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Spatial and Temporal Changes and Driving Factors of Desertification Around Qinghai Lake, China

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ABSTRACT

The area around Qinghai Lake is one of the most serious desertification areas on the Qinghai-Tibet Plateau. In this paper, combined with field investigation and indoor analysis, the classification and grading system of desertification around Qinghai Lake was established. On this basis, through remote sensing data processing and parameter inversion, the desertification monitoring index model was established. Based on the analysis of Landsat-5/TM remote sensing data from 1990 to 2020, the dynamic change characteristics of desertification land around Qinghai Lake in recent 30 years were obtained. The results show that the desertification area around Qinghai Lake was 1,359.62 km^2, of which the light desertification land was the main one. The desertification spread in a belt around Qinghai Lake, concentrated in Ketu sandy area in the east, Ganzi River sandy area in the northeast, Bird Island sandy area in the northwest, and Langmashe sandy area in the southeast. From 1990 to 2000, the annual expansion rate of desertification around Qinghai Lake was 2.68%, the desertification spread rapidly, and light desertification land was the main part of desertification expansion. From 2000 to 2010, the annual expansion rate of desertification was only 0.83%, but severe desertification land and moderate desertification land developed more rapidly than in the previous period. From 2010 to 2020, the annual expansion rate of desertification was 2.66%, and the desertification was spreading rapidly, mainly with moderate desertification land and light desertification land. In the process of desertification land transfer around Qinghai Lake, the transfer of desertification land and non-desertification land was the main, accompanied by the mutual transformation of different levels of desertification land. The process of desertification around Qinghai Lake was essentially the result of natural and human factors. The special geographical location, climate changes, rodent damage, and human factors around Qinghai Lake were the main causes of desertification.

INTRODUCTION

Qinghai Lake is the biggest inland saline lake in China. With the unique climatic, hydrology, and soil environment of the Qinghai-Tibet Plateau, the Qinghai Lake Basin is a sensitive area of global change and a typical economically fragile area (Ding et al. 2018). In the past 30 years, due to the arid and windy climate, unreasonable reclamation, overgrazing, woodcutting, and others, the original vegetation cover around Qinghai Lake was destroyed, leading to the bare soil, which made the wind-sand activities increasingly serious and the desertification area rapidly expanded (Han 2000). With the rapid expansion of desertification, the functions of Qinghai Lake in enriching the biodiversity, regulating the climate, water conservation, and maintaining the ecological balance of the Qinghai-Tibet Plateau have been greatly weakened (Sun et al. 2008).

The area around Qinghai Lake has become the focus of academia, the public, and government departments. The study of desertification around Qinghai Lake began in the early 1960s (Zheng et al. 1985). Since the 1980s, many scholars have comprehensively studied the aeolian sand accumulation on the eastern shore of Qinghai Lake, the causes, current situations, harm degree, and control measures of desertification around the lake by means of wide area investigation, positioning observation, and experiment (He et al. 1993). Since the 1990s, remote sensing technology has been applied to study the ecological environment, grassland resources, lake changes, lake separation, land use, and desertification around Qinghai Lake (Jan et al. 2006).

Based on RS image processing technology and Landsat-5/TM remote sensing data, this paper analyzed the spatial and temporal evolution processes of desertification around Qinghai Lake in the past 30 years. The temporal and spatial changes and driving factors of desertification were explored in order to grasp the development trends of desertification and to provide a scientific and theoretical basis for the restoration of desertification and the ecological environment around Qinghai Lake.

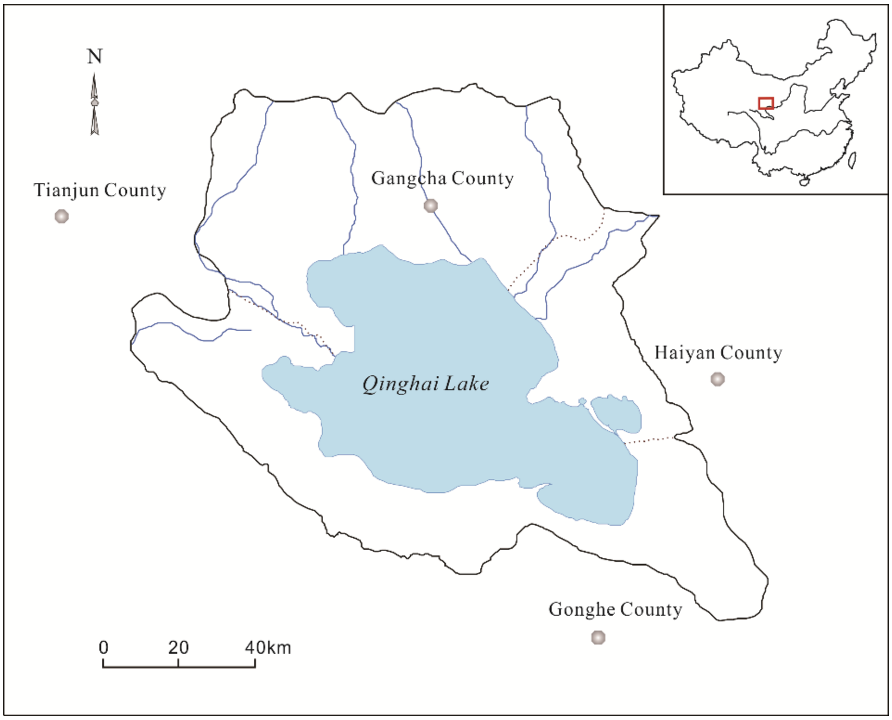

Fig. 1: Geographic location of study area in China.

STUDY AREA

The area around Qinghai Lake is located in the northeastern edge of the Qinghai-Tibet Plateau, and the geographic coordinates are between 36°28′-38°25′ N and 97°53′-101°13′ E. It is about 120 km from north to south and 160 km from east to west, including Qinghai Lake, with a total area of 14,271.9 km^2 (Fig. 1). The administrative areas include some townships of Haiyan County and Gangcha County in Haibei Tibetan Autonomous Prefecture and some townships of Gonghe County in Hainan Tibetan Autonomous Prefecture. The area is adjacent to Qinghai Nan Mountain in the south, Riyue Mountain in the east, Amuniniku Mountain in the west, and Datong Mountain in the north. The terrain is inclined from northwest to southeast with an average altitude of 3,900 m, forming an independent and closed intermountain inland basin.

The study area belongs to the typical plateau semi-arid alpine climate, which is warm and cool in summer and autumn, and cold in winter and spring. The annual mean temperature is between -1.5°C and 7.0°C. The annual mean precipitation is 300-400 mm, of which the precipitation from May to September accounts for about 90% of the total, and the annual mean evaporation is about 1,440 mm. The main soil types are alpine frost desert soil, alpine meadow soil, alpine grassland soil, gray cinnamon soil, chernozem, chestnut soil, swamp soil, aeolian sand soil, etc. The vegetation types mainly include temperate grassland, desert semi-shrub, alpine shrub, and alpine meadow. The land use types are cultivated land, woodland, marshland, gravel land, bare land, sandy land, waters, beach and bedrock, etc.

MATERIALS AND METHODS

Desertification Land Classification

The classification of desertification land is an objective reflection of the degree of degradation. In this paper, based on the existing standards and methods for the division of desertification (Li et al. 2001), through field investigation and laboratory analysis, and then combined with the changes of vegetation, soil, and other factors, the desertification lands around Qinghai Lake were divided into light desertification land (LDL), moderate desertification land (MDL), severe desertification land (SDL), and extremely desertification land (EDL).

LDL: The area of quicksand is under 5%, and there is almost no wind-sand flow. The vegetation coverage is over 30%, mainly distributed in fixed coppice sandbags and sporadic grassland. Most of the surface remains in the state of native grassland. There is a small amount of wind erosion and wind deposition, and the surface appears spot-like quicksand, which is equivalent to fixed sand.

MDL: The area of quicksand is 5%-25%, and the wind-sand flow is not obvious. Semi-fixed sand and semi-naked gravel are distributed in the patch. The vegetation coverage is 20%-30%, and there are some sporadic sand dunes. Grassland has been significantly degraded, and the important constructive species of native vegetation have taken a secondary position, while the sandy vegetation has become the main species. Flaked quicksand and coppice dunes have appeared in large numbers, which is equivalent to semi-fixed sand.

SDL: The area of quicksand is 25%-50%, the wind-sand flow and the quicksand texture are obvious, with irregular patch distribution, and the sand dunes are clearly visible. The vegetation coverage is 10%-20%, and there are coppices in the topsoil. The native vegetation no longer exists, sandy grass coppices are the dominant species, and the wind erosion and wind landform are obvious.

EDL: The area of quicksand is over 50%, and a large area of sandland is continuously distributed. Sand dunes, dune ridges, and other landforms are obvious. The vegetation coverage is under 10%. The original surface form has been destroyed and replaced by quicksand.

Data Sources and Processing

In this paper, eight Landsat-5/TM images in 1990, 2000, 2010, and 2020 were selected as the data source, with orbit numbers 133/34 and 133/35, respectively. In order to reduce the impact of seasonal phase and cloud cover on monitoring, remote sensing images with less than 10% cloud cover in summer and autumn were selected as far as possible, and the receiving time is shown in Table 1. In addition, the temperature, precipitation, evaporation, and other meteorological data of monitoring sites around Qinghai Lake from 1960 to 2020 were obtained. The 1:50,000 topographic map, land use map, vegetation map, and DEM data with 90m resolution around Qinghai Lake were obtained. The observation data of animal husbandry ecology and economic statistical data in Haiyan County, Gangcha County, and Gonghe County were also obtained.

We used ENVI 5.0 software to preprocess the remote sensing images, such as radiometric calibration, FLAASH atmospheric correction, and image cutting and mosaic. For geometric correction, the 1: 50,000 topographic map was taken as a reference, the control points were selected from the topographic map, and the quadratic polynomial resampling method was selected to correct them. The correction accuracy was controlled within 0.5 pixels, and the ground resolution was controlled within 30m×30m. Then, with the support of ARC/INFO software, the data were extracted by the human-computer interaction interpretation method, referring to the soil, vegetation, meteorological, and others around Qinghai Lake.

Desertification Difference Index Model

In this paper, the normalized vegetation index (NDVI) reflecting vegetation coverage was used to indicate the degree of desertification, because it was generally considered a good indicator of desertification. Landsat TM reflectance data in infrared and near-infrared bands after radiometric and geometric correction were used to calculate NDVI. As for the inversion of surface albedo, the inversion model (1) of Landsat TM data established by Liang (2000) was used to estimate the surface albedo in the study area.

$$\text{albedo} = 0.356\rho_{TM1} + 0.130\rho_{TM3} + 0.373\rho_{TM4} + 0.085\rho_{TM5} + 0.072\rho_{TM7} - 0.0018 \quad \ldots(1)$$

Based on the Albedo-NDVI feature space, the desertification monitoring index model was established in the study area, and multi-temporal desertification index images were obtained by this model. The detailed process can be seen in the reference (Zeng et al. 2006). The expression of the desertification monitoring difference index model is:

$$\text{DDI} = 1.3437\text{NDVI} - \text{albedo} \quad \ldots(2)$$

Monitoring information extraction: According to the data obtained from two field surveys in 2019 and 2020, combined with the map data of vegetation type, soil type, and land use type of the study area, through the means of visual interpretation, the typical sample areas of different desertification types were selected and determined from the Landsat TM images obtained in 2020. With the support of image processing software, the connection between the map of the sample area and the image of the desertification difference index was established to determine the position of the typical sample area on the image of the desertification difference index. The DDI values of different desertification types were calculated, and the monitoring indicators of different desertification types were finally determined. Based on the desertification monitoring indicators as shown in Table 2, the spatial distribution characteristics of desertification in four phases of 1990, 2000, 2010, and 2020 were obtained.

Based on a change-monitoring tool in ENVI 5.0 software, the raster data of desertification distribution in the study period were counted, and the transfer matrix of desertification was obtained. Subsequently, the transfer quantity and direction of desertification around Qinghai Lake in recent 30 years were analyzed, and the spatio-temporal evolution processes of desertification were restored.

Table 1: Remote sensing images of Landsat-5 in the study area.

Track No.	Receive time (year - month - day)			
133/34	1990-08-12	2000-08-23	2010-08-15	2020-08-21
133/35	1990-08-12	2000-08-23	2010-08-15	2020-08-21

Table 2: Desertification detecting indicator around Qinghai Lake.

Desertification type	LDL	MDL	SDL	EDL
DDI value	51-63	43-50	34-42	23-33

RESULTS AND ANALYSIS

Spatial Changes of Desertification

After the development and evolution of nearly 30 years, the desertification situation around Qinghai Lake had been quite serious. In 2020, the desertification area reached 1,359.62 km^2, accounting for 9.53% of the total area. Among them, EDL, SDL, MDL, and LDL accounted for 18.17%, 14.89%, 23.27%, and 43.66% of the total desertification area, respectively. The desertification lands spread around

Table 3: Changes in desertification area in each county around Qinghai Lake.

year	Haiyan County		Gangcha County		Gonghe County	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
1990	442.88	59.98	98.09	13.28	197.37	26.73
2000	632.25	65.72	109.66	11.40	220.18	22.89
2010	665.76	63.69	127.14	12.16	252.40	24.15
2020	757.51	55.71	306.38	22.53	295.73	21.75

Table 4: Changes in desertification area and degrees around Qinghai Lake.

Desertification type	1990		2000		2010		2020	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
EDL	249.73	33.82	249.73	25.96	246.59	23.59	247.06	18.17
SDL	183.89	24.91	191.58	19.91	205.43	19.65	202.51	14.89
MDL	210.65	28.53	221.18	22.99	237.54	22.72	316.42	23.27
LDL	94.08	12.74	299.60	31.14	355.75	34.03	593.63	43.66
Total	738.34	100.00	962.09	100.00	1,045.30	100.00	1,359.62	100.00

Table 5: Transfer matrix among different desertification types and non-desertification around Qinghai Lake (%).

Period	Land type	EDL	SDL	MDL	LDL	Non-desertification
1990-2000	EDL	100	0	0	0	0
	SDL	0	92.29	1.75	1.44	4.52
	MDL	0	4.54	92.87	0.63	1.96
	LDL	0	0	0	100	0
	non-desertification	0	0.05	0.15	1.55	98.25
2000-2010	EDL	98.32	0	1.68	0	0
	SDL	0	94.74	1.53	0.25	3.48
	MDL	0.07	4.73	89.12	3.52	2.56
	LDL	0	0	0.85	97.72	1.43
	non-desertification	0.01	0.05	0.15	0.54	99.25
2010-2020	EDL	99.84	0	0	0	0.16
	SDL	0.29	89.37	1.38	8.07	0.89
	MDL	0	1.91	53.82	20.65	23.62
	LDL	0.08	0.24	30.38	54.23	15.07
	non-desertification	0	0.12	0.57	2.53	96.78

Qinghai Lake in the belt mostly concentrated distribution. Among them, the large areas were the Ketu sandy area in the east of the lake, the Ganzi River sandy area in the northeast of the lake, the Bird Island sandy area in the northwest of the lake, and the Langmashe sandy area in the southeast of the lake. EDL was concentrated in the Ketu sandy area. SDL was mainly distributed in Ganzi River sandy area and Bird Island sandy area. MDL was mainly distributed in the northern pass area of the Ketu sandy area and the lakeside area of Sand Island. SDL had the largest distribution area and was the main type of desertification land in the Ganzi River sandy area, Bird Island sandy area, and Langmashe sandy area.

From the perspective of the administrative division, the main body of desertification was mainly distributed in Haiyan County. In 2020, Haiyan County, Gangcha County, and Gonghe County accounted for 55.71%, 22.53%, and 21.75% of the total desertification area, respectively. From 1990 to 2020, the desertification area in the three counties showed a continuous upward trend, but the increase ranges were slightly different in different years, resulting in obvious changes in the proportion of desertification area of the three counties in the total desertification area of the study area (Table 3). In general, the proportion of desertification areas in Haiyan County and Gonghe County in the total desertification area decreased slightly, but the proportion of desertification areas in Gangcha County in the total desertification area increased significantly.

Changes in Desertification Area

The spatial and temporal evolution processes of desertification around Qinghai Lake in recent 30 years were restored by using desertification images in four periods (Table 4). The desertification area around Qinghai Lake in 1990, 2000, 2010, and 2020, was 738.34 km^2, 962.09 km^2, 1,045.30 km^2, and 1,359.62 km^2, accounting for 5.17%, 6.74%, 7.32%, and 9.53% of the total area, respectively.

From 1990 to 2000, the desertification area around Qinghai Lake increased by 223.75 km^2, with an annual mean expansion rate of 2.68%. For different desertification types, except that the area of EDL was nearly basically, the area of SDL, MDL, and LDL showed different degrees of growth, with growth of 7.69 km^2, 10.53 km^2, and 202.52 km^2, respectively. During this period, desertification expanded rapidly, LDL was the main body of desertification expansion, and the degree of desertification increased year by year.

From 2000 to 2010, the desertification area around Qinghai Lake increased by 83.21 km^2, and the annual mean expansion rate was only 0.83%, which was significantly slower than that in the previous period. EDL was reversed, the area decreased by 3.14 km^2, but the areas of SDL, MDL, and LDL increased by 13.85 km^2, 16.36 km^2, and 55.15 km^2, respectively. During this period, the expansion rate of desertification slowed down, and the area of LDL decreased significantly, but the area of SDL and MDL developed rapidly compared with the previous period.

From 2010 to 2020, the desertification area around Qinghai Lake expanded to 314.32 km^2, with an annual mean expansion rate of 2.66%, which was significantly faster than the previous period. The area of SDL decreased by 2.91 km^2, while the area of EDL, MDL, and LDL increased by 0.47 km^2, 78.88 km^2, and 237.89 km^2, respectively. During this period, desertification was still expanding rapidly, MDL and LDL were the main bodies of desertification expansion, and the degree of desertification was increasing year by year.

Desertification Type Transfer

From 1990 to 2000, EDL did not change to other desertification types, 1.75% of SDL significantly reversed to MDL, 1.44% of SDL significantly reversed to LDL, and 4.54% of MDL developed into SDL (Table 5). During this period, the development speed of MDL was greater than the reverse speed of SDL, and desertification showed an expansion trend.

From 2000 to 2010, 1.68% of EDL significantly reversed to MDL, 1.53% of SDL significantly reversed to MDL, 0.07% of MDL developed to EDL, 4.73% of MDL developed to SDL, and 0.85% of LDL developed to MDL (Table 5). During this period, the development speed of desertification was obvious.

From 2010 to 2020, the area of EDL did not change, 0.29% of SDL developed to EDL, 1.38% significantly reversed to MDL, 1.91% of MDL developed to SDL, 30.38% of LDL developed to MDL, and 0.24% of LDL developed to SDL (Table 5). During this period, the development speed of desertification was higher than in the previous period.

Desertification Land and Non-Desertification Land Transfer

From 1990 to 2000, 4.52% of SDL and 1.96% of MDL reversed to non-desertification land, with the reverse area of 12.44 km^2; 1.75% of non-desertification land developed into desertification land, and the transfer area was 236.19 km^2. During this period, the development speed of desertification was much faster than the reverse speed.

From 2000 to 2010, 3.48% of SDL, 2.56% of MDL, and 1.43% of LDL reversed to non-desertification land, with the reverse area of 16.61 km^2; 0.75% of non-desertification land developed into desertification land, and the transfer area was

99.82 km^2. During this period, the development speed of desertification decreased compared with the previous period.

From 2010 to 2020, 23.62% of MDL, 15.07% of LDL, and 0.89% of SDL reversed to non-desertification land, with the reverse area of 111.94 km^2; 3.22% of non-desertification land developed into desertification land, and the reverse area was 426.26 km^2. During this period, desertification developed rapidly.

DRIVING FACTORS OF DESERTIFICATION

Natural Factors

The natural factors including drought, wind, and sandy soil were important factors to promote the temporal and spatial changes of desertification around Qinghai Lake.

According to the inter-annual variation curve of climate elements around Qinghai Lake in recent 60 years, we can see that the annual mean temperature increased significantly, and the annual mean precipitation increased slowly. Fig. 2 shows the annual mean temperature around Qinghai Lake has shown a rising trend in the past 60 years, the annual mean temperature was about 1.9°C, and the inter-annual trend rate was 0.30°C/10a. Since 1961, the annual mean temperature had increased year by year, but the increasing trend was obvious from 2011 to 2020. From 2011 to 2020, the annual mean temperature increased by 1.19°C, with an annual mean increase of 0.12°C. The annual mean temperature of the decade was 0.93°C higher than that of the previous 50 years, and the increase was significantly higher than that in the 1960s, 1970s, 1980s, and 1990s. In Fig. 3, the annual mean precipitation in the study area fluctuated and increased in the past 60 years, the annual mean precipitation was about 340 mm, and the inter-annual trend rate was 9.26 mm/10a. In the past 60 years, the annual precipitation exceeded 500 mm in 1967 and 1989 respectively. From 2011 to 2020, the annual mean precipitation increased significantly. The annual mean precipitation of the decade was 22.46 mm

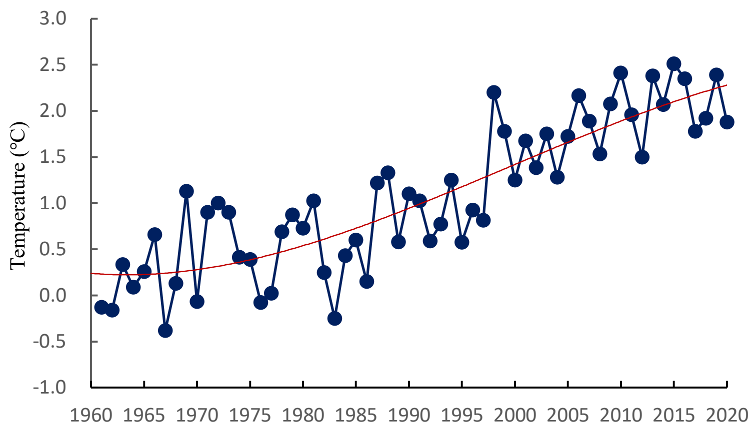

Fig. 2: Changes in annual mean temperature from 1961 to 2020.

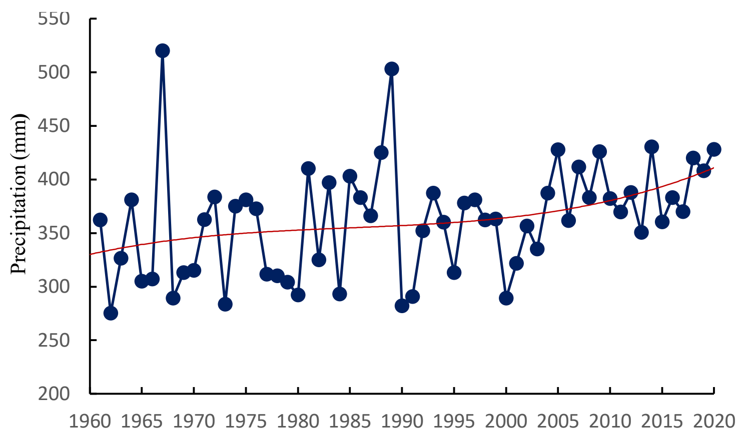

Fig. 3: Changes in annual mean precipitation from 1961 to 2020.

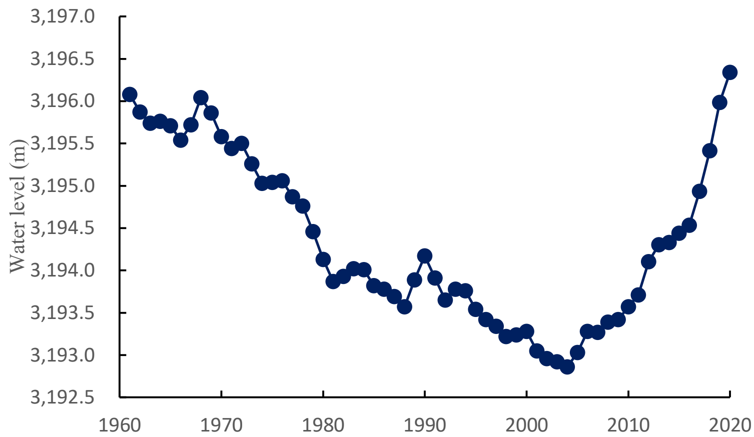

Fig. 4: Changes in the annual mean water level of Qinghai Lake from 1961 to 2020.

higher than that of the previous 50 years, and the increase was significantly higher than that in the 1960s, 1970s, and 1990s.

As for seasonal climate changes, the temperature was low in spring, but the wind speed was the largest, and the precipitation was less, so desertification was most likely to occur. The main soil types in the study area were light chestnut soil, chestnut soil, aeolian sandy soil, swamp soil, etc., the sand content of these soil types was about more than 80%, and the ability to resist wind erosion was weak. The surface vegetation was sparse and the coverage was low, which made the sandy surface in a bare or semi-bare state. All these factors combined aggravate the degree of desertification around Qinghai Lake.

Water Level Changes in Qinghai Lake

River water and precipitation were the main supply source of Qinghai Lake. There were 70 rivers of different sizes flowing into Qinghai Lake. In recent years, the flow of these rivers continued to decrease, with frequent seasonal interruptions. The annual mean total supply of Qinghai Lake was 3.457 billion m^3, and the annual mean evaporation was 3.93 billion m^3. The evaporation was larger than the supply, and the annual mean loss of water was 473 million m^3.

The water level changes of Qinghai Lake from 1961 to 2020 are shown in Fig. 4. The water level of Qinghai Lake decreased year by year from 1961 to 2004. Although there were fluctuations, the decreasing trend was obvious, and the decreasing rate was 0.76 m/10a. The water level continued to decrease from 3,196.08 m in 1961 to 3,192.86 m in 2004. Many scholars have studied the reasons for the decline of the water level, believing that the warm and dry climate is the main reason for the decline of the water level of Qinghai Lake.

With the decrease of the water level and the retreat of the lake surface, the lake-bottom sediments in some shallow water areas along the lakeside belt exposed from the water surface, becoming the main material source of desertification. Under the action of wind, land desertification was accelerated. As the water level of Qinghai Lake had been declining for a long time, the ecosystem of the whole basin had been continuously degraded, and the expansion of land desertification had been accelerated under the action of wind.

However, the water level turned into a rising period since 2005, with a rising rate of 2.01 m/10a, and the water level reached 3,196.34 m in 2020. Some scholars believe that the most important factors for the rise of the water level were climate changes, combined with the factors such as returning farmland to grassland, grassland closure, and ecological restoration, which had significantly enhanced the water conservation capacity around Qinghai Lake.

Rodent and Locust Damage

The rodent damage around Qinghai Lake was mainly caused by *Eospalax fontanierii* and *Ochotona curzoniae*. In severe areas, there were 75-165 rodents and more than 2,250-2,700 rodent holes per hectare. The average daily consumption of *Eospalax fontanierii* was about 264g of fresh grass, and that of *Ochotona curzoniae* was about 66g of fresh grass. The annual mean loss of fresh grass per hectare of grassland was up to 2,200-4,900 kg. Locust was another major damage to the grasslands in the study area. There were nearly 10 common locust species, such as *Altichorthippus fallax, Chorthippus dubius*, *Bryodema luctuosum*, and *Angaracris rhodopa*, among which *Chorthippus Fieber* and *Myrmeleotettix* were the most widely distributed and the most abundant. In severe areas, the density of locusts could reach more than $300/m^2$, and the annual mean loss of fresh grass per hectare of grassland was more than 1,500kg.

The grassland ecosystem around Qinghai Lake was frequently affected by rodent and locust damage. The rodent holes and "black soil beaches" on the natural grasslands became the breakthrough of wind erosion, which accelerated soil desertification and created conditions for grassland degradation and desert expansion. According to statistics, only in Gangcha County on the northern shore of the lake, the area of grassland degradation reached 5.794×10^5 hm^2, including 7.3×10^4 hm^2 of "black soil beaches".

Overloading and overgrazing: The local economy around Qinghai Lake was dominated by agriculture and animal husbandry, and the output value of animal husbandry accounted for about 70% of the total agricultural output value. The number of livestock had been increasing since 1949, especially from 1949-1969 and 2004-2013. Due to overloading and overgrazing, the grasslands could not recuperate and gradually degenerated. According to the survey, the total amount of livestock in Gangcha County in 2020 was equivalent to 126.25×10^4 sheep units, but the theoretical livestock carrying capacity of grassland in this county was only 106.97×10^4 sheep units, overloaded by 19.28×10^4 sheep units, and the degree of overloading reached 18.02%.

With the increase of livestock, grassland coverage and productivity decreased, which accelerated the process of desertification. According to vegetation monitoring data, the forage yield around Qinghai Lake decreased by 3.05-4.64 kg/a, and the height of grassland vegetation decreased by 0.75-1.28cm/a. The proportion of excellent forages represented by *gramineous* forages in the biological community decreased by 1%-3%, and the forage yield decreased, resulting in the reduction of the livestock carrying capacity of grassland. Vegetation was insufficient to cover the sandy surface, which led to the further development of grassland desertification.

Over Cultivation and Random Digging

In the 1950s and 1960s, the grasslands around Qinghai Lake began to be blindly reclaimed. Most of the reclaimed lands were extensive management. With the decline of land fertility, farmers often abandoned these lands because their income was lower than expenditure. According to statistics, a total of 15,800 hm^2 of grasslands were reclaimed from 1990 to 2000, of which 2,000 hm^2 were returned to grasslands from 2010 to 2020, and the rest were in the barren state. Affected by severe wind erosion and desertification, some barren lands transformed into the sandy landscape, and completely lost their original ecological functions.

Due to the lack of fuel in the area around Qinghai Lake, local residents went to the fixed sandy lands to cut down shrubs such as *Salix cheilophila*, *Salix cupularis*, and *Caragana jubata*, resulting in serious damage to the vegetation. The phenomenon of arbitrarily digging traditional Chinese medicinal materials was also very serious. *Gentiana macrophylla* in beach land and piedmont plain, *Notopterygium incisum* and *Astragalus mongholicus* in the steep slope, *Ephedra geradiana* in arid grassland were dug wantonly, resulting in small pits and mounds everywhere on the grasslands. With the decrease in vegetation coverage, the land lost its natural protective barrier, and the sand was blown up by the wind, exacerbating the further development of soil erosion and desertification.

DISCUSSION AND CONCLUSIONS

The results show that the desertification around Qinghai Lake was quite serious. In terms of spatial distribution, the desertification lands spread around Qinghai Lake in a belt shape, which is concentrated in the Ketu sandy area in the east of the lake, Ganzi River sandy area in the northeast of the lake, Bird Island sandy area in the northwest of the lake, and Langmashe sandy area in the southeast of the lake. In terms of administrative division, the desertification lands were mainly distributed in Haiyan County, while the area of Gangcha County and Gonghe County was relatively small.

The desertification area around Qinghai Lake expanded rapidly, increasing by 621.28 km^2 in 30 years, with an annual mean expansion rate of 2.06%. From 1990 to 2000, the annual mean expansion rate of desertification was 2.68%, and LDL was the main body of desertification expansion. From 2000 to 2010, the annual mean expansion rate of desertification was only 0.83%, but SDL and MDL developed rapidly compared with the previous period. From 2010 to 2020, the annual mean expansion rate of desertification was 2.66%, and the desertification still spread rapidly, mainly MDL and LDL. In the process of desertification land transfer around Qinghai Lake, the desertification land and non-desertification land were mainly transferred, accompanied by the mutual transfer between different levels of desertification land.

In fact, the spatial and temporal evolution processes of desertification around Qinghai Lake were the result of natural and human factors. Due to the unique natural environment around Qinghai Lake, such as drought climate, windy, sandy surface, sparse vegetation, and decline of water, there was a slow natural desertification process. Rodent damage, locust damage, and unreasonable human activities destroyed the surface ecosystem, accelerated surface erosion, and artificially exacerbated the process of desertification.

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