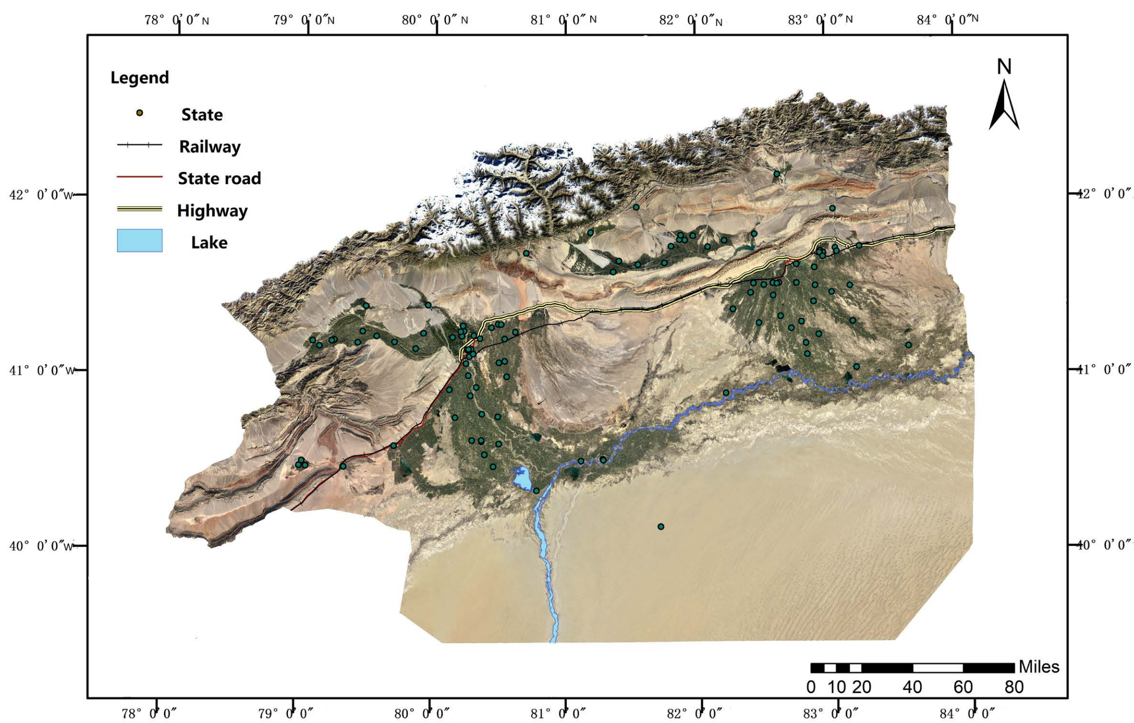


Figure 1. Schematic diagram of the study area.

index RSEI includes four natural factors of vegetation coverage, humidity, temperature, and dryness. Its value is an index to evaluate the quality of the ecological environment through principal component transformation on the basis of the four ecological indexes. It is an important factor related to changes in the ecological environment, so its value can directly reflect the quality of the ecological environment. RSEI can provide strong support for the quality of the ecological environment in the study area, and its expression is as follows:

$$\text{RSEI} = f\left(\text{NDVI}, \text{WET}, \text{LST}, \text{NDBSI}\right) \quad (1)$$

In Formula (1), NDVI, WET, LST and NDBSI represent greenness, humidity, temperature, and dryness, respectively.

1) Greenness Index (NDVI)

The greenness index is generally expressed by the normalized vegetation index (NDVI), which quantifies vegetation by measuring the difference between near-infrared (strong reflection by vegetation) and red light (absorption by vegetation), and its value ranges from −1 to 1. Areas with values less than or close to zero indicate no green leaves, and areas with values greater than zero have greenness proportional to their values [13]. Calculated as follows:

$$\text{NDVI} = \left(\text{NIR} - \text{Red}\right) / \left(\text{NIR} + \text{Red}\right) \quad (2)$$

In Formula (2), NIR is the near-infrared band, and Red is the infrared band.

2) Humidity Index (WET)

Soil moisture can well reflect the quality of the ecological environment in the region and plays an important role in the monitoring of the surface environment [14]. Using the tasseled cap transforms to invert soil moisture is a common method in the field of remote sensing because it can effectively remove redundant data. Calculated as follows:

$$\text{WET} = 0.1511\rho_2 + 0.1973\rho_3 + 0.3283\rho_4 + 0.3407\rho_5 - 0.7117\rho_6 - 0.4559\rho_7 \quad (3)$$

In Formula (3), ρ_i (i = 1, 2, 3, …).

3) Heat Index (LST)

In this paper, the surface temperature is used to represent the heat index, and the atmospheric correction method in the single-channel algorithm is used for inversion. First, estimate the influence of the atmosphere on the surface thermal radiation, and then subtract this part of the atmospheric influence from the total thermal radiation observed by the satellite sensor to obtain the surface thermal radiation intensity, and then convert this thermal radiation intensity into the corresponding surface thermal radiation intensity. Temperature [15] [16] [17].

Calculated as follows: Using the thermal infrared band in the Landsat data, the brightness temperature $L\lambda$ is calculated and corrected for the radiance ε. The formula is:

$$L\lambda = \text{gain} * \text{DN} + \text{bias} \quad (4)$$

$$B\left(Ts\right) = \left[L\lambda - L_{\uparrow} - \tau\left(1-\varepsilon\right)L_{\downarrow}\right] / \tau\varepsilon \quad (5)$$

In Formula (4), $L\lambda$ represents the brightness temperature, DN represents the gray value of the pixel, and gain and bias are the gain value and bias value of band 6, respectively. $B(Ts)$ is the black body radiance; $L_{\uparrow}$ and $L_{\downarrow}$ are atmospheric up and down atmospheric radiances; τ is the transmittance in the thermal infrared band of the atmosphere; ε is the surface-specific emissivity [18] [19] [20].

The temperature calculated by Formula (5) needs to be corrected by specific emissivity to be used as the surface temperature LST:

$$\text{LST} = 1201.14 / \ln\left[774.89B(Ts)+1\right] \tag{6}$$

4) Dryness Index (NDBSI)

The dryness index also plays an important role in the monitoring and evaluation of the ecological environment. The main reasons for the "dryness" of urban areas are the expansion of building land and large areas of bare land. For this reason, the combination of bare land index (SI) and building index (IBI) is selected as the dryness index, which is expressed as (NDBSI) [21]. Calculated as follows:

$$\begin{aligned}\text{NDBSI} &= (\text{IBI}+\text{SI})/2\text{IBI} \\ &= \left\{B52B5+B4-\left[B4B4+B3+B2B2+B5\right]\right\}/ \\ &\quad \left\{B52B5+B4+\left[B4B4+B3+B2B2+B5\right]\right\}\end{aligned}$$

$$\text{SI} = \left[(B5+B3)-(B4+B1)\right]/\left[(B5+B3)+(B4+B1)\right] \tag{7}$$

5) Principal Component Analysis

Principal component analysis (PCA) is a multivariate statistical method, which refers to extracting multiple influencing factors in an event and analyzing them, obtaining independent influence indices of each factor, and selecting factors with larger influence indices for comprehensive evaluation. It is often used for multi-band remote sensing image transformation enhancement, which can comprehensively and effectively evaluate the ecological environment.

6) Construction of Remote Sensing Ecological Index

This study uses the principal component analysis method to calculate the four indicators, that is, the remote sensing ecological index is composed of the first principal component (PC1) of the above four indicators. Due to the different numerical ranges of the above indicators, the four indicators need to be normalized. The specific formula is as follows:

$$\text{RSEI} = (\text{RSEI0} - \text{RSEI0-min})/(\text{RSEI0-max} - \text{RSEI0-min}) \tag{8}$$

In Formula (8): RSEI is the remote sensing ecological index, which is the main component converted after the normalization of the four indices. RSEI0 is the initial value of the remote sensing ecological index (RSEI0 = 1 − PC1). RSEI0-max and RSEI0-min are the maximum and minimum values of the initial value RSEI0. The closer the remote sensing ecological index is to 1, the better the quality of the ecological environment, and the closer to 0, the worse the quality of the ecological environment [22].

4. Results and Analysis

4.1. Principal Component Analysis of Ecological Environment Indicators

From Table 1, it can be concluded that in 2013, 2016, and 2019, the eigenvalues of the first principal component of the eco-environmental indicators were 0.04177, 0.025994, 0.043087, and the contribution rates of the eigenvalues were 88.12%, 77.86%, and 80.47%, respectively. The contribution rates are all greater than 75%, indicating that PC1 contains most of the information of the four indicators.

From Table 2, it can be concluded that the average values of the RSEI index in the study area in 2013, 2016, and 2019 changed greatly, which were 0.706087, 0.252431, and 0.362991, respectively. It showed a trend of first decreasing and then increasing. Judging from the changing trends of the four ecological indicators, the greenness index values of the three phases are not much different, all-around 0.55; the humidity index value has an obvious downward trend from 0.51 to 0.37 from 2016 to 2019; the heat index value also shows The trend of first rising and then falling; the overall change trend of dryness index is not obvious.

Table 1. Principal component analysis of remote sensing ecological index.

main ingredient	2013		2016		2019	
	Eigenvalues	Contribution rate/%	Eigenvalues	Contribution rate/%	Eigenvalues	Contribution rate/%
PC1	0.04177	88.12	0.025994	77.86	0.043087	80.47
PC2	0.003053	6.45	0.00457	13.69	0.007822	14.61
PC3	0.002123	4.47	0.002604	7.8	0.001695	3.17
PC4	0.000453	0.96	0.000218	0.65	0.000938	1.75

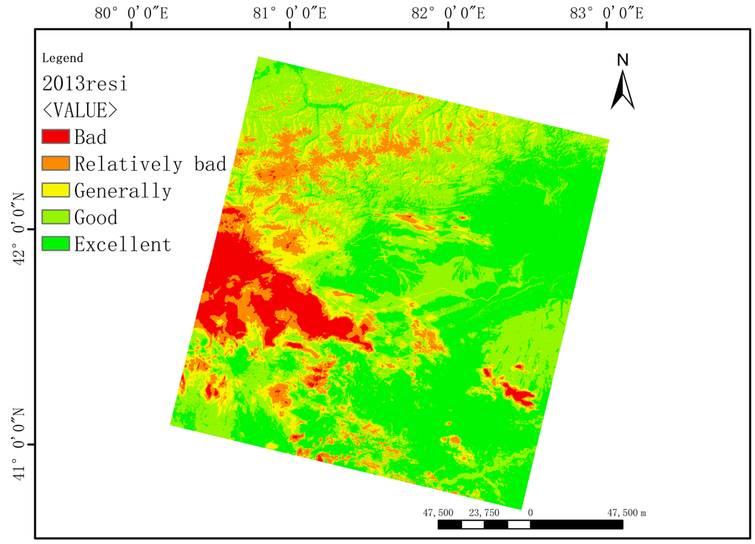
Table 2. Changes in indicators and RSEI in each year.

Years	Statistics	NDVI	WET	LST	NDBSI	RSEI
2013	minimum	0.282949	0	0	0.189962	0.00
	maximum value	0.829646	1	1	1	1.00
	mean	0.551062	0.560717	0.679531	0.73902	0.706087
	standard deviation	0.054982	0.058341	0.197966	0.042214	0.194214
2016	Minimum value	0.303425	0	0	0.188403	0.00
	maximum value	0.82262	1	1	1	1.00
	mean	0.560216	0.517234	0.747147	0.745052	0.252431
	standard deviation	0.067593	0.05389	0.155016	0.04341	0.161314
2019	Minimum value	0.294624	0	0	0.176308	0.00
	maximum value	0.843884	1	1	1	1.00
	mean	0.53775	0.378647	0.672776	0.719391	0.362991
	standard deviation	0.042633	0.123164	0.170523	0.086464	0.195464

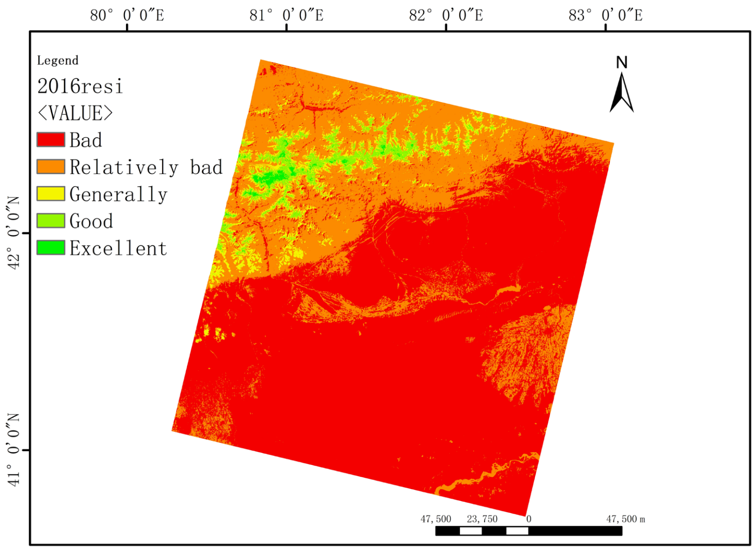
From the mean value of each index, the humidity index and the heat index have large changes, indicating that the main influencing factors of the RSEI changes in the Aksu area are these two indexes. In general, the ecological environment quality of Aksu has deteriorated greatly in the past nine years and has gradually improved in recent years.

4.2. Analysis of Temporal and Spatial Variation of RSEI

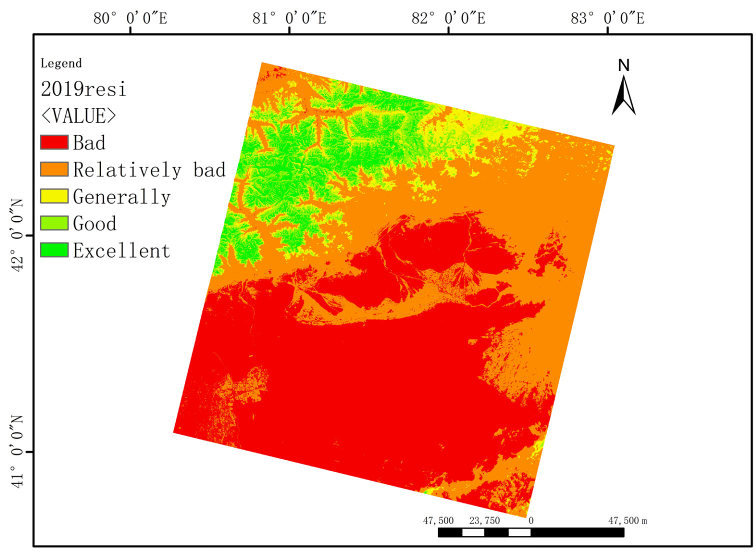
According to the ecological environment classification standard in "Technical Specification for Ecological Environment Assessment", the remote sensing ecological index is divided into 5 grades according to the interval of 0.2, ecological poor (0 - 0.2), ecological poor (0.2 - 0.4), ecological average (0.4 - 0.6), ecologically good (0.6 - 0.8) and ecologically excellent (0.8 - 1.0) to obtain the spatial distribution of RSEI in Figure 2.



(a)



(b)



(c)

Figure 2. Hierarchical distribution of remote sensing ecological index in northern Aksu. (a) 2013; (b) 2016; (c) 2019.

From **Figure 2** of the spatial distribution of the remote sensing index of the ecological environment, it can be seen that the quality of the ecological environment in the northern part of Aksu in 2013 was generally in a good state; in the three years from 2013 to 2016, the quality of the ecological environment declined rapidly, and the ecological environment of the Gobi, fan-shaped and human settlement areas The quality is extremely poor; the ecological environment quality has slightly improved from 2016 to 2019, and the improvement is mostly concentrated around Baicheng County. Areas with lower environmental quality levels are mainly concentrated in human settlements such as prefectures and villages, and special landform areas such as the Gobi and fan-shaped land, indicating that human activities have a greater impact on the environment.

Figure 3 shows the changing trend of ecological environment quality in the two time periods of 2013-2016 and 2016-2019. As can be seen from **Figure 3**, from 2013 to 2016, the quality of the ecological environment deteriorated in a wide range, mostly concentrated in human settlements and areas with special terrain such as the Gobi; from 2016 to 2019, the severity of the ecological environment decreased, and the Gobi and other special terrains The ecological quality of the region has basically not changed, and the ecological environment quality of the human settlement area is still deteriorating, and the degree is slightly lower than that in 2013-2016.

5. Discussion

5.1. Advantages of the RSEI Model

The quality of the ecological environment is affected by many factors. Although a certain outstanding impact index can reflect the quality of the ecological environment to a certain extent, the comprehensive analysis of multiple indicators

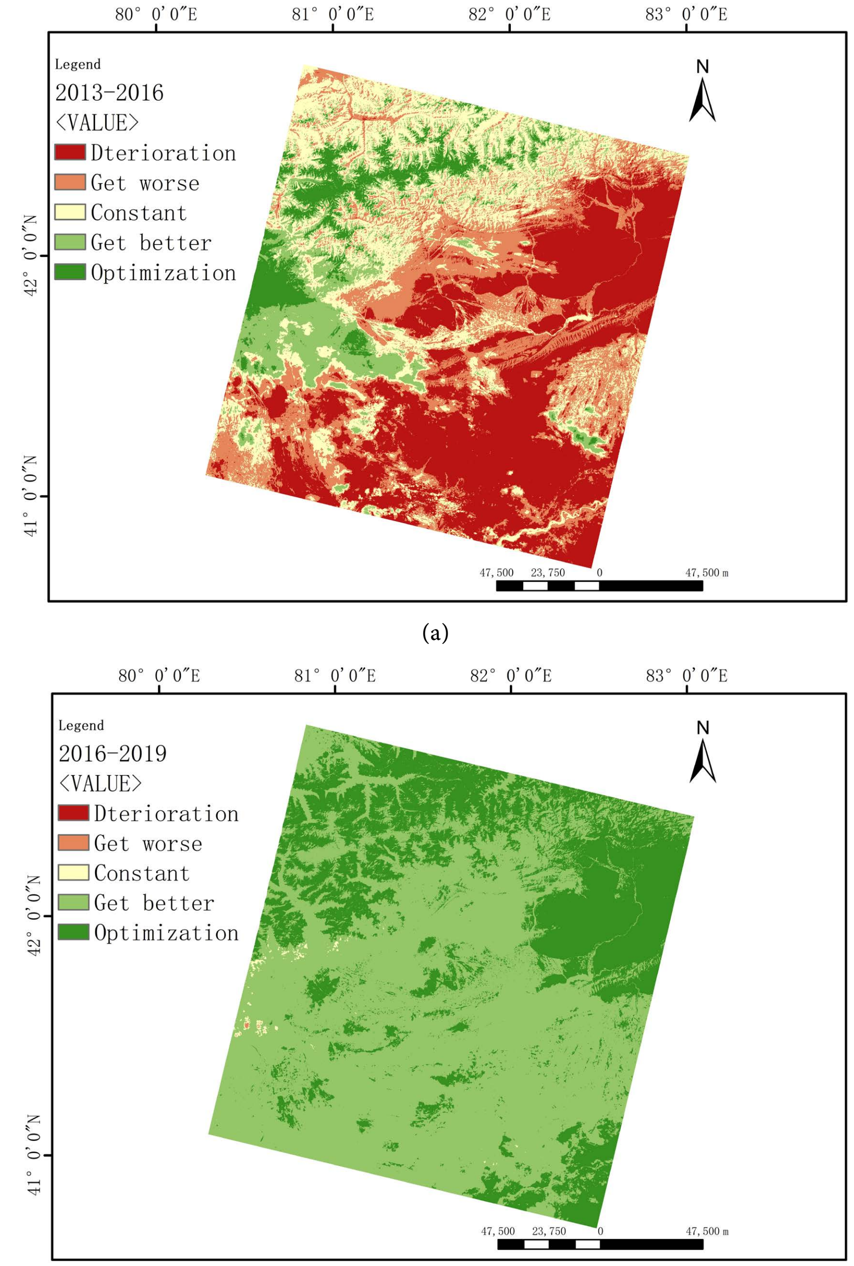


Figure 3. Difference change detection chart. (a) 2013-2016; (b) 2016-2019.

can reflect the results more comprehensively. RSEI comprehensively evaluates the quality of the ecological environment by integrating the four main environmental impact factors of greenness, humidity, heat, and dryness. It can be seen from Table 1 that the contribution rates of the selected four indicators in the first principal component (PC1) all reach more than 77%, indicating that PC1 concentrates most of the characteristics of the four indicators, so the RSEI constructed based on PC1 is more effective than a single indicator, representative. From the results in Table 2, the average correlation of RSEI is the largest, which also shows that RSEI is more suitable for evaluating the quality of the ecological environment than a single indicator.

5.2. Analysis of Changes in Ecological Environment Quality

The results of the RSEI index in 2013, 2016, and 2019 showed that the ecological environment quality in the study area declined sharply from 2013 to 2016, but it recovered from 2016 to 2019, but not much. The reasons for this result are inseparable from the economic construction of human activities. The urban system planning in the Aksu region has been implemented since 2012, and it is expected to complete the planning goals by 2030. The plan mentioned vigorously developing the urban economy, expanding the scale of the city, and speeding up the development of natural landscape resources. These plans led to the expansion of cities and towns, the reconstruction of desert areas, and the transformation of the tourism industry. Economic development has led to environmental degradation in some regions, so the overall quality of the ecological environment shows a sharp decline. However, the quality of the ecological environment improved from 2016 to 2019, indicating that after the economy began to develop, human beings paid attention to the importance of sustainable development, so they were also saving the environmental damage while developing the economy.

6. Conclusions

Through the analysis of the ecological environment quality index (RSEI) of the northern Aksu region in different periods, it is concluded that:

1) The ecological environment quality index of the northern Aksu region in 2013, 2016, and 2019 were 0.706087, 0.25243, and 0.362991 respectively. From 2013 to 2016, the ecological environment quality of the northern Aksu region declined sharply, with a magnitude of about −0.45. Environmental quality has risen by +0.11.

2) The areas where the quality of the ecological environment in the northern Aksu region has declined significantly are the human settlements and the Gobi.

3) Humidity index and heat index are the two major factors that have the greatest impact on the quality of the ecological environment in the northern Aksu region.

The data as a whole show that the ecological environment in the northern Aksu region has deteriorated seriously, and the severely deteriorated area is close to the human living area, indicating that the quality of the ecological environment is seriously affected by human activities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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