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Assessment and analysis of the freeze-thaw erosion sensitivity in Tibet, China

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Freeze-thaw erosion is one of the main types of soil erosion in Tibet. Large amounts of loose material produced by freeze-thaw erosion provide material basis for debris flow disasters in high mountains. Five indexes are chosen to assess freeze-thaw erosion sensitivity. They are annual range of temperature, annual precipitation, slope gradient, slope aspect and vegetation coverage. The spatial distribution of annual precipitation is obtained using TRMM precipitation data, and vegetation coverage was calculated by MODIS NDVI data. The intensity and spatial distribution characteristics of freeze-thaw erosion in Tibet were analyzed through freeze-thaw erosion sensitivity evaluation. The results show the distribution of freeze-thaw erosion is very extensive in Tibet, with the freeze-thaw erosion area of 79.40×104 km^2, accounting for 66.00% of the total area of the Tibet. Freeze-thaw erosion sensitive area is 69.83×104 km^2, among which moderate and more sensitive area is 61.64×104 km^2, accounting for 77.63% of the total freeze-thaw erosion area in Tibet. The regional differentiation of freeze-thaw erosion sensitivity is obvious. Different intensities of freeze-thaw erosion sensitivity appear in different regions. Highly sensitive types are mainly distributed in humid and semi-humid high mountain areas, and semi-arid alpine highland areas. Moderately sensitive types are distributed in the alpine arid regions of the plateau.

freeze-thaw erosion, sensitivity assessment, geographic information system, remote sensing, Tibet

Оценка и анализ подверженности территории воздействию термоэрозионных процессов в Тибете, Китай

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Термоэрозия является одним из основных видов эрозии почв в Тибете. Большое количество рыхлого материала, создаваемого термоэрозией при замораживании и оттаивании, обеспечивает материальную основу для стихийных бедствий, связанных с селевыми потоками в высокогорье. Для оценки чувствительности к термоэрозии выбрано пять показателей: годовой диапазон температуры, годовые осадки, уклон, аспект склона и залесенность. Пространственное распределение годовых осадков получается с использованием данных о осадках TRMM, а залесенность рассчитывается по данным MODIS NDVI. Характеристики интенсивности и пространственного распределения термоэрозии в Тибете были проанализированы с помощью оценки чувствительности. Результаты показывают, что развитие термоэрозии в Тибете очень обширно, площадь охвата данным процессом 79,40×10^4 км^2, что составляет 66,00% от общей площади Тибета. Территория, чувствительная к термоэрозии, составляет 69,83×10^4 км^2, среди которых область умеренной и более сильной чувствительности составляет 61,64×10^4 км^2, что составляет 77,63% от общей площади развития термоэрозии в Тибете. Региональная дифференциация подверженности к термоэрозии очевидна. Разные интенсивности чувствительности к промерзанию и оттаиванию проявляются в разных регионах. Высоко чувствительные типы в основном распределены во влажных и полувлажных высокогорных районах и в полузасушливых высокогорных районах. Умеренно чувствительные типы распространены в альпийских засушливых районах нагорья.

термоэрозия, оценка чувствительности, ГИС, дистанционное зондирование, Тибет

Introduction

Freeze-thaw erosion is the soil erosion that occurs in slopes, trench walls, riverbeds, canals, etc. in permafrost areas, under the action of freeze-thaw alternation due to the frequency of temperature [*Zhang, 2007*]. It mostly occurs in high latitudes, high altitudes, and cold regions in the late winter and early spring period [*Zhang, 2005*]. As one of the main ways of soil erosion, freeze-thaw erosion has caused widespread attention with the deteriorating ecological environment in 21st century. The evaluation of freeze-thaw erosion sensitivity is to evaluate the sensitivity of ecosystems to human activities, identify regions that are prone to freeze-thaw erosion, and provide scientific basis for people's production and life [*Wang, 2017*]. Based on the study about the sensitivity of freeze-thaw erosion both at home and abroad, and the natural environment of the Tibet, the evaluation indicators and sensitivity grades of major factors affecting freeze-thaw erosion were selected. Then the sensitivities of freeze-thaw erosion in Tibet were evaluated, which can provide scientific basis for formulating soil freeze-thaw erosion control measures.

Study area

Tibet is located in the southwest of China, belongs to an alpine sub-continent climate. The annual average temperature in the Tibet is 4.2°C, and the average annual precipitation is 593.7 mm which mainly concentrated in summer. The complex and diverse soil and vegetation types, and the alternating wet-dry and freeze-thaw cycles, created conditions for the development of freeze-thaw erosion. The Tibet and its high mountainous regions are the most concentrated and intense regions of freeze-thaw erosion in China [Hui-Xia, 2005]. Therefore, the study of freeze-thaw erosion in the Tibet Autonomous Region has positive effects on the improvement of freeze-thaw erosion theory.

Extraction of freezing and thawing region

Qiu, et al. believe that the lower boundary of the permafrost in Tibetan Plateau is equivalent to the -2°C to -3°C isotherm of annual average temperature, the 2.5 °C isotherm of annual average temperature is selected as the lower bound of the permafrost. The lower bound of freeze-thaw erosion area in Tibet is 200 meters lower at altitude than the 2.5 °C isotherm of annual average temperature. Therefore, we take the bound that the altitude of 2.5 °C isotherm minus 200 meters as the lower bound of the freeze-thaw erosion zone in Tibet [*Qiu, 2000*]. The altitude of freeze-thaw erosion lower bound is acquired according to the following formula (1):

$$H = \frac{66.302 - 0.919X_1 - 0.1438X_2 + 2.5}{0.005596} - 200, \qquad (1)$$

where H is the altitude of freeze-thaw erosion lower bound, X_1 is latitude (°) and X_2 is longitude (°).

The freezing and thawing region are extracted as follows: (1) Extract the latitude (X_1) layer and longitude (X_2) layer using DEM; (2) Calculate the altitude (H) the lower bound of freeze-thaw erosion zone, and get the potential freeze-thaw erosion zone; (3) Then remove the glacier area, lake area, and desertification area from the potential freeze-thaw erosion area using land-use type map and obtain the freeze-thaw erosion area.

Evaluation indexes

Selection of evaluation indexes

There are many factors influencing freeze-thaw erosion, and according to previous studies, freeze-thaw erosion is closely related to climate, topography, hydrology and vegetation [*Guo, 2015*]. Therefore, annual range of temperature, annual precipitation, slope, slope aspect and vegetation coverage are chosen as the evaluation indexes to assess freeze-thaw erosion sensitivity.

Acquisition of evaluation indexes

(1) Annual range of temperature

Annual range of temperature is calculated by regression Equation (2) between latitude, longitude, and altitude, which is established by *Qiu et al.* (2000).

$$A = 3.1052 + 1.2418X_1 - 0.2275X_2 - 0.0004133X_3, \quad (2)$$

where A is the annual range of temperature, X_1 is the latitude, X_2 is longitude, and X_3 is the altitude.

(2) Annual precipitation

Precipitation is an important driving force for the movement of freeze-thaw erosion products, which increased the possibility of freeze-thaw erosion. We obtained the daily precipitation data (year: 2014-2016) by summing the 3-hourly precipitation (unit: mm) retrieved from the TRMM 3B42 product. Then average annual precipitation was calculated by Equation (3)

$$Y = \sum Y_i, \quad (3)$$

where *n* is the length of the time series of one year.

(3) Slope and aspect

Slope affects the amount of freeze-thaw erosion and the magnitude of erosion displacement. Aspect can lead to different types of freeze-thaw erosion. Slope and aspect are extracted by DEM using the slope and aspect tools in ArcGIS. DEM data are obtained from the SRTM (Shuttle Radar Topography Mission), which is 90 meters.

(4) Vegetation coverage

Vegetation can reduce the damage of freeze-thaw erosion on the surface and soil, and decrease the temperature difference of the ground, thus reducing the degree of freeze-thaw erosion. Based on the maximum value of MODIS NDVI in summer in the past three years, combined with the vegetation type map, the vegetation coverages of different vegetation types were obtained by using the pixel dichotomy model.

$$f_g = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}, \quad (4)$$

where f_g is the vegetation coverage, $NDVI_{soil}$ and $NDVI_{veg}$ are *NDVI* values of full vegetation pixels and full soil coverage pixels.

Evaluation System

The comprehensive evaluation of freeze-thaw erosion is a synthesis of multiple factors affecting this complex process of freeze-thaw erosion, and is to make it a single index form [*Xie, 2017*].

Grading criteria of evaluation index

According to the specific distribution of each index value in the freeze-thaw erosion area of Tibet, and to previous studies, the sensitivity levels of various factors affecting freeze-thaw erosion are determined.

Table 1. Grading criteria of evaluation index

Evaluation index	**Sensitivity**				
	Insensitive	**Mild**	**Moderate**	**High**	**Extremely high**
Annual range of temperature (°C)	≤18	18-20	20-22	22-24	>24
Annual precipitation (mm)	≤100	100-200	200-300	300-400	>400
Slope (°)	0-3	3-8	8-15	15-25	>25
Aspect (°)	0-45, 315-360	45-90, 270-315	90-135	225-270	135-225
Vegetation coverage (%)	≥80	60-80	40-60	20-40	<20
Grading assignment	1	3	5	7	9

Evaluation method

Evaluation indexes that affect freeze-thaw erosion are integrated to obtain a comprehensive evaluation index for sensitivity assessment of freeze-thaw erosion [*Wang, 2004 #3*]. The comprehensive evaluation index can be calculated by using formula (5).

$$s = \sqrt[n]{\prod_{i=1}^{n} C_i}, \tag{5}$$

where *S* is the comprehensive evaluation index, C_i is the grading assignment of index I, *n* is the number of indexes.

Based on field surveys and previous studies, the sensitivity of freeze-thaw erosion in the study area is divided into five grades (Table 2).

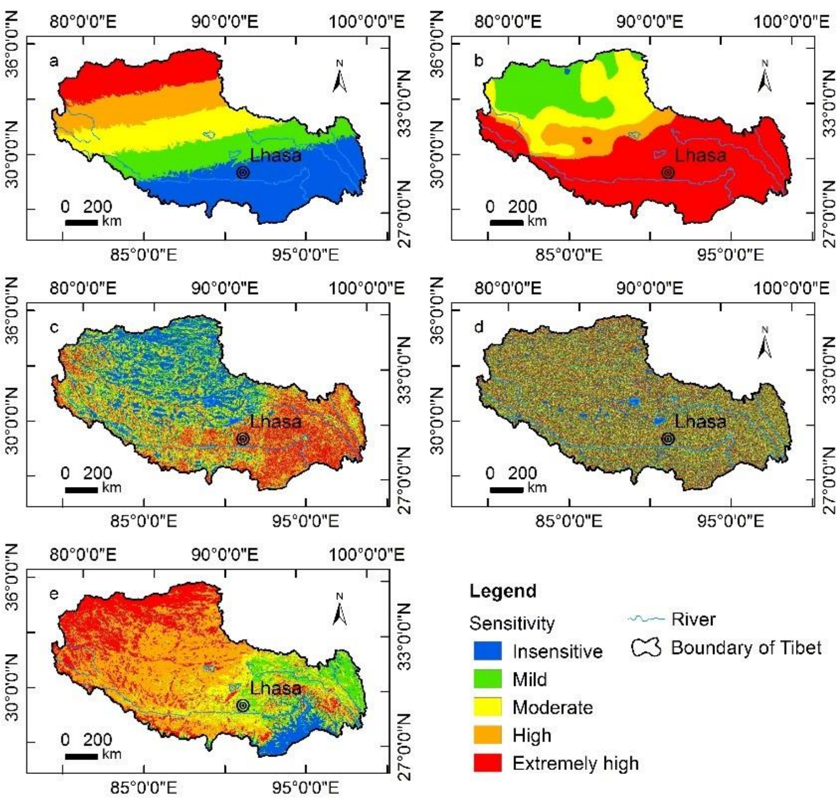

Fig. 1. Spatial distributions of freeze-thaw erosion sensitivity indexes in Tibet: annual range of temperature (a), annual precipitation (b), slope (c), slope aspect (d) and vegetation coverage (e)

Table 2. Grades about sensitivity of freeze-thaw erosion

	Sensitivity				
	Insensitive	**Mild**	**Moderate**	**High**	**Extremely high**
Evaluation of estimate (S)	<2	2-3.5	3.5-5.5	5.5-7.5	≥7.5

Results

The distribution of freeze-thaw erosion is very extensive in Tibet (Table 1), with the freeze-thaw erosion area of 79.4×104 km^2, accounting for 66.00% of the total area, indicating that freeze-thaw erosion is one of the main types of soil erosion. Freeze-thaw erosion sensitive area is 69.83×104 km^2, among which moderate and more sensitive area is 61.64×104 km^2, accounting for 77.63% of the total freeze-thaw erosion area in Tibet.

There is a significant difference in the spatial distribution of freeze-thaw erosion sensitivity in the Tibet. The sensitivity map (Fig. 2) shows that the sensitivity of freeze-thaw erosion in the high-altitude areas in the south is higher than that in the high latitudes in the north. Highly sensitive areas and extremely highly sensitive areas are mainly distributed in the southwest region. Some areas in the southeast are insensitive and mild sensitive as situated in the mountain canyons.

Table 3. Statistics about sensitivity of freeze-thaw erosion.

Sensitivity	**Area (10^4 km^2)**	**A (%)**	**B (%)**
Insensive	9.56	12.05	7.95
Mild	8.19	10.32	6.81
Moderate	42.29	53.27	35.16

High	18.74	23.60	15.57
Extremely high	0.61	0.77	0.51
Total of freeze-thaw zone	79.40	100.00	66.00
Non-freeze-thaw zone	40.90		34.00
Total	120.30		100.00

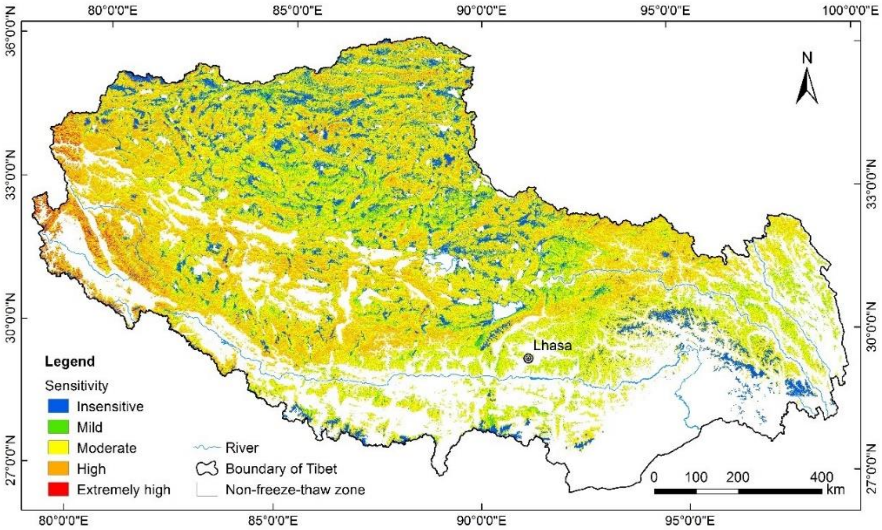

Fig. 2. Sensitivity of freeze-thaw erosion

Conclusions

According to the analysis, the conclusions are as followed:

(1) Freeze-thaw erosion is one of the main type of soil erosion in Tibet, and the distribution of freeze-thaw erosion is very extensive.

(2) The regional differentiation of freeze-thaw erosion sensitivity is obvious.

References

Guo B. et al. (2015). An estimation method of soil freeze-thaw erosion in the Qinghai-Tibet Plateau. Natural Hazards, 78: 1843-1857.

Hui-Xia L.I., Liu S.Z., Zhong X.H. (2005). GIS-Based Sensitivity Evaluation on Freeze-Thaw Erosion in Tibet. Soil & Water Conservation in China, 07: 44-46, 51. (in Chinese)

Qiu G., Zhou Y., Cheng G. et al. (2000). Geocryology in China. Beijing: Science Press, 15-20, 115

Wang L., Xiao Y., Jiang L., Ouyang Z. (2017). Assessment and analysis of the freeze-thaw erosion sensitivity on the Tibetan Plateau. Journal of Glaciology & Geocryology, 39 (01): 67-75. (in Chinese)

Wang X., Zhong X., Fan J. (204). Assessment and spatial distribution of sensitivity of soil erosion in Tibet. Journal of Geographical Sciences, 14: 41-46. (in Chinese)

Xie S., Qu J., Xu X., Pang Y. (2017). Interactions between freeze-thaw actions, wind erosion desertification, and permafrost in the Qinghai-Tibet Plateau. Natural Hazards, 85: 829-850.

Zhang et al. (2005). The classification and assessment of freeze-thaw erosion in Tibet. Journal of Geographical Sciences, 10: 635-640. (in Chinese)

Zhang J., Liu S., Yang S. (2007). The classification and assessment of freeze-thaw erosion in Tibet. Journal of Geographical Sciences, 17: 165-174. (in Chinese)