The aeolian desertification process and driving mechanism of Qinghai Lake basin from 2004 to 2019

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Abstract. We calculated the area of seven ecosystems, used the NDVI index to analyze the temporal-change of vegetation-covered land in the Qinghai Lake basin from 2004 to 2019, and the principal component analysis to analyze the driving mechanism of desertification. The results showed that grasslands are the dominant ecosystem, and the desert ecosystem had an area of 32 km^2, accounting for only 0.1% of the total area. The evolution of desertification was in the reversal stage. The vegetation cover increased from 54% in 2004 to 66% in 2019, showing a change process of mild destruction-slow restoration: 2004-2008, high degree vegetation-covered land dominated the declination of vegetation with the dynamic trend of -5.67%; 2009-2013, medium degree vegetation-covered land dominated the restoration of vegetation with the dynamic trend of 2.45%; 2014-2019, medium and high degree vegetation-covered land showed an increasing trend with the dynamic trend of 0.86% and 1.17% respectively. Natural and human factors, which were manifested as the domination of human activities and the exacerbation effect of natural factors, influenced desertification. The first principal component integrated both anthropogenic and natural factors accounted for 52.27% of the contribution rate, while the second principal component included only natural factors that accounted for 23.77%.

1 Introduction

Desertification is one of the most serious environmental problems in the world today, posing a serious threat to human survival and development [1, 2]. China is one of the region's most seriously threatened by desertification. Land desertification poses a serious threat to humans and restricts regional resource development and sustainable economic development. In the northwest part of China, the rapid expansion of desertification will lead to a serious decline in grassland productivity, intensification of grassland ecological crisis, degradation of sandy vegetation, and rampant dust storms. It affects the development of the local economy and society and poses a serious threat to the development of surrounding areas [3, 4].

Qinghai Lake is the largest plateau inland saltwater lake in China, an important water body for maintaining ecological security in the northeastern part of the Tibetan Plateau. A natural barrier to control the spread of desertification to the east in the west has an irreplaceable role in protecting and maintaining biodiversity, regulating climate in the northwest, water connotation, and maintaining ecological balance. The area around Qinghai Lake also belongs to the area sensitive to global climate change and fragile ecosystems [5-6]. However, with

regional climate change and increasing human activities in the last 30 years, the deserted land in the lake-ring area of Qinghai Lake is expanding rapidly. It spreads around the lake in a ring-like pattern and forms four large sand areas in the lake's east: Ganzi River in the lake's northeast, Bird Island on the north shore of the west of the lake, and Longma Shegang on the southeast edge of the lake basin [5,7,8].

Therefore, from the 1980s, many scholars began to conduct comprehensive analysis and research on the causes, current situation, harm, and management countermeasures of the wind-sand accumulation, peri-lake desertification on the east coast Qinghai Lake [9, 10]. Remote sensing technology has also been applied to the region since the 1990s. Scholars have established remote sensing monitoring system indicators of desertification in the Qinghai Lake basin [11]. They studied the dynamics, distribution, driving mechanism, and continuity of desertification in the Qinghai Lake basin [12-15]. It showed that the desertification area was growing. Some scholars also evaluated the decertified land in the Qinghai Lake basin and proposed ecological environment reconstruction. Some scholars have also evaluated the decertified land in the Qinghai Lake basin and proposed ways and countermeasures to reconstruct and protect the ecological environment around Qinghai Lake [11,16-18]. The above studies show that the development and

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evolution of decertified land in the Qinghai Lake basin and the driving mechanism have been explored to some extent. However, considering the slow and concentrated development of desertification at spatial and temporal scales, monitoring and analyzing it for a long time series can help to better grasp the dynamics and driving mechanism of desertification [19, 20]. Few scholars have paid attention to the desertification of Qinghai Lake in the past five years, especially the lack of research on the region's current situation by remote sensing technology. It has led to a "fault line" in the research and adversely affected the understanding of desertification in the region. There lacks of year series data with a large period in the existing research, especially for the mutual transfer between different levels of patches and vegetation. In this study, remote sensing images are selected to analyze the changes in different ecosystems. NDVI is used to analyze the temporal change characteristics of vegetation. Finally, the dynamics and driving mechanism of desertification of Qinghai Lake are clarified by using Principal Component Analysis to better understand the ecological reconstruction and protection of Qinghai Lake and its surrounding area. The aim is to provide basic data and management guidance for the reconstruction and protection of Qinghai Lake and its surrounding ecological environment.

2 Method

2.1 Data source and processing

2.1.1 NDVI data

The Normalized Difference Vegetation Index (NDVI) can accurately reflect the vegetation coverage on the ground. At present, long-term NDVI data based on satellite remote sensing such as SPOT/VEGETATION and MODIS has been widely used in researches such as dynamic change monitoring of vegetation, land use/cover change detection, macro-vegetation coverage classification, and net primary productivity estimation in different regions. Applications. The 1KM Vegetation Index (NDVI) spatial distribution data set of China's growing season is based on SPOT/VEGETATION NDVI satellite remote sensing data. The maximum value synthesis method is used to generate the vegetation index data set of the growing season since 1998 based on monthly data. This data set effectively reflects the distribution and change of vegetation coverage on spatial and temporal scales in various countries. It has very important reference significance for monitoring vegetation change, the rational use of vegetation resources, and the research in other related fields to the ecological environment. The NDVI data of the growing season is the maximum value of the NDVI data from March to November (spring, summer, and autumn). The data space covers the entire country, and the data acquisition time is from 1998 to 2019. Since there is only data from January to June in 2020, the data for 2020 is temporarily missing. The downloaded data is in ARCGIS GRID format with a spatial resolution of 1km.

2.1.2 Vegetation coverage

Fractional vegetation cover (FVC) is an important biophysical parameter describing the Earth's surface system. Fractional vegetation cover refers to the percentage of the vertical projection of vegetation (including leaves, stems, and branches) on the ground to the total area of the statistical area[21]. The calculated vegetation coverage is also different in the same area because of the difference in the total area. According to the principle of the pixel dichotomy model, the formula for calculating vegetation coverage is

$$fc = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \qquad (1)$$

$NDVI_{soil}$ is the value of NDVI of the covered area completely prepared for bare soil cargo. $NDVI_{veg}$ is the value of NDVI representing the pixel completely covered by vegetation.

According to the method of estimating $NDVI_{veg}$ and $NDVI_{soil}$ proposed by Li Miaomiao for previous scholars' research on vegetation coverage, combined with the NDVI gray-scale statistical distribution of the data source, the upper and lower thresholds of NDVI are intercepted with 95% confidence to represent respectively $NDVI_{veg}$ and $NDVI_{soil}$ [22]. Using the Extract by mask function provided by ArcGIS, extract the basic NDVI image of the Qinghai Lake basin based on the NDVI data and the vector boundary data of the Qinghai Lake basin area. Then use the grid calculator function of ArcGIS to calculate the vegetation coverage distribution using the above formula summary graph. After calculation, the vegetation coverage can be divided into 5 levels, namely non-vegetation coverage (VFC<20%), low vegetation coverage (20%<VFC<45%), and medium vegetation coverage (45%<VFC<60%), mid-high level vegetation coverage (60%<VFC<75%), high vegetation coverage (75%<VFC). Among them, the vegetation coverage of all levels is the value range we consider based on the VFC characteristic distribution of the study area.

2.1.3 Ecosystem distribution data

Based on the 1:100,000 scale land use/land cover data obtained by remote sensing interpretation of the macro-structure data of China's terrestrial ecosystem, through the identification and research of various types of ecosystems, multiple periods of China's terrestrial ecosystem types are formed after classification processing Spatial distribution data set. The seven ecosystem types for the three years of 2005, 2010, and 2015 are respectively counted to provide a basis for subsequent data analysis.

The definition of China's terrestrial ecosystem types is shown in the table below, which is divided into 7 major ecosystem types:

(1) Farmland ecosystem, which mainly includes paddy field 11 and dry land 12 in the remote sensing classification system of land use/land cover;

(2) Forest ecosystem, mainly including dense forest land (with forest land) 21, shrub 22, open forest land 23, and other forest lands 24 in the remote sensing

classification system of land use/land cover;

(3) Grassland ecosystem, which mainly includes high-coverage grassland 31, medium-coverage grassland 32, and low-coverage grassland 33 in the remote sensing classification system of land use/land cover;

(4) Water bodies and wetland ecosystems, mainly including swamps 64, rivers 41, lakes 42, reservoirs 43, glaciers and permanent snow 44, beaches 46 in the remote sensing classification system of land use/land cover;

(5) Desert ecosystems, mainly including sandy land 61, Gobi 62, saline land 63, and alpine desert 67 in the remote sensing classification system of land use/land cover;

(6) Settlement ecosystem, mainly including urban 51, rural residential area 52, industrial and mining 53 in the remote sensing classification system of land use/land cover

(7) Other ecosystems, mainly including bare land 65 and bare rock and gravel land 66 in the remote sensing classification system of land use/land cover.

2.1.4 Driving factor data

Natural factors and human factors are the major driving factors affecting land desertification. Based on the comprehensive research of many scholars on the driving mechanism of desertification in the arid area of Northwest China, combined with the four counties along the coast of Qinghai Lake, Gangcha, Gonghe, Haiyan, and Tianjun counties. There are correlations between data and various data, and 10 representative indicators are selected from man-made and natural driving factors. Among them, the natural driving factors include four indicators: annual precipitation, annual average temperature, annual average wind speed, and annual sunshine hours, which are derived from the meteorological data of the National Meteorological Science Data Center (China) (http://data.cma.cn/) Station site data. The selected man-made driving factors include six indicators, including agricultural population, arable land area, livestock breeding capacity, number of tourists, afforestation area, and water conservancy construction projects derived from the 2001-2014 Qinghai Province Economic and Social Development Statistical Database Compilation.

2.2 Principal component analysis

The principal component analysis is a multivariate statistical method that reduces the dimensions of variables. It is based on the original variable information as much as possible, and someone linearly transformed multiple correlated variables to filter out comprehensive independent factors. Comprehensively reflect the information of most of the original variables, which can avoid the influence of subjective arbitrariness. Considering the complexity and diversity of the driving factors for the desertification of Qinghai Lake, this study uses principal component analysis to extract the human factors that affect the desertification of Qinghai Lake. It aims to find out the main driving factors for the desertification of Qinghai Lake and provide information for the prevention and control of the desertification of

Qinghai Lake. Scientific theoretical basis. Principal component analysis was carried out on the selected driving factors through SPSS software. To judge whether each driving factor is suitable for principal component analysis, the KMO test is performed on the driving data. The KMO statistic is 0.79 (KMO>0.5), indicating a certain linear relationship between the driving factors, and principal component analysis is suitable, followed by further data processing to obtain the central component load matrix and variance contribution rate.

3 Results and Discussion

3.1 Temporal evolution of desertification

3.1.1 Status of desert ecosystem and vegetation cover

Grasslands are the dominant ecosystem in the area and have a very low level of desertification. In 2015, it can be observed from Table1 that the lagoon area has 32 km^2 of the desert ecosystem, accounting for only 0.1% of the total area, while the farmland ecosystem, forest ecosystem, grassland ecosystem, water and wetland ecosystem, settlement ecosystem, other ecosystems accounting for 1.76%, 4.39%, 46.01%, 20.05%, 12.60%, and 8.73% respectively. In 2019, it can be illustrated from Figure1 that the lagoon area has 19598km2 of vegetation-covered land, accounting for 66% of the total area. Among them, low degree, medium degree, medium-high degree, high degree vegetation-covered land accounted for 14.95%, 15.43%, 25.35%, 44.27% of the total vegetation-covered land area, respectively. The deserted land spreads around Qinghai Lake in the shape of a ring belt. It is mostly concentrated, forming the sand area in the lake's east: Ganzi River in the lake's northeast, Bird Island in the northwest coast of the lake, and the sand area of Longma Shegang in the southeast edge of the lake basin [5,7,8].

3.1.2 Temporal change of desertification and vegetation-covered land

The dynamic trend is a common indicator used to reflect the magnitude and rate of change of area in different land-use types per unit time and the type difference in regional land-use change [23-25]. The dynamic trend of vegetation-covered land as a land type can reflect the change in vegetation cover during the study period with the following model equation:

$$k = \frac{Ub - Ua}{Ua} \times \frac{1}{T} \times 100\% \qquad (2)$$

Where K is the dynamic trend of a certain type of vegetation-covered land during the study period; Ua and Ub are the amounts of a certain type of vegetation-covered land at the beginning and end of the study period, respectively; T is the study period. The dynamic trend of vegetation-covered land in the Qinghai Lake basin was calculated to obtain the dynamic trend of vegetation-covered land in each class at each period.

After 2000, with the implementation of many ecological construction projects in Qinghai Lake, sand prevention and control have entered a new stage. In 2015, the lagoon area has only 32 km^2 of the desert ecosystem, accounting for only 0.1% of the total area, though it had a net increase of 11 km^2 area after 2010. The area of farmland ecosystem, forest ecosystem, grassland ecosystem, and water and wetland ecosystem had all experienced a slight increase of 7 km^2, 1 km^2, 12 km^2, and 39 km^2 respectively. The proportion of the share increased by 0.02%, 0.00%, 0.02%, 0.12% respectively which demonstrated that the environment had been improved during 15a period and the increasingly stable situation with controlled desertification. It can also be seen from Figure 1 that combined with the characteristics of changes in vegetation-covered land of different classes, the evolution of desertification in Qinghai Lake can be considered being in the reversal stage: the area of vegetation-covered land shows a fluctuating increasing trend in the reversal stage, and the vegetation cover increases from 54% in 2004 to 66% in 2019, reaching a maximum of 69% in 2017, the average annual expansion rate is 0.8%. In terms of land area with different degrees of vegetation cover, the area of low degree and medium degree vegetation cover shows a fluctuating decreasing trend. The area of medium degree and high degree vegetation cover shows a stable trend; while high degree vegetation cover shows a fluctuating trend of increase. And the amount of increase in the low degree, medium degree, medium-high degree, high degree vegetation-covered land is -1573, -1065, -645 and 2618 respectively, indicating that during this 15a period high degree vegetation cover land is the main part of the increase in vegetation-covered land area.

From 2004 to 2008, the area of vegetation-covered land in the Qinghai Lake basin had a net decrease of -199km^2. In terms of land with different degrees of vegetation cover, the area of land with low and medium-high degree vegetation cover showed different levels of growth, accounting for a dynamic trend of 2.08% and 4.78%, respectively. The land area with medium and high degree vegetation cover showed different levels of reduction, accounting for a dynamic trend of -0.19% and -5.67%, respectively. It can be seen that the vegetation in the Qinghai Lake basin was still damaged to a slight extent during this period, and high vegetation-covered land played a dominant role in the declination of vegetation. From 2009 to 2013, the area of vegetation-covered land in the Qinghai Lake basin had a net increase of 18km2. Among them, only the area of medium and high degree vegetation-covered land showed an increasing trend, with the dynamic trend of 2.45% and 0.52%, respectively; both low and medium-high vegetation-covered land area both showed a decreasing trend, with the dynamic trend of -2.72% and -0.70% respectively. It can be observed that the vegetation in the Qinghai Lake basin recovered during this period, with medium degree vegetation-covered land playing a dominant role in the restoration of vegetation. From 2014 to 2019, the area of vegetation-covered land in the Qinghai Lake basin had a net decrease of -11km^2. Among them, the land area covered by medium and high degree vegetation continued to show an increasing trend, with the dynamic trend of 0.86% and 1.17%, respectively; the land area covered by low and medium-high degree vegetation still showed a decreasing trend, with the dynamic trend of -2.89% and -0.46% respectively. It indicates that the ecological quality of the Qinghai Lake basin has been improved; the vegetation has been well restored gradually though still confronted the threat of desertification, and the work of sand prevention and control has been proven to be effective during this period.

In conclusion, during the 15a period from 2004 to 2019, the vegetation-cover land in the lagoon area showed different developmental trends at different stages, which showed a change process of mild destruction-slow restoration, and the work on controlling desertification has been proven to be effective.

Table 1. Change of land area with different types of ecosystems in Qinghai Lake/km^2

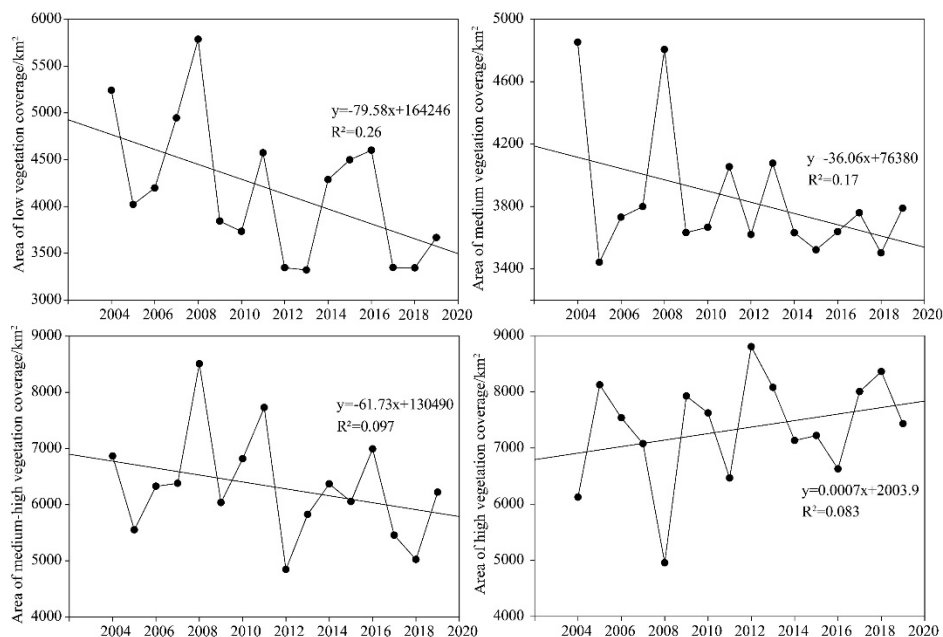| Year	Farmland ecosystem	Forest ecosystem	Grassland ecosystem	Water and wetland ecosystem	Desert ecosystem	Settlement ecosystem	Other ecosystems
2005	551	1389	14560	6311	21	4051	2776
2010	560	1389	14549	6308	21	4057	2775
2015	558	1390	14572	6350	32	3992	2765

Figure 1. Change of area for different vegetation-covered land in Qinghai Lake
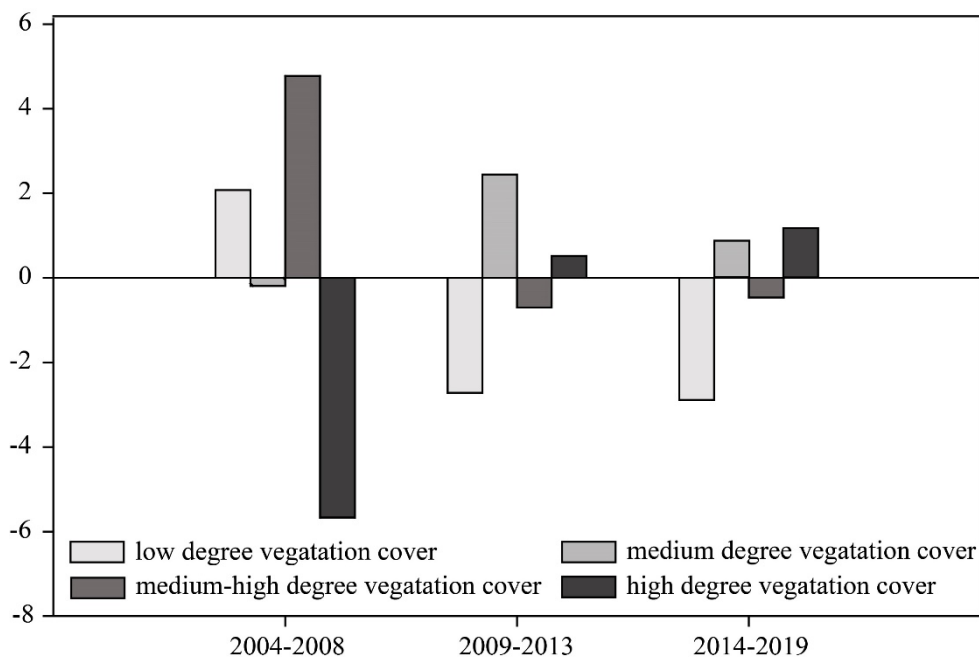

Figure 2. Change of dynamic trends for different degrees of vegetation cover in Qinghai Lake

3.2 Driving force of Desertification

The cumulative variance contribution of the two principal components amounted to 76.05%, which contained most of the information in the data with a high confidence level (Table 2). The contribution rate of the first principal component is 52.27%, which integrates 8 indicators such as mean annual precipitation, wind speed, arable land area, agricultural population, livestock breeding capacity, number of tourists, afforestation area, water construction projects. It mainly explain the combined effect of explaining the anthropogenic and natural factors on the desertification of Qinghai Lake; the contribution rate of the second principal component is 23.77%, including only

average sunshine hours. Desertification is a complex process, which is influenced by many aspects. In a comprehensive view, the expansion and reversal of desertification from 2004 to 2014 the interaction between natural and human factors, which is specifically manifested as the domination of human activities and the exacerbation effect of natural factors.

From 2004 to 2008, the four counties along Qinghai Lake paid increasing attention to the management of the ecological environment. In terms of the combined natural and human driving force, the mean annual precipitation is gradually decreasing, indicating a risk of increasing drought along the coast of Qinghai Lake, which increases the difficulty of desertification control to a certain extent. However, with the implementation of artificial

afforestation projects and mountain closure projects, the annual afforestation area has increased significantly. Especially from 2006 onwards, with a fluctuating increase in afforestation area and a significant increase in forest cover, it enhances wind and sand control. Despite implementing 'Returning farmland to forest' measures, the arable land area still increased steadily after 2004. The cultivation of cropland is precisely the key factor causing desertification. The control of desertification often shows a lagging ecological restoration effect, so the cultivation of cropland in this period will still have a negative environmental effect on the maintenance of ecological stability [26]. Extreme water scarcity can be a determinant factor of desertification. The mean annual precipitation of the Qinghai Lake basin is concentrated between 200-400 mm, compared with the mean annual precipitation of 400-500 mm in the horqin and maohuusu sands. The decertified land takes longer to recover itself [27-28]. The increase of agricultural population and the livestock breeding capacity, and the local arable land is mainly irrigated farmland while the number of water construction projects is relatively small. It results in a surge in water consumption, water scarcity, and the death of some forest vegetation due to lack of water, making the ecological protection capacity weakened. In addition, the rampant sand and wind caused by drought have increased the desertification of the land. The interannual trends of mean annual temperature, average sunshine hours, and wind speed are not obvious in terms of natural driving factors. The variance contribution rate is only 23.77%, which further indicates that human driving factors dominate the development of desertification in this period. Therefore, the desertification in the Qinghai Lake basin was curbed during this period. The desertification level was on a weakening trend, but still suffered a certain degree of ecological damage, mainly by human activities.

In 2009, the ecological construction of the four counties along Qinghai Lake entered a stage of accelerated development, and the work of sand prevention and control stepped into a new historical stage with the largest investment and the fastest advancement ever. The prevention and control of desertification were effective. In terms of the combined natural and human driving force, though the mean annual precipitation demonstrated a decreasing trend, the four counties along Qinghai Lake continuously increased the construction of water construction projects, Shazhuyu irrigation area transformation, and Huangyu home over the fish passage. Other water conservancy projects have been implemented by implementing channel lining, off the good pressure field and many other ecological resources protection measures, reducing the drought on the ecological environment of Qinghai Lake disturbance, and promoting the reversal of desertification. Since 2011, the afforestation area has increased significantly, the forest coverage rate has improved significantly, and the wind and sand control capacity has been enhanced. In addition, with the development of the economy, the livestock breeding volume has increased year by year, up to 2,375,200 at the end of 2014. However, with the governments of four counties, including Gangcha County, comprehensively promoting the ecological livestock recycling economy-based livestock industry, the traditional livestock production methods have been transformed to such ecological and efficient intensive production methods as artificial forage and warm shed breeding. Several ecological livestock recycling economy zones have been created, so the livestock industry The development of animal husbandry does not significantly impact the ecological environment. Furthermore, the four counties along the coast of Qinghai Lake have made great efforts to build ecological tourism by organizing the Cang Yang Jatso Love Song Concert, Qinghai Lake Fish Watching and Release Festival, strengthening the construction of scenic spots such as Wugu Mountain, Fairy Bay, Huangyu Home, and other supporting facilities. The brand influence of 'Qinghai Lake Culture' based on the 'fish culture' and 'sea sacrifice culture' has been further enhanced, with the number of tourists increasing from 1.45 million to 3.30 million. This also objectively promotes the transformation of the economic structure and the ecological protection of Qinghai Lake. In terms of natural driving factors, from 2009 to 2014, mean annual precipitation gradually decreased, the mean annual temperature fluctuated and increased, and the wind speed showed a decreasing trend. Taken together, the changes in mean annual temperature and precipitation are not conducive to sand control and sand management, while the changes in wind speed help to promote the reversal of desertification to a certain extent. The phenomenon of desertification in Qinghai Lake was improved, and the vegetation was restored during this period, which is related to the ecological construction of four counties along Qinghai Lake.

Water resources are the essence of ecological problems in arid and semi-arid areas. To further curb land desertification in the Qinghai Lake basin while implementing the return of farmland to forests and building wind and sand control belts, we should focus on solving the water problem. By reasonably regulating human production and management activities, optimizing the allocation of water resources, and promoting the efficient use of water resources, we can control land desertification in the Qinghai Lake basin from the source.
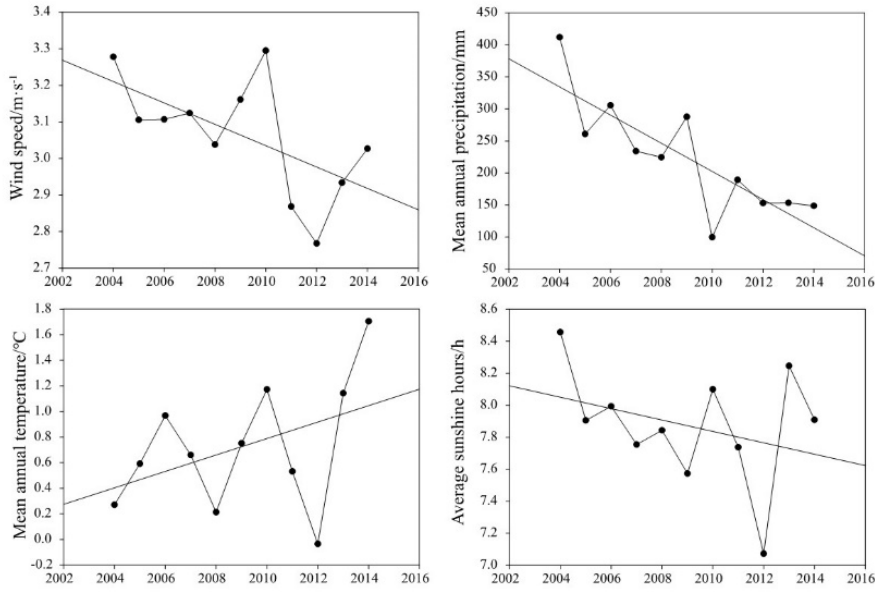
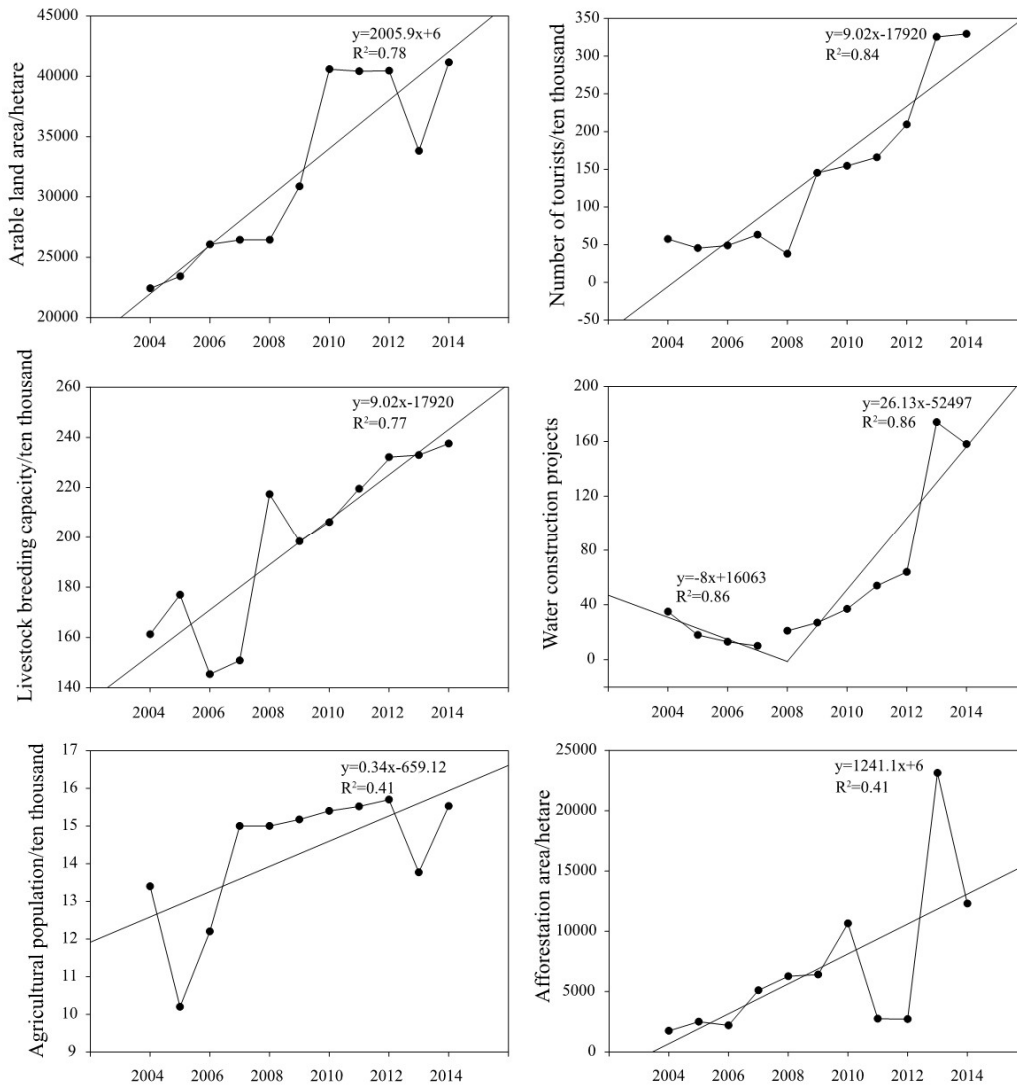**Figure 3.** Dynamic changes of natural factors for desertification in Qinghai Lake

Figure 4. Dynamic changes of human activities for desertification in Qinghai Lake.
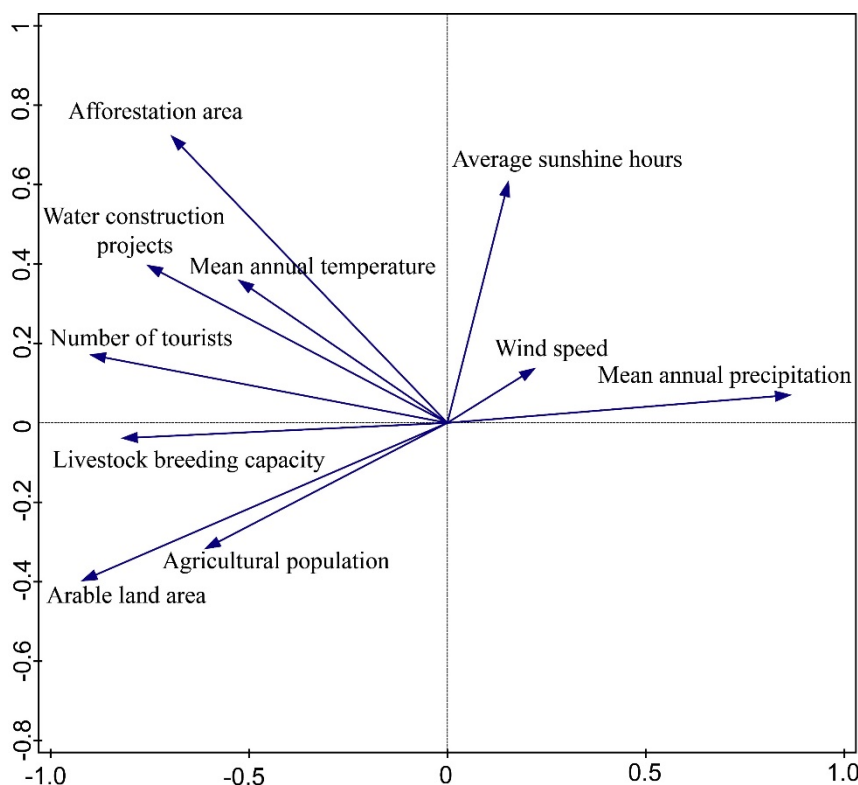
Figure 5. The variance contribution rate of each principal component.

Table 2. Load matrix and variance contribution rate of each principal component from 2004 to 2014

Index	First principal component	Second principal component
Mean annual temperature/°C	0.465	0.712
Average sunshine hours/h	-0.228	0.879
Mean annual precipitation/mm	-0.836	0.126
Wind speed/m $\cdot$ s^{-1}	-0.550	0.579
Agricultural population/ten thousand	0.584	-0.381
Arable land area/hectare	0.867	-0.241
Livestock breeding capacity/ten thousand	0.886	-0.194
Number of tourists /ten thousand	0.939	0.187
Afforestation area /hectare	0.708	0.472
Water construction projects	0.835	0.379
Variance contribution rate/%	52.27	23.77
Cumulative variance contribution rate/%		76.05

4 Conclusion

(1) In 2015, grasslands are the dominant ecosystem in the area, and the desert ecosystem had an area of 32 km², accounting for only 0.1% of the total area. The area of farmland ecosystem, forest ecosystem, grassland ecosystem, and water and wetland ecosystem had all experienced a slight increase of 7 km², 1 km², 12 km², and 39 km², respectively. The desertification in Qinghai Lake can be in the reversal stage: the vegetation cover increased from 54% in 2004 to 66% in 2019.

(2) The vegetation-covered land in the lagoon area showed a change process of mild destruction-slow restoration. From 2004 to 2008, the vegetation in the Qinghai Lake basin was still damaged to a slight extent, and a high degree of vegetation-covered land played a dominant role. From 2009 to 2013, the vegetation in the Qinghai Lake basin recovered with medium degree vegetation-covered land playing a dominant role. From 2014 to 2019, the vegetation has been well restored gradually, though still confronted the threat of desertification.

(3) The most important driving factor for desertification in Qinghai Lake is the anthropogenic factor, and it has two-sided effects. From 2004 to 2008, human disturbance activities such as agricultural population increase, land reclamation, livestock increase, and the resulting drought and water shortage caused ecological degradation. They hindered the reversal of desertification in the area. From 2009 to 2014, with the implementation

of many ecological construction projects, desertification has been curbed.

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