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Desertification and its relationship with permafrost degradation in Qinghai-Xizang (Tibet) plateau

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Abstract

Desertification in Qinghai-Xizang (Tibet) Plateau is part of Chinese desertification. In the past decades, due to the climate warming, the climate condition in Qinghai-Xizang (Tibet) Plateau has been relatively dry. This has resulted in permafrost degradation and other environmental problems. In addition, the vegetation and the soil layer were also destroyed by unreasonable economic activities. Cultivated and grassland lands have become deserted. Nowadays, the desertification is still expending. In this paper, the factors affecting the desertification in Qinghai-Xizang (Tibet) Plateau were examined, and the desertification as well as its relationship with permafrost degradation was also discussed.

Keywords: Desertification; Permafrost degradation; Environmental effect; Qinghai-Xizang(Tibet) Plateau

1. The desertification in Qinghai-Xizang (Tibet) plateau

In the past decades, the climate in Qinghai-Xizang (Tibet) Plateau is becoming warmer and therefore relatively dry, and this has resulted in the retreating of most glaciers, the uplifting of the snow lines, permafrost degradation, lakes areas shrinking, some swamps and wetlands becoming dry, the surface salinity increasing, some fixed sand dunes becoming active, and the wind erosion on the surface becoming stronger. Meanwhile unreasonable economic activities destroyed the vegetation and soil layers. Such phenomena converted non-desert lands and grasslands into deserts. At present, the desertification phenomenon is spreading. The desert area in Qinghai province was 597×10^4 km^2 in the 1960s. However, it expanded to 790×10^4 km^2 in the 1980s, which corresponds to the 10.95% of the total provincial area. From 1959 to 1977,

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within 18 years, 193×10^4 km^2 of desert area was added. This means that the desertification area expanded 10.722×10^4 km^2 per year on average. The expansion rate was 1.8% (Shi, 1992). As reported by Lanzhou Institute of Desert Research, Chinese Academy of Sciences, in 1993, the desert area was 1860.9 km^2 in the middle basin area of the Yaluzangbu River, Lahsa River and Nyingchi River in Tibet, which is equivalent to 97.5% of the total cultivated area in the region. In the surrounding area of Zhaling Lake and Eling Lake, in the upper part of Huanghe (Yellow) River, the sand dunes are expending and the active sand dunes are overlapping the grasslands. This has resulted in the area of useful grasslands shrinking annually. The active sand dunes, moving sand and frigid hungriness in the banks of the Tongtianhe River, in the upper part of Changjiang River, are now expanding southeasterly along the Tongtianhe River valley. There were swamps and wetlands before the 1950s in the Ruoergai area. But now most parts have become grasslands and, even worse, some parts are deserts. At present, the desert grasslands are distributed in valley terrains and their surrounding hill slope areas of the Huanghe River, the Baihe River and the Heihe River.

2. Analysis of desertification factors in Qinghai-Xizang (Tibet) plateau

In the Qinghai-Xizang (Tibet) Plateau (Fig. 1), continuous permafrost, island discontinuous permafrost, and deep seasonal frozen soil are common. Some of the factors that contributed to desertification in the Qinghai-Xizang (Tibet) Plateau are similar to other desert regions. However, some of the factors are related to the frozen soil. Desertification requires following conditions: abundant material sources, dry climates, windy and sparse vegetation. In other words, these factors can be summarized as natural factors and human-induced factors. The natural factors include the climate, frozen soil conditions, and material sources.

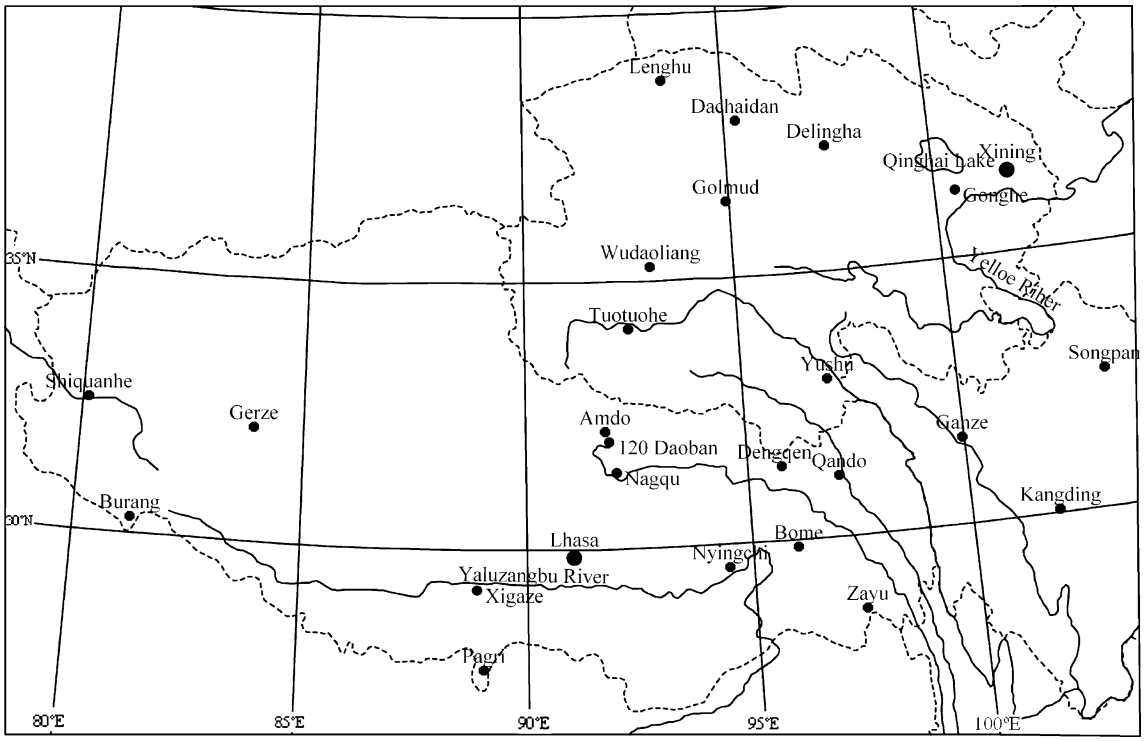

Fig. 1. The general geographic map of the Qinghai-Xizang (Tibet) Plateau.

2.1. Climate condition

Drought and deficit rain climates are the preconditions of desertification. Most parts of the Qinghai-Xizang (Tibet) Plateau belong to alpine, arid, and semi-arid climate regimes. Drought and strong winds are common features of this area. It is high and cold. Semi-desertification and desertification take place in the large area of Kekexili, located in the north of the Tanggula Mountains and west of the Qinghai-Xizang (Tibet) highway. Precipitation is just 100–200 mm per year. In the plateau plain and valley region in the western Kunlun Mountains, such as Tianshuihai Lake, and Kangxiwa, the annual precipitation is just 30–50 mm (Li, 1990), which ranks as one of the driest regions in the Qinghai-Xizang (Tibet) Plateau. Furthermore, the seasonal distribution of precipitation is significant. More than 70% of the precipitation comes in summer (June–August). Fifteen percent of the whole year precipitation comes in winter and spring.

The wind is the main natural force of the desertification, which plays a very important role in forming the surface features of desertification. Wind is controlled by westerly about 6–9 months (clod season) in the Qinghai-Xizang (Tibet) Plateau and most of it are strong westward wind in winter. It is one of the places with the most strong-wind day-numbers in China. The wind is strong in Qinghai-Xizang (Tibet) Plateau. Generally, the annual average wind speed is 3.0–4.0 m/s. The time that the wind speed is greater than the critical wind speeds for uplifting sand is more than 180 days every year. The time that the wind stronger than 17.2 m/s is 30–129 days and 40–50% occurs in spring. Such features provide the fundamental dynamics for surface wind erosion. The drought season and windy season occurred in the same period, which also accelerates the desertification processes.

2.2. Frozen soil condition

At present, the permafrost area is about 141×10^4 km^2 in Qinghai-Xizang (Tibet) Plateau, belonging to the high altitude permafrost in middle and lower latitudes. Due to the cold and drought climate, freezing effect and weathering are strong. The thawing–freezing processes are frequent. The sunlight time is long, and the value of the solar direct radiation is large. In the area below 5000 m a.s.l., the radiation is about 251.2–360.1 J/cm^2 a, which is the region with the largest radiation values in China. On the surface of the Qinghai-Xizang (Tibet) Plateau, even in cold winter months (November or February to March), the daily maximum temperature can reach to above 0 °C. The daily range of the surface soil (rock) temperature is large, and alternating minus and positive temperatures are frequent. The time that the temperature alternates between minus and positive values is about 150–230 days/year. Such conditions result in frequent and strong thawing–freezing processes in the active layer in frozen regions (Yang et al., 2003). Sometimes, several thawing–freezing processes cycles may occur within one day. This results

Table 1
The degradation area of the sub-type grasslands in Nagqu region in Tibet ($\times 10^2$ km^2)

Grassland type	Degradation extent			Total	The percent takes the related sub-type grassland area (%)
	Slight	Medium	Severe		
Frigid meadow grassland	397.6	272.42	21.28	691.30	35.2
Frigid grassland	1883.81	925.81	439.11	3248.73	12.0
Plateau frigid meadow	585.75	505.45	101.70	1192.90	20.3
Alpine frigid meadow	761.36	414.58	11.22	1187.16	22.5
Frigid swamp meadow	559.88	216.88	51.15	827.91	64.2
Sub-alpine meadow	20.77	35.10	10.08	65.95	98.4

The slight degradation grassland refers to herbage production and vegetation coverage decreased. The grasses become short. But the components of the grass community, dominant, sub-dominant and the associated genera do not change. The medium degradation grassland is defined as, besides herbage production, vegetation coverage and the height of grass decreased, the components of the grass community have changed. The promising pasture decreased. The inedible grass and the noxious weed significantly developed. Even worse, they became the dominant genera. The severe degradation grassland refers to the vegetation community shrank and even disappeared. The large area bare land appeared. Desertification was evident and the soil texture became coarse. The pasture utilization value decreased significantly.

in quick wind erosion and broken processes for rock. The compact force of the soil grain is decreased due to the repeated thawing–freezing processes. Therefore, the ability to protect the surface from wind erosion is minimal (Wang, 1997).

The growth period of the vegetation in the permafrost area in the Qinghai-Xizang (Tibet) Plateau is short. The plants are small, and generally the height is about 10–25 cm. The total vegetation cover is about 15–40%. These result in the surface suffering from the dryness, and bare or semibare condition. The ability of the surface against to resist wind erosion is very weak. In the last decades, due to the climate warming and the increasing of the human activities, the permafrost in the QinghaiXizang (Tibet) Plateau is under degradation regionally. The permafrost degradation has caused the seasonal thawed layer to thicken, the disappearance of the permafrost layer, the underground water level lowering, the soil moisture content in the surface layer to decrease, and the ground temperature to increase. Therefore, the surface becomes dry. The types of grasslands and vegetation also changed. These accelerated the grassland degradation. In some areas that suffered accelerated degradation, desertification appeared. The analysis of the grassland degradation types in Nagqu area in Tibet showed that the severest degradation occurred on the alpine swamp meadow and subalpine meadow (Table 1). Moreover, these two kinds of grasses are most developed in permafrost regions. This also demonstrates that there is a close relationship among grassland degradation, desertification and permafrost degradation (Wang and Xie, 1998; Wang, 1998). Permafrost degradation is the special natural factor causing permafrost region desertification.

2.3. The material source condition

Most of the mountains on the Qinghai-Xizang (Tibet) Plateau are composed of lightly metamorphous

Table 2
The grain analysis of the desertification land in different regions in the Qinghai-Xizang(Tibet) Plateau (%)

Region	Type series	Type	Extremely large sand	Large sand	Middle sand	Small sand	Extremely small sand	Powder sand	Clay	Data source
			>1 mm	1–0.5	0.5–0.25	0.5–0.125	0.125–0.063	0.063–0.002	Below 0.002	
The basins of Yaluzangbu River, Lasha River and Nyingchi River in Tibet	gravel	semi-bared gravel	3.36	1.60	5.0	14.46	34.76	39.25	1.63	Wang, 1997
	sand	moving sand			8.97	69.76	20.26	1.00		
		Semi-fixed sand		0.97	12.16	9.23	33.36	43.47	0.05	
		fixed sand			0.70	8.00	24.10	63.55	3.65	
The basin of Shiquanhe River	gravel	gravel	11.72	2.04	16.1	38.76	26.28	5.10		Jin, 1994
		gravel	10.04	11.99	24.99	37.1	15.1	0.77		
	sand	present alluvial land		1.33	6.5	32.26	54.87	5.03		
		sand dune			13.67	64.07	21.90	0.37		
The basin of Qinghai Lake	sand	fixed sand			4.51	48.55	17.34	8.40	20.81	Wang, 1997
		present wind-induced sand			10.69	75.59	6.05	5.04	2.66	
The basin located in northern part of 120 Daoban of Qinghai-Tibet Highway	sand	semi-fixed sand dune		2.88	18.51	22.23	23.16	29.47	3.76	Wang, 1998
		present wind-induced sand		2.05	27.96	37.61	20.36	8.79	3.23	
Northern bank of Tuotuohe River	sand	semi-fixed sand dune		1.69	12.88	45.31	26.98	9.68	3.46	

plate rock, schist, marlite, and sandstone. They easy break into rocky grains and become rich sand sources. The sediment material on the surface of the Qinghai-Xizang (Tibet) Plateau and the valley areas are mainly alluvial material with high sand content. These supply the potential material for desertification (Table 2). As showed by Table 2, the high content of the small and extremely small sands are common characteristics of the grain components in different areas. However, the content of the powder sand and the clay is relatively low. The adhesion force among the grains is weak. The powder sand and the clay grains are very easily blown away, but the large sand, small sand, and the extremely small sand remain. After blowing away, the content of the small grains in the present wind-induced sand dune is less than that in the fixed and semi-fixed sand dunes (Jin, 1994).

2.4. The human-induced factor

In the last decades, in addition to climate warming and drying, unreasonable economic activities have destroyed the vegetation and the soils, leading to desertification in areas that are not natural desert. Furthermore, such desertification is expanding. Desertification processes in the Qinghai-Xizang (Tibet) Plateau are caused by natural factors and human-induced factors. What extent do human activities contribute to the present desertification? This is a very complicated problem. Because only the natural factors can supply the desertification conditions, the anthropogenic factors can, nevertheless, enhance the desertification. Along with the rapid growth of the population and the economic activities on the Qinghai-Xizang (Tibet) Plateau, the amount of the necessary meat, food, mineral resources and fuel will increase. These have resulted in overgrazing, over cultivating, abusive mining practices for gold, over cutting and digging the vegetation as fuel, and over digging for herbs. Naturally this will enhance the desertification processes. Especially in some parts of the eastern Qinghai-Xizang (Tibet) Plateau, the human-induced effect is already far beyond the natural amplitude, showing that human activities are the main factor in desertification now. This has caused the appearance of patch moving sand dunes and desertification in the Ruoergai region and the river valley of the upper part of the Changjiang River and Huanghe River.

3. Interaction between permafrost degradation and desertification

The permafrost environment is a very fragile ecological environment. Once destroyed, the recovery processes is terribly slow. In most cases, even worse, it is irreversible. Especially in the very unstable discontinuous permafrost area, changing outside conditions can cause the sensitive feedback. At the present, desertification is changing the permafrost environment.

3.1. Desertification caused changes of permafrost environment and ecological conditions

Severe desertification can cause the permafrost degradation. Permafrost degradation can change regional environmental ecological conditions. This has forced the alpine swamp meadow, alpine meadow and alpine grassland meadow in the discontinuous permafrost region to evolve backward to some extent (Fig. 2). This naturally accelerated the processes of grassland degradation. Especially in the lower permafrost island, the degradation of the swamp meadow grassland is most significant. The evolution directions in Fig. 2 can cause repeated vicious cycles. These would result in the desertification area become larger. If no measures were used to prevent the vegetation evolution and grassland degradation in permafrost regions, the permafrost environment and the ecological balance would be destroyed. This would result in the loss of water and soil. The two kinds of irreversible vicious cycles would be inescapable (Fig. 3). Eventually this would result in grassland degradation with large areas of desertification, and a worsened ecological environment.

The existence of permafrost can supply abundant moisture and special ecological environments for plant growing. This is reason for restraining the desertification. Permafrost degradation would cause the increase of the seasonal thawing depth, the increase of the surface layer ground temperature, the decrease of the water content, and the decrease of the floristic number. Eventually, it would result in the acceleration of desertification. Generally speaking, permafrost layers and soil desertification complement each other, and have evolved with each other that make up of the ecological balance system in

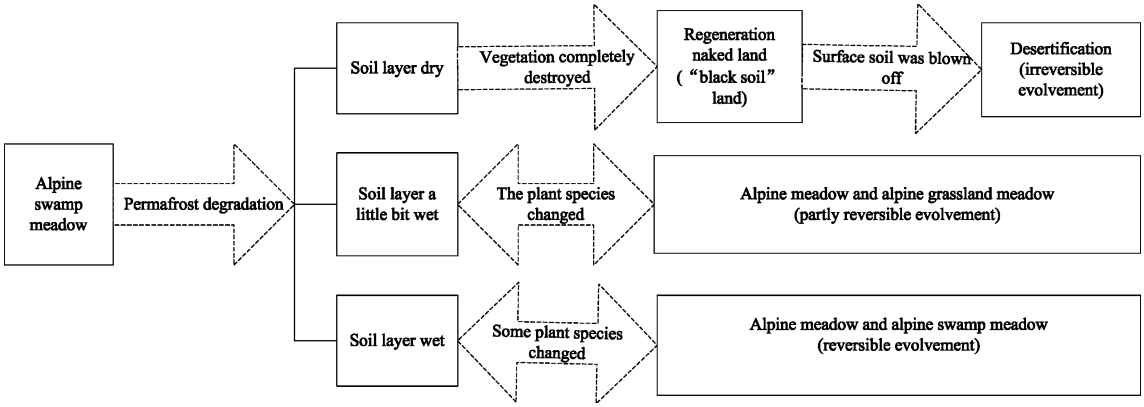

Fig. 2. Succession of the alpine swamp meadow in discontinuous permafrost regions.

permafrost regions in the Qingha-Xizang (Tibet) Plateau.

3.2. The environmental effect of the desertification

The ecological environment in the Qingha-Xizang (Tibet) Plateau is not only the natural environment, but also the composite system of the anthropogenic social economic activities. Soil desertification in the permafrost region is one of the important factors in this composite system. The occurrence and development of the desertification has a close relationship with the whole permafrost environment. It not only causes the permafrost degradation as well as the environmental and ecological problems, but also closely relates to human society. Unreasonable economic activities are the main factor causing the desertification. Nevertheless, the economic activities are also affected by desertification. The interaction between desertification and permafrost can introduce two kinds of environmental effects. One is desertification on a large scale. The other is, as the desert spread, the sand cover area and the sand dunes increase, resulting in ground temperature increases in desertification area and permafrost degradation, which would cause surface drying, grassland degradation, and enhance the desertification processes in turn.

Soil desertification can result in the increase of the surface albedo, which also can cause a climate effect.

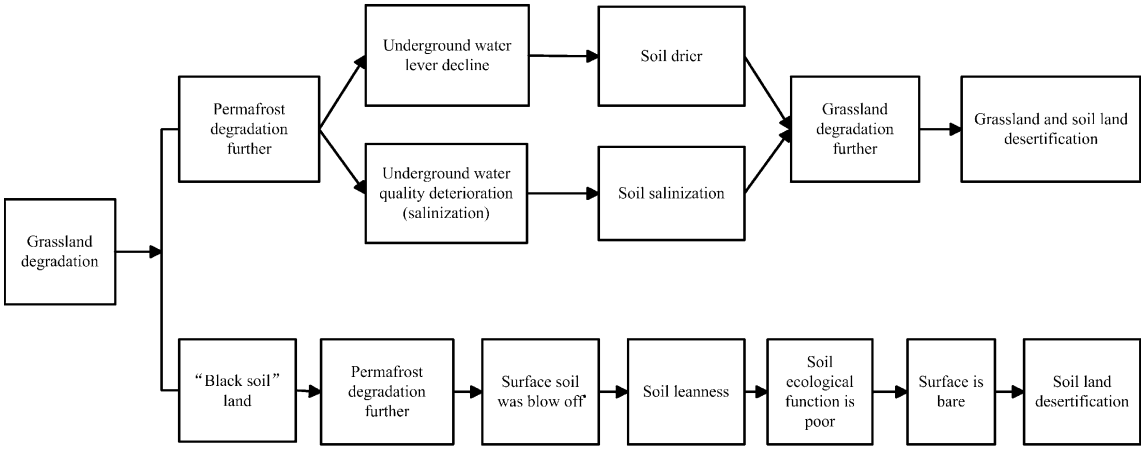

Fig. 3. Succession of the permafrost and ecological environment during grassland degradation.

The increased albedo causes the convective effect of the surface atmosphere to decrease. Therefore, it is not reasonable to ignore the affect of the increased albedo on desertification and the future climate.

The desertification processes in Qingha-Xizang (Tibet) Plateau are based on slow natural desertification processes, plus the interaction between the natural factors and the anthropogenic factors. These two kinds of factors supplement each other. Therefore, the trends of the desertification in the Qingha-Xizang (Tibet) Plateau are mainly determined by the trends of the natural and anthropogenic factors. The prevention of desertification is a complicated system engineering problems. Only as synthetic measures are used, can the permafrost degradation speed be restrained.

In other words, the frigid, semi-arid climate, permafrost, and the commonly distributed desert area are the general features of the permafrost regions in the Qingha-Xizang (Tibet) Plateau. The desertification and its relationship with permafrost as well as their feedback to the climate on the plateau will profoundly affect the future environmental changes in permafrost regions on the Qingha-Xizang (Tibet) Plateau.

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