Postprint: Study on Aeolian Sand Environment and Sandification Types in Maqu Alpine Meadow

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Abstract

Desertification of alpine meadows in Maqu County represents a typical case of desertification occurring in the Qinghai-Tibet Plateau region, whose causes, trends, and management have consistently attracted considerable attention. By employing a three-dimensional laser scanner combined with field monitoring and laboratory analysis, the regional aeolian environment was characterized. Based on regional sediment grain size and morphological characteristics, desertification types were classified into blowout desertification type and complex desertification type according to the complexity of sand material sources. The results indicate that the region' s annual drift potential is 164.34 VU, the resultant drift potential is 91.57 VU, the resultant drift direction is 132.37°, and the wind direction variability is 0.56, belonging to an intermediate-ratio low wind-energy environment. Through comprehensive analysis of the length ratio, volume ratio, major axis, degree of alignment with the regional prevailing wind direction, and sediment grain size characteristics between blowouts and sand accumulation areas surrounding the blowout desertification type, blowouts are identified as the primary contributors to sand accumulation in this desertification type region. During the modern desertification process, for the complex desertification type, in addition to surrounding wind erosion areas, active dunes, and desertified grasslands contributing sand material to regional sand accumulation, the Yellow River channel also provides a certain amount of sand material to regional sand accumulation.

Full Text

Preamble

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Study on Wind-Sand Environment and Desertification Types in the Alpine Meadow of Maqu

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Abstract: Desertification of alpine meadows in Maqu County represents a typical case of land degradation in the Qinghai-Tibet Plateau region, attracting significant attention regarding its causes, trends, and remediation. Using a three-dimensional laser scanner combined with field monitoring and laboratory analysis, this study reveals the regional wind-sand environment. Based on grain size and morphological characteristics of sediments, desertification types are classified into blowout desertification and complex desertification according to the complexity of sand material sources. Results show that the regional annual drift potential is 164.34 VU, the resultant drift potential is 91.57 VU, the resultant drift direction is 132.37°, and the wind direction variability is 0.56, indicating a medium-ratio, low wind-energy environment. By analyzing the length ratio, volume ratio, long axis orientation, alignment with the regional prevailing wind direction, and sediment grain size characteristics of blowouts and sand accumulation areas, it is evident that blowouts serve as the primary contributors to sand accumulation in this desertified region. During contemporary desertification processes, complex desertification types receive sand material not only from surrounding wind-eroded areas, activated dunes, and desertified grasslands, but also from the Yellow River channel, which provides a certain amount of sand material for regional accumulation.

Keywords: Maqu; alpine meadow; 3-D laser scanner; desertification process; morphological parameters

As a crucial component of China’ s “Two Screens and Three Belts” ecological security framework, the Qinghai-Tibet Plateau not only establishes the foundation for China’ s modern monsoon climate but also constitutes an important ecological barrier and the headwater region for numerous rivers both domestically and internationally. Maqu County, located on the southeastern edge of the Qinghai-Tibet Plateau, features abundant water and grass resources with extensive high-quality pastureland, representing an essential component of the plateau ecosystem and a critical runoff generation, water conservation, and water supply area in the upper Yellow River basin.

Since the Industrial Revolution, intensified human activities and greenhouse gas emissions have caused global climate warming. In this context, the Qinghai-Tibet Plateau, as an ecologically fragile zone, exhibits exceptional sensitivity to climate change, manifested through reduced surface runoff, lowered groundwater levels, vegetation destruction, grassland degradation, and soil erosion. Additionally, with regional economic growth and increased material living standards, human-land conflicts have become prominent. Rapid population growth, overgrazing, and unreasonable grassland utilization have led to degradation and desertification, severely constraining sustainable resource utilization and economic development, endangering ecological security in the upper Yellow River, and even threatening downstream water conservancy facilities.

Previous studies have clarified regional desertification causes and material sources using grain size and mineral analysis methods, revealing that ancient aeolian sand in Maqu primarily originates from river terraces, with modern fluvial deposits also providing some sand material, though in relatively small quantities. However, these studies have not fully detailed the characteristics of regional desertification types or clearly identified contributions from various sand sources, which limits guidance for subsequent sand control efforts. To date, sand source identification in modern aeolian engineering remains poorly resolved due to methodological and technical limitations, resulting in blind spots or insufficient targeting in existing sand control projects that fail to optimize protection benefits.

Given these challenges, finding new methods and perspectives to clarify characteristics of typical regional desertification types and solve regional sand source identification requires further investigation. This study employs a three-dimensional laser scanner combined with traditional methods such as field surveys and laboratory analysis to further subdivide regional desertification type characteristics. This approach not only provides valuable references for future sand control engineering in Maqu' s alpine meadows but also offers a new perspective and methodology for sand source identification.

1.1 Study Area Overview

Maqu County, administered by Gannan Tibetan Autonomous Prefecture in Gansu Province, is situated at the eastern end of the Qinghai-Tibet Plateau, connecting Gansu, Qinghai, and Sichuan provinces. The county covers a total area of 90.98$\times10^{4}$ hm^2. The Yellow River enters from Muxihe Township in the western part of the prefecture, loops through the region, and flows back into Qinghai. The elevation ranges from 3,300 to 4,806 m. Soil types include alpine meadow soil, subalpine meadow soil, meadow soil, peat soil, marsh soil, and dark brown forest soil. The regional climate is a typical plateau continental monsoon climate, with an average annual precipitation of 615.5 mm, average annual evaporation of 1,353.4 mm, and an average annual temperature of 1.2°C. Natural vegetation includes steppe meadows, alpine meadows, and alpine shrubs, with alpine meadows being the most widely distributed vegetation type.

The study area is located on the southern bank of the Yellow River in Maqu County. Building upon previous research, this paper divides the Yellow River' s desertification belt into two types based on the complexity of sand material sources: blowout desertification and complex desertification. Complex desertification is characterized by concentrated and contiguous dune distribution with larger areas, including causes such as fixed dune activation, thermal slump, and wind erosion patches. The sand material sources include activated dunes, wind-eroded depressions, and desertified grasslands. Blowout desertification occurs in smaller areas surrounded by alpine meadows, with isolated dunes and a clearly defined giant blowout upwind of the sand accumulation body.

1.2 Research Methods

Data were obtained through a combination of field positioning observations and laboratory analysis. First, an automatic weather station was installed at a typical location in the study area (33°55 0.83 N, 102°9 8.09 E) using an HOBO U30 model to collect regional wind speed, wind direction, temperature, and humidity data. The wind speed and direction sensor was installed at 2.0 m above the surface, while temperature and humidity sensors were at 1.5 m, with a data collection interval of 5 minutes.

Second, a 3-D laser scanner (RIEGL VZ2000) was used to scan mobile dunes, blowouts, and surrounding areas. The scanner has a horizontal scanning angle of 0–360°, vertical scanning angle of -30° to +70°, maximum measurement range of 2,500 m, single measurement accuracy of 3 mm@100 m, and repeat measurement accuracy of 5 mm@100 m. Grain size analysis was performed using a Mastersizer 3000 laser particle size analyzer, with each sample measured three times and averaged. Graphical methods were used to calculate particle size and sorting parameters.

2.1 Average Wind Speed

As shown in Table 1, the maximum monthly average wind speed was 3.06 $m \cdot s^{-1}$, while the minimum was 1.78 $m \cdot s^{-1}$. Analysis of monthly average wind speed trends reveals that wind speeds were relatively low from May to August, then increased fluctuatingly, peaking in December at 3.06 $m \cdot s^{-1}$ before gradually decreasing. Sand-driving wind, the minimum wind speed required to initiate sand particle movement, is crucial for sand transport and represents an indispensable parameter in aeolian theory research and engineering design, as well as an important indicator for measuring wind-sand activity intensity and geomorphic evolution.

Compared with monthly average wind speed trends, monthly average sand-driving wind speed shows slight differences, specifically increasing from May to December, peaking at 7.74 $m \cdot s^{-1}$ in December, then gradually decreasing.

2.2 Sand Transport Potential

Drift potential (DP) is a key indicator for measuring regional wind-sand activity intensity and geomorphic evolution, reflecting the regional potential sand transport capacity and calculated in vector units. Based on Fryberger' s calculation equation, the regional annual drift potential is 164.34 VU, the resultant drift potential is 91.57 VU, the resultant drift direction is 132.37°, and the wind direction variability is 0.56, indicating a medium-ratio, low wind-energy environment. Further analysis reveals two dominant wind groups: one primarily from the west and northwest with larger drift potential, and another from the north, north-northeast, and east with smaller drift potential. These two wind groups are distributed at acute angles to each other.

2.3 Blowout Desertification Type

Blowout morphology is commonly used for classification. Based on geometric form, blowouts are divided into trough-shaped, dish-shaped, and bowl-shaped types. Domestic scholars have further subdivided these based on specific study areas. In this study area, the blowout is an oval-shaped giant blowout with a length of 358.7 m, width of 206.49 m, and length-width ratio of 1.74:1. The erosion entrance has nine gullies, all located in the northwest direction, with wind-eroded remnants present at the bottom center. The surrounding walls are steep erosion scarps with abundant loose sand material at their base. The northeast and southwest erosion scarps are steeper than the northwest and southeast walls because the regional prevailing wind is northwesterly. Airflow enters from the northwest corner and exits toward the southeast, scouring the northeast and southwest walls. Since the surrounding material consists of ancient channel deposits with high sand content and poor cohesion, the walls collapse under gravity after wind scouring, intensifying degradation of surrounding desertified grasslands.

The blowout outlet is a slope transitioning from gentle to steep, where wind-eroded debris migrates out of the blowout. The sand accumulation area is located southeast of the blowout, with a length of 630.6 m and length ratio of 1.28:1 between blowout and accumulation area, fully consistent with blowout length to sand accumulation volume ratios reported in literature. Using the surrounding intact alpine meadow as a reference surface, the blowout volume is calculated as 5.1×10^{4} m^{3}, while the sand accumulation volume is 4.5×10^{4} m^{3}, a difference of 0.6×10^{4} m^{3}.

Analysis of grain size composition (Table 2) shows that compared with blowout sediments, the sand accumulation area contains higher proportions of coarse and medium sand, and lower proportions of very fine sand, silt, and clay. This volume difference indicates that during transport, fine materials are blown away to greater distances while coarse materials remain or travel shorter distances, resulting in smaller sand accumulation volume than blowout volume. Integrating blowout morphology, volume, and sediment grain size characteristics confirms that blowouts are the primary contributors to regional sand accumulation.

2.4 Complex Desertification Type

Compared with blowout desertification, complex desertification covers a larger area with diverse causes including fixed dune activation, ancient dune activity, and thermal slump. The sand sources include surrounding activated dunes, wind-eroded land, and desertified grasslands. Using the 3-D laser scanner, typical changes under representative wind conditions were documented (Figure 5). The monitoring area covers approximately 2.3×10^{4} m^2. Using the elevation of intact alpine meadows as a reference surface, volumes of accumulation and erosion were calculated. Results show 6.1×10^{4} m^3 of sand material above the reference surface and 4.5×10^{4} m^3 below, indicating net accumulation of 1.6×10^{4} m^3. This phenomenon occurs for two reasons: first, compacted sand material becomes loose after wind erosion, increasing porosity and volume; second, external material input exists beyond local depression erosion. A typical isolated dune in the area also shows accumulation under single wind events, with the dune measuring 59.3 m long, 22.9 m wide, and 2.1 m high. The northeast side of the dune crest shows erosion (46.98% of area) while the southwest side shows accumulation (53.02% of area), with eroded and accumulated volumes of 0.6×10^{4} m^3 and 0.62×10^{4} m^3 respectively, consistent with the overall area pattern.

During autumn and winter, reduced precipitation and glacial meltwater decrease Yellow River discharge, exposing riverbeds covered by loose alluvial deposits in summer that subsequently move with wind, providing abundant sand material for regional desertification. Sediment samples collected from exposed riverbeds toward both banks reveal differentiation patterns (Table 3). Riverbed deposits are dominated by coarse, medium, and fine sand (22.9%, 51.25%, and 11.78% respectively). Floodplain deposits contain less coarse and medium sand than riverbed deposits, with coarse sand decreasing from 22.9% to 4.36% and medium sand from 51.25% to 40.81%, while fine sand increases from 11.78% to 37.98%. First and second terrace deposits show further decreases in coarse and medium sand proportions and increases in very fine sand and silt.

Grain size parameters calculated using Folk and Ward standards show that moving from riverbed to terraces, mean grain size decreases from 329.35 m to 105.62 m. Sorting coefficients range from 0.93 to 1.46, indicating moderate to poor sorting. Skewness coefficients range from 0.04 to 0.30, showing very fine skewed to fine skewed distributions with coarser particle bias. Kurtosis coefficients range from 1.31 to 2.28, indicating narrow to very narrow distributions with relatively concentrated particle distributions.

Integrating erosion-deposition changes, typical dune dynamics, and sediment grain size characteristics of the complex desertification type reveals that surrounding wind-eroded depressions and activated dunes remain the primary contributors to sand accumulation, though the Yellow River channel also provides a certain amount of sand material for regional desertification.

3 Conclusions and Discussion

Research results indicate that both monthly average wind speed and monthly average sand-driving wind speed are lowest in summer and higher in autumn and winter, peaking in December before gradually decreasing. During autumn and winter, withered meadows and livestock grazing weaken vegetation' s protective effect on surface soil compared to the growing season, exposing abundant loose material that intensifies regional desertification under wind action.

The regional annual drift potential is 164.34 VU, resultant drift potential is 91.57 VU, resultant drift direction is 132.37°, and wind direction variability is 0.56, representing a medium-ratio, low wind-energy environment. Based on the complexity of sand material contributions, the Yellow River desertification belt is subdivided into blowout desertification and complex desertification types.

Blowout desertification features isolated dunes with smaller areas and an upwind blowout. The long axis orientation, length ratio between wind erosion and accumulation areas, volume, and other morphological parameters, along with sediment grain size characteristics, show high consistency with the regional prevailing wind direction. The desertification process is relatively simple, with sand material primarily originating from the blowout.

Complex desertification exhibits concentrated and contiguous dune distribution with larger areas. Causes include dune activation, regional wind erosion, and thermal slump. Sand sources encompass surrounding activated dunes, wind-eroded land, and desertified grasslands, representing a wider range of sources and more complex processes than blowout desertification. During contemporary desertification, surrounding wind-eroded depressions remain the main contributors to sand accumulation, though the Yellow River channel also supplies sand material.

Based on these findings, sand control recommendations are proposed: For blowout desertification, while controlling mobile dunes, emphasis should be placed on managing upwind blowouts to cut off sand sources at their origin. For complex desertification, in addition to establishing control and ecological restoration projects in surrounding areas, reasonable protective measures should be implemented near upwind river channels to block sand movement from the riverbed to both banks, thereby reducing management difficulty for downwind desertified meadows and mobile dunes.

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Note: Figure translations are in progress. See original paper for figures.