DYNAMIC MONITORING OF ECOLOGICAL ENVIRONMENT QUALITY IN GANSU PROVINCE SUPPORTED BY GOOGLE EARTH ENGINE

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ABSTRACT:

With the rapid development of remote sensing technology, this technology has been widely used in the field of ecological environment monitoring. The Remote Sensing Ecological Index (RSEI) is based on remote sensing data and integrates the four factors of greenness, dryness, wetness, and heat. This study took Gansu Province as the research object and calculated its remote sensing ecological index in 2000, 2010 and 2020. The results showed: (1) In general, the average RSEI increased from 0.2665 to 0.3299, reflecting the positive trend of ecological environment quality in Gansu Province. (2) The ecological environment grades in Gansu Province were mainly poor and bad grades, which accounted for about 78% in 2000 and dropped to 65% in 2020. (3) In terms of space, the RSEI index showed a decreasing characteristic from southeast to northwest. The areas with better ecological quality were the Longnan Mountains and the Gannan Plateau, while the areas with poorer ecological quality are the Hexi Corridor. (4) From 2000 to 2010, the ecological environment quality improved slightly, and the area with slight improvement accounted for 30.17%. From 2010 to 2020, the ecological environment was relatively stable, and the stable area accounted for 71.15%. This study supplements the blank of ecological environment quality evaluation in Gansu Province and aims to provide a reference for ecological environment protection and sustainable development in Gansu Province.

1. INTRODUCTION

The ecological environment is a complex integrated system, which includes water resources, biological resources, climate resources, and land resources, and is inseparable from the survival and development of human beings (Zhang et al., 2021; Schneider,2012). With the acceleration of China's economic development and urbanization, ecological environment problems are becoming more and more serious, and the spatial differentiation of the ecological environment is significant. The northwest region is located deep in the interior of northwest China, and its natural ecological environment is extremely fragile (Wei et al., 2020). The western development strategy has promoted the continuous growth of the economic aggregate in the western region, but further aggravated the deterioration of the ecological environment in the northwest region (Zhuo and Deng, 2020; Zheng et al., 2022). At present, the northwest region is facing serious soil erosion, aggravation of land desertification, reduction of biodiversity, reduction and pollution of water resources, and serious air pollution. Ecological construction is an urgent problem to be solved in the development and construction of the western region, and it is necessary and important to evaluate the quality of its ecological environment, to provide a reference for sustainable development.

The commonly used methods of traditional ecological environment quality evaluation mainly include the Pressure-State-Response model (PSR) and Ecological Index (EI). The PSR model mainly explains the logical relationship between the environment and the economy from the perspective of the interaction between people and the environment, including three aspects: pressure index, state index, and response index (Fu et al., 2011). The Ecological Index model is proposed by the Ministry of Environmental Protection and reflects the quality of the ecological environment from five aspects: organisms, plants, water bodies, land, and environmental pollution (Yu and Zhao, 2020). The above evaluation methods all need to obtain a large amount of data, which are mainly from statistical yearbooks or field survey data. But these data are scarce and difficult to obtain. In addition, it is impossible to visually analyze the quality of the regional ecological environment. Remote sensing technology has the advantages of large data volume, fast acquisition speed, and wide monitoring range. With the rapid development of remote sensing technology, this technology has been widely used in the field of ecological environment monitoring. Scholars often use remote sensing indices to evaluate the regional ecological environment, such as Normalized Difference Vegetation Index, Land Surface Temperature, Impervious Surface Percentage, etc (Chen et al., 2020). In 2013, Xu (2013) proposed the Remote Sensing Ecological Index (RSEI), a new method of ecological environment quality evaluation based entirely on remote sensing data. The index integrates four factors greenness, dryness, wetness, and heat. The principal component analysis method is used to objectively and comprehensively evaluate the ecological environment quality of the region, which solves the problems of single evaluation index (Xu, 2018).

At present, the remote sensing ecological index is an important issue in ecological environment monitoring research. Domestic and foreign scholars have conducted verifications at different scales such as provinces, cities, urban agglomerations, and watersheds (Fan et al.,2020; Jiang et al., 2021; Wang 2021). For

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instance, Wu et al. (2022) analyzed the ecological environment quality of the Sahel region in Africa from 2001 to 2020 based on MODIS images and the RSEI index. The results showed that different land cover types in the region showed different trends in RSEI and the spatial differentiation of RSEI was large. Wen et al. (2019) evaluated the ecological environment quality of the Pingtan Comprehensive Experimental Zone from 2007 to 2017, and the results showed that the RSEI index showed a trend of first decreasing and then increasing. The construction and development of this area in the early stage led to the decline of RSEI, and the strengthening of ecological construction in the later stage promoted the improvement of the ecological environment. Lu et al. (2021) evaluated the ecological environment quality of Beijing from 2001 to 2020 based on the RSEI index. The results show that the RSEI index of Beijing has increased from 0.59 to 0.64 in the past 20 years, and the area of improved ecological environment quality has increased from 13.04% to 21.64%. The quality of the ecological environment has been improved. The above studies all show that RSEI can monitor changes in regional ecological environment quality.

Gansu Province is one of the provinces in the Northwest Region and an important part of the "Silk Road Economic Belt". However, due to the prominent ecological problems in Gansu Province in recent years, it has attracted great attention from the national government (Ma et al., 2010). This study took Gansu Province as the research object and calculated its remote sensing ecological index in 2000, 2010 and 2020 to explore the ecological environment quality status and changing trends of Gansu Province. This study supplements the blank of ecological environment quality evaluation in Gansu Province and aims to provide a reference for ecological environment protection and sustainable development in Gansu Province.

2. STUDY SITE AND METHOD

2.1 Study Site

Gansu Province (32°31´-42°57´N, 92°13´-108°46´E) is located in Northwest China, at the intersection of the Qinghai-Tibet Plateau, Loess Plateau, and Inner Mongolia Plateau (Zhang et al., 2020). The total land area of Gansu Province is about 453,700 km², and the total population is 26,257,100 (Ma et al., 2019). Gansu Province has complex climate types, including subtropical monsoon climate, temperate monsoon climate, temperate continental arid climate, and plateau mountain climate. In terms of topography, the topography of Gansu Province is complex and diverse, mainly mountainous and plateau landforms. In addition, the elevation decreases from southwest to northeast, and the elevation is mostly above 1000-2000m (Figure 1).

Gansu Province is situated in the upper reaches of the Yellow River and is relatively dry. Currently, Gansu Province faces problems such as land desertification, land salinization, soil erosion, etc. The natural ecological environment is fragile and the ecological self-recovery ability is weak (Liu et al., 2020). The economy of Gansu Province is relatively backward and the governance of the ecological environment needs to be improved. In addition, the growth of population and economy has further increased the pressure on the ecological environment.

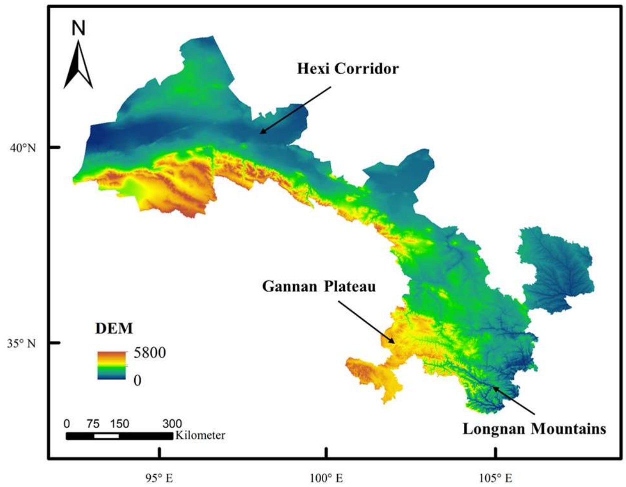

Figure 1. Location of Gansu Province.

2.2 Method

2.2.1 Construction of RSEI Indicator: To evaluate the ecological environment quality of Gansu Province, this paper uses the Remote Sensing Ecological Index (RSEI) proposed by Xu, which is constructed based on the pressure-state-response model. Dryness reflects the current pressure on the ecological environment, greenness represents the current state and changes of the ecological environment, wetness and heat reflect the climate change caused by changes in the ecological environment (Hu and Xu,2019).

The greenness index is the normalized vegetation index (NDVI), which is currently the most widely used vegetation index to represent the coverage and biomass of plants (Carlson and Ripley, 1997). The wetness index is the humidity component of the Tasseled Cap Transformation method, which is used to reflect the humidity of soil and vegetation (Lobser and Cohen,2007). The dryness index is the average of the selected bare soil index (SI) and building index (IBI) to reflect the dryness of the soil (Rikimaru et al., 2002). The heat index is the surface temperature, which reflects the thermal infrared radiation of the ground objects. In this paper, the SMW algorithm is used to invert the surface temperature (Ermida et al., 2020). The calculation formulas of the four indicators are as follows:

$$NDVI = (\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED}) \tag{1}$$

$$WET_{TM} = 0.0315\rho_{BLUE} + 0.2021\rho_{GREEN} + 0.3102\rho_{RED} + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR1} - 0.6109\rho_{SWIR2} \tag{2}$$

$$WET_{OLI} = 0.1511\rho_{BLUE} + 0.1972\rho_{GREEN} + 0.3283\rho_{RED} + 0.3407\rho_{NIR} - 0.7117\rho_{SWIR1} - 0.4559\rho_{SWIR2} \tag{3}$$

$$SI = [(\rho_{SWIR1} + \rho_{RED}) - (\rho_{NIR} + \rho_{BLUE})]/(\rho_{SWIR1} + \rho_{RED}) - (\rho_{NIR} + \rho_{BLUE}) \tag{4}$$

$$IBI = [2\rho_{SWIR2}/(\rho_{SWIR1} + \rho_{NIR}) - \rho_{NIR}/(\rho_{NIR} + \rho_{RED}) - \rho_{GREEN}(\rho_{SWIR1} + \rho_{GREEN})]/[2\rho_{SWIR2}/(\rho_{SWIR1} + \rho_{NIR}) + \rho_{NIR}/(\rho_{NIR} + \rho_{RED}) + \rho_{GREEN}(\rho_{SWIR1} + \rho_{GREEN})] \tag{5}$$

$$NDBSI = (SI + IBI)/2 \tag{6}$$

$$LST = A_i\frac{Tb}{\varepsilon} + B_i\frac{1}{\varepsilon} + C_i \tag{7}$$

$$\varepsilon_b = FVC\varepsilon_{b,veg} + (1 - FVC)\varepsilon_{b,bare} \tag{8}$$

$$FVC = (NDVI - NDVI_{bare})/(NDVI_{veg} - NDVI_{bare}) \tag{9}$$

where ρ_{RED} = the red band of the Landsat image
ρ_{BLUE} = the blue band of the Landsat image
ρ_{GREEN} = the green band of the Landsat image
ρ_{NIR} = the near infrared 1 band of the Landsat image
ρ_{SWIR1} = the short-wavelength infrared 1 band of the Landsat image
ρ_{SWIR2} = the short-wavelength infrared 2 band of the Landsat image
Tb = Brightness temperature of TIR channel
ε = specific emissivity
A_i,B_i,C_i = Linear regression coefficients
$\varepsilon_{b,veg}$ = Specific emissivity of vegetation
$\varepsilon_{b,bare}$ = Specific emissivity of bare ground
$NDVI_{bare}$ = NDVI values for fully naked pixels
$NDVI_{veg}$ = NDVI values for fully vegetated pixels

2.2.2 Application of RSEI on the GEE Platform: The Google Earth Engine (GEE) platform is a free online platform developed by Google for processing massive amounts of remote sensing data. The main advantage of this platform lies in the amount of data and processing capabilities. On the one hand, the platform has massive remote sensing data, such as Landsat series, Sentinel series, vector boundary data, surface temperature, and the number of global water bodies. On the other hand, the platform has strong remote sensing data processing and analysis capabilities. Based on the API interface, it can realize large-scale and long-term image processing. At present, it has been applied to various fields such as global forest change, water resources change, land use, and urban construction (Kumar and Mutanga 2018; Gorelick et al.,2017; Tamiminia et al., 2020). In this study, the RSEI calculation is performed based on the GEE platform. The specific steps are as follows:

Step1: Filter images and de-cloud processing. In this study, the "LANDSAT/LT05/C01/T1_SR"and "LANDSAT/LC08/C01/T1_SR" datasets were selected based on the GEE platform. In the cloud removal process, the QA quality band is selected for cloud removal, and then the images of the year are fused using the mean algorithm.

Step2: Component index calculation. RSEI is obtained by coupling the four indicators of WET, NDVI, NDBSI, and LST.

Step3: Calculate the RSEI index. After normalizing the four component indicators, the principal component analysis method is used to calculate the RSEI index. The calculation formulas are as follows:

$$RSEI_0 = 1 - \{PC1[f(WET, NDVI, LST, NDBSI)]\} \tag{10}$$

$$RSEI = (RSEI_0 - RSEI_{0min})/RSEI_{0max} - RSEI_{0min} \tag{11}$$

where $PC1$ = the first principal component
$RSEI_0$ = initial value of RSEI
$RSEI_{0min}$ = minimum value of RSEI
$RSEI_{0max}$ = Maximum value of RSEI

3. RESULT

3.1 Principal Component Analysis Results

Principal component analysis is performed on the four indicators of NDVI, WET, NDBSI, and LST. It can be found that the contribution rates of the first principal component are 81.81%, 78.90%, and 84.41%, respectively, which indicates that the first principal component concentrates the main features of the data and can be used as a data source for subsequent calculations. From the perspective of the first principal component, the NDVI and WET indicators are positive, indicating that they have a positive effect on the ecological environment. However, the NDBSI and LST indicators are negative, which represent a negative effect on the ecological environment. In addition, the contribution rate of NDVI and NDBSI to the first principal component is relatively high, which reflects that greenness and dryness have a greater impact on the quality of the ecological environment.

3.2 Analysis of the Results of RSEI

The RSEI of Gansu Province in 2000, 2010, and 2020 were calculated through the GEE platform (Table 2). In general, the average RSEI increased from 0.2665 to 0.3299 and the growth rate was 0.0032 per year. The upward trend of RSEI was obvious, which indicated that the overall ecological environment of Gansu Province has improved in the past 20 years. The four sub-indicators exhibited the following characteristics: (1) The NDVI index has risen from 0.4685 to 0.5227 in the past 20 years, reflecting the increase in vegetation coverage in Gansu Province. This was closely related to the vigorous implementation of environmental protection projects such as returning farmland to forests and the construction of the Three North Shelter Forests in Gansu Province during this period. (2) WET was the most variable among the four indicators, and the wet indicator in 2020 was twice that of 2000, which was mainly related to the increase of precipitation and the improvement of vegetation coverage. (3) The NDBSI indicator dropped significantly from 0.3182 to 0.1529. The index consists of the bare soil index and the building index. The building index increased with the acceleration of urbanization, and the bare soil index decreased with the increase of soil moisture. Finally, the decrease of the bare soil index was significantly greater than the increase in the building index. (4) The LST index first decreased and then increased, which also reflected the trend of global warming.

Year	Indicator	PC1	PC2	PC3	PC4
2000	NDVI	0.83	0.55	-0.03	-0.06
	WET	0.16	-0.35	0.02	-0.92
	NDBSI	-0.49	0.73	0.33	-0.35
	LST	-0.20	0.22	-0.94	-0.14
	Eigenvalue	0.0253	0.0043	0.0010	0.0003
	Contribution rate	81.81%	14.02%	3.28%	0.89%
2010	NDVI	0.75	0.64	0.15	0.09
	WET	0.15	-0.25	-0.23	0.93
	NDBSI	-0.50	0.38	0.69	0.35
	LST	-0.40	0.62	-0.67	0.07
	Eigenvalue	0.0432	0.0081	0.0031	0.0003
	Contribution rate	78.90%	14.75%	5.74%	0.61%
2020	NDVI	0.67	0.58	0.41	0.22
	WET	0.16	-0.25	-0.39	0.87
	NDBSI	-0.60	0.06	0.67	0.43
	LST	-0.40	0.78	-0.48	0.08
	Eigenvalue	0.0675	0.0082	0.0039	0.0003
	Contribution rate	84.41%	10.26%	4.91%	0.41%

Table 1. Principal Component Analysis Results.

Indicator	2000	2010	2020
NDVI	0.4685	0.5066	0.5227
WET	0.2885	0.6839	0.6832
NDBSI	0.3182	0.3139	0.1529
LST	0.7799	0.701	0.7554
RSEI	0.2665	0.3154	0.3299

Table 2. Average of component indicators and RSEI.

To better analyze the ecological environment quality of Gansu Province, this study graded the RSEI as follows: Bad(0-0.2), Poor(0.2-0.4), Moderate (0.4-0.6), Good(0.6-0.8)、High(0.8-1.0). In the past 20 years, the ecological environment grades in Gansu Province have been dominated by bad and poor grades, accounting for more than 65% (Figure 2). From 2000 to 2010, the proportion of bad grade decreased from 50% to 43%, and the sum of good and high grade increased from 7% to 14%, which reflected the significant improvement of the ecological environment quality in Gansu Province. From 2010 to 2020, the proportion of each grade has not changed significantly. The proportion of good grade has increased from 10% to 13% and the proportion of high grade has increased from 4% to 5%. The changes of RSEI ecological grade showed a continuous and positive trend.

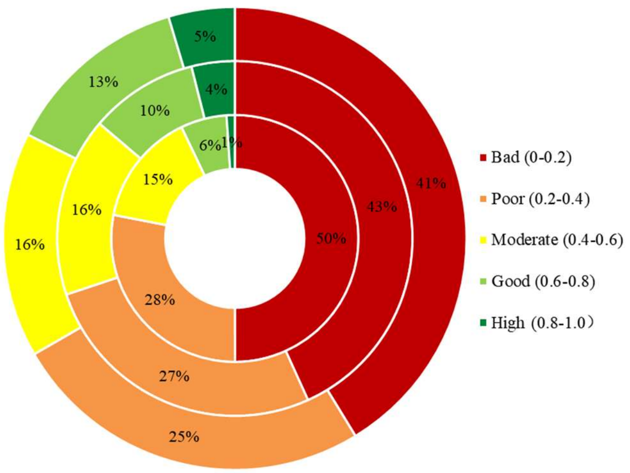

Figure 2. The proportion of each ecological grade area (From outside to inside are 2020, 2010, 2000).

From the perspective of spatial distribution (Figure 3-5), the ecological environment quality of the part of Gansu Province near Qinghai Province (higher altitude) was better than that of the part near Inner Mongolia (lower altitude). The RSEI index showed a characteristic of decreasing from southeast to northwest. In addition, from the perspective of landform types, the areas with the best ecological quality in Gansu Province were the Longnan Mountains and the Gannan Plateau, where the vegetation coverage was relatively high. The ecological quality of the Hexi Corridor was the worst in Gansu Province, because of the poor vegetation coverage, fragmented terrain and concentrated precipitation, resulting in serious soil erosion.

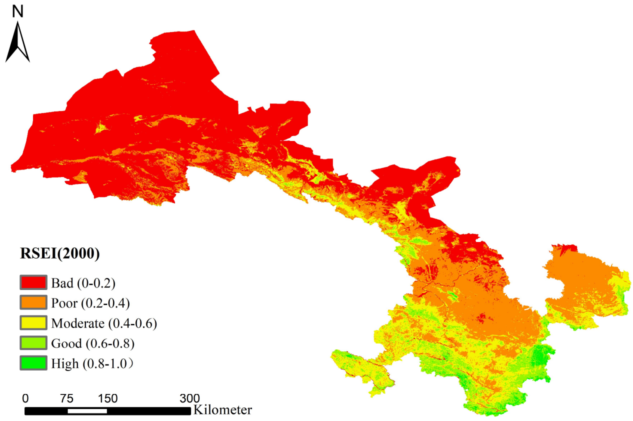

Figure 3. Distribution of RSEI ratings of Gansu Province in 2000.

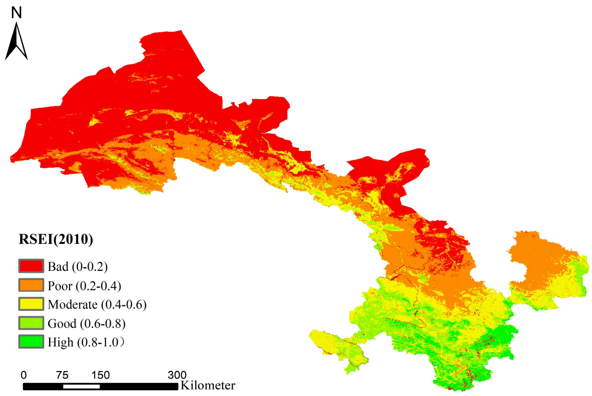

Figure 4. Distribution of RSEI ratings of Gansu Province in 2010.

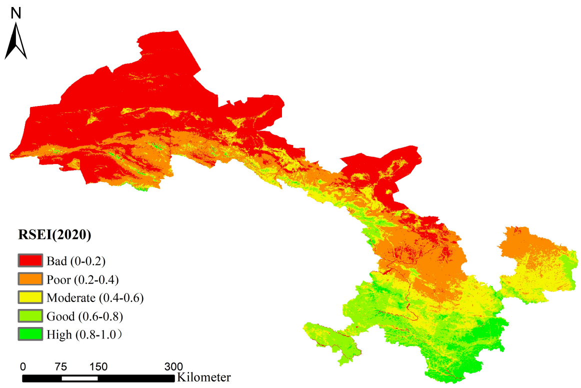

Figure 5. Distribution of RSEI ratings of Gansu Province in 2020.

3.3 Dynamic Changes of Ecological Environment

To more intuitively reflect the spatial changes of the ecological environment quality in Gansu Province, the difference calculation was performed using the raster calculator of ArcGIS. The results were divided into five intervals: significantly degraded (-1.0~-0.2), slightly degraded (-0.2~-0.05), stable (-0.05~0.05), slightly improved (0.05~0.2), and significantly improved (0.02~1.0).

From 2000 to 2010, the ecological environment quality changes in Gansu Province were mainly stable and slightly improved (Figure 6). The stable area accounted for 60.11% and the slightly improved area accounted for 30.17% (Figure 8). From the perspective of spatial changes in ecological quality, the slightly improved areas were mainly distributed in the southeast of Gansu Province, dominated by the Longnan Mountains and the Gannan Plateau, while the stable areas were dominated by the Hexi Corridor.

From 2010 to 2020, there was no significant change in the quality of the ecological environment in Gansu Province, and the stable area accounted for 71.15% (Figure 7-8). Compared with 2000-2010, the proportion of slightly improved areas and significantly improved areas decreased while the proportion of slightly degraded areas increased. From the perspective of spatial changes in ecological quality, the degraded areas were mainly concentrated in the Gannan Plateau, which was mainly due to the serious degradation of grassland and vegetation coverage in this area. In addition, the ecological environment quality of Hexi Corridor had no obvious changes and was relatively stable.

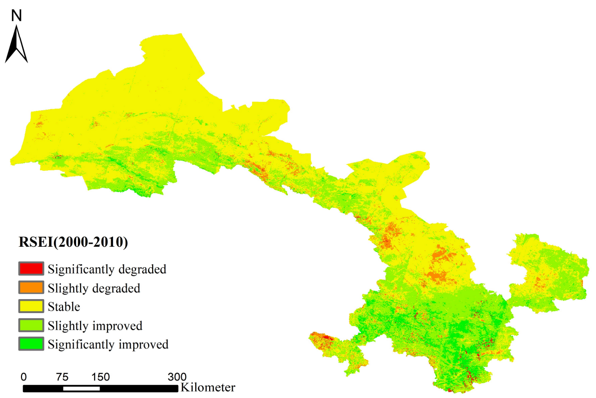

Figure 6. Changes in ecological quality from 2000 to 2010.

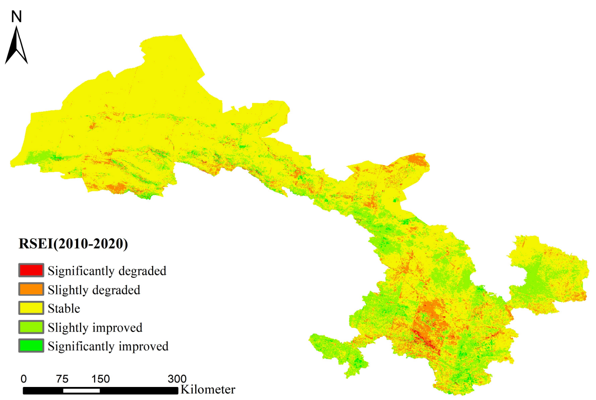

Figure 7. Changes in ecological quality from 2010 to 2020.

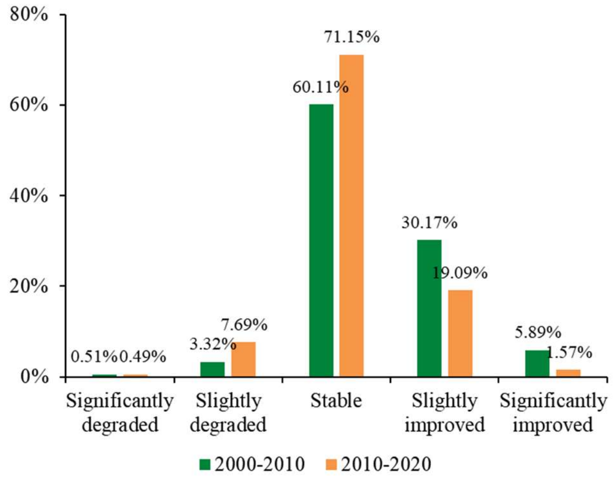

Figure 8. The proportion of changes in ecological environment quality.

4. CONCLUSION

In this study, we evaluated the ecological environment quality of Gansu Province from 2000 to 2020 based on the GEE platform and the RSEI model. The main conclusions were as follows: (1) In general, the average RSEI increased from 0.2665 to 0.3299, reflecting the improvement of the ecological environment in Gansu Province in the past 20 years. (2) The ecological environment grades in Gansu Province have been dominated by bad and poor grades, accounting for more than 65%. Additionally, the area of poor and bad grades decreased while the area of good and high grades increased. The change of RSEI ecological grade showed a continuous and positive trend. (3) In terms of space, the RSEI index showed a characteristic of decreasing from southeast to northwest. Areas with better ecological quality were the Longnan Mountains and the Gannan Plateau. (4) From the dynamic changes of ecological environment quality in Gansu Province, the ecological environment quality improved slightly from 2000 to 2010, and the slightly improved areas accounted for 30.17%, mainly distributed in the Longnan Mountains and the Gannan Plateau. From 2010 to 2010, the ecological environment was relatively stable, and the stable area accounted for 71.15%.

The quality of the ecological environment in Gansu Province has improved in the past 20 years, but it can also be found that the speed of improvement is gradually decreasing. As an important part of the "Silk Road Economic Belt" and a significant province in the development of the western region, the government must promote ecological security and economic development for mutual benefit and win-win results. For example, establish and improve the ecological compensation mechanism, promote the comprehensive management of the grassland ecological environment, and strengthen the management and control of the closure of desertified land.

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