

## Postprint: Main Aeolian Environment Characteristics and Formation Mechanisms of the Ujumqin Sandy Land

**Authors:** Zhang Hao, Dang Xiaohong, Meng Zhongju, Gao Yong, Liu Yang, Qin Qingchuan

**Date:** 2024-03-01T21:18:34+00:00

### Abstract

Clarifying the regional aeolian sand movement environment and sediment grain-size characteristics is crucial for studying wind-blown sand flow and holds significant importance for the prevention and control of regional aeolian sand disasters. This study utilizes wind regime data from the Ujumqin Sandy Land to investigate the characteristics of sand-driving wind regimes and sand transport potential variations, while integrating sediment grain-size data to reveal the spatial differentiation patterns of the aeolian environment in this region. The results indicate that: (1) The annual average frequency of sand-driving winds in the Ujumqin Sandy Land is 33.8%, with average wind speeds ranging between  $3.34\text{--}5.40\text{ m}\cdot\text{s}^{-1}$  and average sand-driving wind speeds ranging between  $6.46\text{--}8.49\text{ m}\cdot\text{s}^{-1}$ . The frequency and speed of sand-driving winds are greater in the northern part than in the southern part, and greater in the western part than in the eastern part. (2) Throughout the year, the frequency and speed of sand-driving winds are highest in spring, with sand-driving winds predominantly from the southwest direction, and WSW winds having the highest frequency. (3) The sand transport potential in the sandy land ranges from 19.2 to 193.7 VU, indicating a generally low wind-energy environment with predominantly sharp bimodal wind regimes. The sand transport potential is greater in the northern part than in the southern part, and greater in the western part than in the eastern part. Throughout the year, sand materials generally migrate toward the east and northeast, with spring being the primary period of aeolian sand activity. (4) The sandy land is dominated by coarse and medium sand fractions, with sediment grain sizes being relatively coarse in the southern and western parts and finer in the eastern part. Sediments in the northern and eastern parts of the sandy land exhibit poor sorting, with grain-size fractions being significantly influenced by external sources. Overall, aeolian sand activity is strongest in the northern part of the sandy land, making it suitable for artificial

vegetation establishment or installation of sand barriers for sand fixation. In the eastern part of the sandy land, shelterbelts should be planted to prevent continuous eastward migration of sand materials.

## Full Text

### Study on Main Aeolian Sand Environment Characteristics and Formation Mechanism in Wuzhumuqin Sandy Land

ZHANG Hao<sup>1</sup>, DANG Xiaohong<sup>1,2,3</sup>, MENG Zhongju<sup>1,2</sup>, GAO Yong<sup>1,4</sup>, LIU Yang<sup>5</sup>, QIN Qingchuan<sup>6</sup>

<sup>1</sup>School of Desert Management, Inner Mongolia Agricultural University, Hohhot 010018, Inner Mongolia, China

<sup>2</sup>National Positioning and Observation Research Station of Hangjin Desert Ecosystem, Ordos 017400, Inner Mongolia, China

<sup>3</sup>Baotou Forestry and Grassland Bureau, Baotou 014030, Inner Mongolia, China

<sup>4</sup>Key Laboratory of Sandstorm Physics (A Characteristic and Advantageous Discipline Jointly Built by Central and Local Governments), Hohhot 010018, Inner Mongolia, China

<sup>5</sup>Research Institute of Water Resources of Inner Mongolia Autonomous Region, Hohhot 010020, Inner Mongolia, China

<sup>6</sup>Dongwuzhumuqin Banner Water Conservancy Development Center, Xilinhot 026300, Inner Mongolia, China

## Abstract

Clarifying the regional aeolian sand movement environment and sediment grain size characteristics is crucial for studying sand flow and holds significant importance for regional sand disaster prevention and control. This study utilizes wind regime data from the Wuzhumuqin Sandy Land to investigate the variation characteristics of sand-driving wind regimes and sand transport potential, while combining sediment grain size data to reveal the spatial differentiation patterns of the aeolian sand environment in this region. The results indicate: (1) The annual average frequency of sand-driving wind in Wuzhumuqin Sandy Land is 33.8%, with average wind speeds ranging from 3.34–5.40  $\text{m} \cdot \text{s}^{-1}$  and average sand-driving wind speeds between 6.46–8.49  $\text{m} \cdot \text{s}^{-1}$ . The frequency and wind speed of sand-driving wind are greater in the northern and western parts of the sandy land than in the southern and eastern parts. (2) The overall annual sand-driving wind frequency and wind speed are highest in spring, with sand-driving wind directions predominantly from the southwest, and the highest frequency occurring in the WSW direction. (3) The sand transport potential in the sandy land ranges from 19.2–193.7 VU, representing a low wind-energy environment with predominantly sharp bimodal wind regimes. Sand transport potential is greater in the northern and western parts than in the southern and eastern parts. Throughout the year, sand materials are transported toward the

east and northeast, with spring being the most critical period for aeolian sand activity. (4) The sandy land is primarily composed of coarse and medium sand fractions, with soil particle sizes being coarser in the south and west and finer in the east. Sediment sorting is poor in the northern and eastern parts of the sandy land, and particle size components are significantly influenced by external factors. Overall, aeolian sand activity is strongest in the northern part of the sandy land, making it suitable for artificial vegetation establishment or sand barrier installation. Planting shelterbelts in the eastern part of the sandy land can prevent continued eastward sand migration.

**Keywords:** wind regime; sand transport potential; sediments; spatial differences; Wuzhumuqin Sandy Land

---

Aeolian sand disasters are natural processes where strong near-surface winds carry sand materials that erode the land surface, alter its morphology, form various aeolian landforms, and cause serious harm to human production and life. In aeolian sand disaster research, sand movement is a key focus. Surface wind regimes are influenced by local topography and climate, resulting in distinct regional characteristics of aeolian sand movement. Aeolian sand movement affects the structural composition of surface sediment systems, while sediment grain size characteristics serve as important indicators reflecting aeolian and depositional environments. Therefore, mastering regional aeolian sand environment characteristics is essential for studying surface sand flow.

In aeolian sand movement research, sand transport potential is generally used as an indicator to measure regional aeolian sand activity intensity. Sand transport potential represents the maximum potential aeolian sand activity intensity within a region, provides a unified evaluation standard for aeolian sand environments, and facilitates comparative analysis of wind energy environments across different regions. Previous studies have utilized sand transport potential to analyze spatiotemporal variation characteristics of aeolian sand activity intensity in the Taklamakan Desert, focusing on estimation deviations of sand transport potential. Other research has found that coastal dunes in Changli, Hebei, show an overall decaying trend in onshore and offshore sand transport potential, and that dune types and orientations are influenced by wind dynamics. However, evaluating aeolian sand environments solely based on sand transport potential has limitations, as it fails to fully consider environmental factors beyond wind regimes. Surface sediment characteristics result from the combined effects of multiple environmental factors and provide important indications of regional wind regimes and depositional environments. Integrating wind energy environments with surface sediment characteristics facilitates accurate understanding of field sand transport patterns and provides more significant scientific reference value.

Wuzhumuqin Grassland is an important component of the Xilingol Grassland. Since the 1980s, global warming, combined with human reclamation and over-

grazing, has caused severe grassland degradation, with an average of 1,000 hm<sup>2</sup> of Wuzhumuqin Grassland being engulfed by sand annually. Severe grassland desertification has led to continuous reduction in grassland carrying capacity, frequent dust weather events, and serious threats to regional residents' survival and development. The "Three-North" Shelterbelt Program focuses primarily on sand prevention and control as its main direction. As an important ecological barrier in northern China, Inner Mongolia holds a prominent strategic position. Wuzhumuqin Sandy Land is one of the primary sources of sandstorms for the Beijing-Tianjin-Hebei region. Controlling Wuzhumuqin Sandy Land and restoring natural grassland are necessary prerequisites for consolidating the northern ecological security barrier, making sand prevention and control efforts in Wuzhumuqin Sandy Land extremely urgent. Current research on Wuzhumuqin Sandy Land has primarily focused on landscape patterns, soil wind erosion, soil physicochemical properties, and vegetation, while studies on aeolian sand environment characteristics remain limited. Therefore, based on meteorological station data from the Wuzhumuqin Sandy Land periphery, this paper systematically analyzes sand-driving wind regime and sand transport potential characteristics, combined with surface sediment grain size data, to reveal the aeolian sand movement environment characteristics and dust migration patterns in this region. The research results enrich regional aeolian sand flow studies and provide scientific references for future regional environmental characteristic analysis and aeolian sand disaster prevention and control in Wuzhumuqin Sandy Land.

### 1.1 Study Area Overview

Wuzhumuqin Sandy Land is located in the eastern part of the Xilingol Grassland in Inner Mongolia, administratively belonging to West Wuzhumuqin Banner, Xilingol League (Fig. 1). It is distributed in a fan shape, wider in the southwest and narrower in the northeast, with elevations ranging from 835–1,957 m. The region has a mid-temperate, typical semi-arid continental monsoon climate, long-term control by the Mongolian High, and relatively harsh natural conditions. Spring is dry and windy, summer is short and dry, autumn frost arrives early, and winter is cold and long. The annual average temperature is 1.6°C, with extreme maximum temperatures of 39.6°C and extreme minimum temperatures of -37.5°C. Annual rainfall is approximately 350 mm, concentrated mainly in June–August. The annual average wind speed is 3.8 m · s<sup>-1</sup>, with extreme maximum wind speeds reaching 28 m · s<sup>-1</sup> and over 70 days of wind above level 8 annually. The main soil types are chestnut soil and chernozem. Sandy land vegetation shows zonal distribution, with *Stipa baicalensis* and *Filifolium sibiricum* communities dominating the southeast, and *Caragana microphylla*, *Stipa grandis*, and *Artemisia frigida* communities dominating the northwest.

## 1.2 Data Sources and Processing

The wind regime data used in this study were obtained from four meteorological stations around Wuzhumuqin Sandy Land: Balagargol Town, Bayan Gol Town, Bayan Hushuo Sumu, and Wulan Halaga Sumu, representing the regional characteristics of the southern, western, northern, and eastern parts of the sandy land, respectively. Data recording began in 2015, with continuous observation at 10-minute intervals at a height of 10 m, totaling 36,288 records of wind speed and direction. Referencing relevant studies, sand particles on the surface of Wuzhumuqin Sandy Land begin to move when wind speed reaches  $5 \text{ m} \cdot \text{s}^{-1}$ ; therefore, this study uses  $5 \text{ m} \cdot \text{s}^{-1}$  as the threshold wind speed for surface sand particle movement. First, all wind conditions with speeds greater than  $5 \text{ m} \cdot \text{s}^{-1}$  in the original meteorological data were calculated separately for each month to determine average sand-driving wind speed, sand-driving wind frequency, and maximum wind speed. Wind direction data were then divided into 16 directional sectors according to azimuth angles, and the sand-driving wind frequency for each direction was calculated separately.

The sand transport potential calculation method adopts the Fryberger sand transport potential calculation model:

$$DP = \frac{V^2(V - V_t)t}{100}$$

where  $DP$  represents sand transport potential in vector units (VU);  $V$  represents wind speed greater than the threshold wind speed (in knots, where  $1 \text{ knot} = 0.5 \text{ m} \cdot \text{s}^{-1}$ );  $V_t$  represents the threshold wind speed (in knots); and  $t$  represents the percentage of observation time during which sand-driving wind acts relative to total observation time. The resultant drift potential (RDP) is the vector sum of sand transport potentials from 16 directions, representing the net sand transport capacity during aeolian sand movement in a region. The resultant drift direction (RDD) represents the overall movement direction of sand materials within the region.

Fryberger's wind energy environment classification method divides the study area into three different wind energy environments: low wind energy ( $DP < 200 \text{ VU}$ ), medium wind energy ( $200 \leq DP < 400 \text{ VU}$ ), and high wind energy ( $DP \geq 400 \text{ VU}$ ). Fryberger also proposed using the wind direction variability index ( $RDP/DP$ ) to reflect the complexity of sand-driving wind directions. The wind direction variability index is inversely proportional to sand-driving wind direction combinations. When  $RDP/DP < 0.3$ , it indicates complex wind conditions; when  $0.3 \leq RDP/DP \leq 0.8$ , it indicates medium wind direction variability, generally representing blunt bimodal or sharp bimodal wind regimes; and when  $RDP/DP > 0.8$ , it indicates low wind direction variability with relatively single wind directions, generally corresponding to narrow or wide unimodal wind regimes. Plotting sand-driving wind speed combinations

and sand transport potential results as rose diagrams enables simple and intuitive analysis of their variations.

Surface sediment samples were collected from different directions in Wuzhumuqin Sandy Land during April 2021, a period when grassland growth conditions were poor, avoiding the influence of surface vegetation on soil particle size. Five flat sample plots were selected in each direction with approximately 5 km intervals between sampling points. At each sampling point, 500 g of surface sand samples (0–3 cm depth) were randomly collected within a 20 cm × 20 cm area. The sampling range basically represents the main regional characteristics of the eastern, western, southern, and northern parts of Wuzhumuqin Sandy Land. A Mastersizer 2000 laser particle size analyzer was used to measure the volume percentage of sediment components for each soil sample, with each sample measured three times and averaged. For convenience, the arithmetic mean of five soil data results from each sampling point was used to characterize the sediment component characteristics of that location. Sediment parameters including mean grain size ( $M_Z$ ), sorting coefficient ( $\sigma$ ), and skewness ( $SK$ ) were calculated according to the Udden-Wentworth scale.

## 2.1 Sand-Driving Wind Characteristics

The overall sand-driving wind frequency in Wuzhumuqin Sandy Land is 33.8%, with an annual average wind speed of 3.34–5.40  $\text{m} \cdot \text{s}^{-1}$ . Influenced by altitude and surface vegetation coverage, sand-driving wind shows obvious spatial distribution differences. As shown in Fig. 2, sand-driving wind frequency is higher in the northern and western parts and relatively lower in the eastern and southern parts. The annual sand-driving wind frequencies for Balagargol Town, Bayan Gol Town, Bayan Hushuo Sumu, and Wulan Halaga Sumu are 48.0%, 37.5%, 28.6%, and 21.4%, respectively. Monthly sand-driving wind frequencies throughout the year show consistent variation trends, all presenting an increasing pattern from January to April, with maximum sand-driving wind frequencies concentrated in April and highest frequencies occurring in spring.

The annual average sand-driving wind speed in Wuzhumuqin Sandy Land ranges from 6.46–8.49  $\text{m} \cdot \text{s}^{-1}$ . Regional distribution patterns of average sand-driving wind speed and frequency are consistent, with larger average sand-driving wind speeds in the western and northern parts showing greater overall variation, while the southern and eastern parts have relatively smaller average sand-driving wind speeds with smaller differences. The annual average sand-driving wind speeds for Balagargol Town, Bayan Gol Town, Bayan Hushuo Sumu, and Wulan Halaga Sumu are 8.49  $\text{m} \cdot \text{s}^{-1}$ , 7.62  $\text{m} \cdot \text{s}^{-1}$ , 6.94  $\text{m} \cdot \text{s}^{-1}$ , and 6.46  $\text{m} \cdot \text{s}^{-1}$ , respectively. Monthly average sand-driving wind speeds throughout the year show synchronous increase and decrease trends, with maximum average sand-driving wind speeds concentrated in April, all peaking in spring.

From the perspective of sand-driving wind direction characteristics (Table 1), Wuzhumuqin Sandy Land is primarily influenced by southwest winds, with the

highest frequency occurring in the WSW direction across different regions. Balagargol Town is dominated by westerly winds (69.0%) and southerly winds (13.2%), followed by northerly winds with frequencies of 13.2%. Bayan Gol Town has a similar wind direction structure to Balagargol Town, dominated by westerly winds (63.7%), followed by northerly winds (17.1%) with a frequency of 17.1%. Bayan Hushuo Sumu is also dominated by westerly winds (59.1%), with northerly winds second (25.1%) at a frequency of 25.1%. Wulan Halaga Sumu is similarly dominated by westerly winds (56.7%), with southerly winds (20.0%) second at a frequency of 20.0%.

Seasonal variations show that spring sand-driving winds in Balagargol Town are similar to annual patterns, dominated by westerly winds (71.2%). Summer is dominated by southerly winds (54.6%), autumn is similar to spring with westerly winds dominant (74.5%), and winter is dominated by southwesterly winds (53.7%). Bayan Gol Town shows westerly winds dominant in spring (79.8%), southwesterly winds in summer (55.5%), westerly winds again in autumn (80.2%), and southwesterly winds in winter (75.9%). Bayan Hushuo Sumu has westerly winds dominant in spring (63.0%), southerly winds in summer (43.6%), westerly winds in autumn (77.3%), and southwesterly winds in winter (72.2%). Wulan Halaga Sumu shows westerly winds dominant in spring (53.1%), southerly winds in summer (38.4%), westerly winds in autumn (62.5%), and southwesterly winds in winter (72.2%). Overall, spring and autumn sand-driving winds in Wuzhumuqin Sandy Land are dominated by westerly directions, summer sand-driving winds are dominated by southwesterly directions except in Wulan Halaga Sumu where southerly easterly winds dominate, and winter wind direction structures are relatively simple, mostly consisting of west-easterly and partial westerly winds.

## 2.2 Sand Transport Potential Characteristics

Wuzhumuqin Sandy Land overall belongs to a low wind-energy environment (Fig. 6), with annual sand transport potential ranging from 19.2–193.7 VU. Sand transport potential is greater in the northern and western parts and smaller in the southern and eastern parts. The annual sand transport potentials for Balagargol Town, Bayan Gol Town, Bayan Hushuo Sumu, and Wulan Halaga Sumu are 193.7 VU, 65.9 VU, 24.4 VU, and 19.2 VU, respectively, with resultant drift potentials of 14.8 VU, 46.2 VU, 67.2 VU, and 44.7 VU. The wind direction variability indices for all regions range between 0.3–0.8, indicating medium wind direction variability with predominantly sharp bimodal wind regimes. Throughout the year, sand materials are transported overall toward the east and northeast directions.

The resultant drift directions for Bayan Gol Town, Bayan Hushuo Sumu, and Wulan Halaga Sumu are similar at  $61.99^\circ$  and  $85^\circ \pm 5^\circ$ , with Balagargol Town's resultant drift direction being southeastward. Spring has the highest sand transport potential, making it the most important sand transport source period. Seasonally, Balagargol Town's resultant drift direction is concentrated in the

northeast, with the strongest aeolian sand activity in spring (sand transport potential of 12.8 VU) and weakest in summer (4.7 VU). Autumn and winter are consistent with sand transport potentials of 6.9 VU and 8.3 VU, respectively, all in the northeast direction. Spring and summer belong to medium wind direction variability, while autumn and winter show low variability.

Bayan Gol Town's resultant drift direction is concentrated in the southeast in spring and in the northeast in the other three seasons. Spring is the most critical period for aeolian sand activity with a sand transport potential of 44.7 VU, while summer and autumn potentials are 24.0 VU and 12.8 VU, respectively. Winter shows the weakest aeolian sand activity with a potential of 5.3 VU. Except for winter's low wind direction variability, the other three seasons show medium variability. Bayan Hushuo Sumu's annual sand transport potential characteristics are consistent with Bayan Gol Town, also showing highest potential in spring (67.2 VU) with a resultant drift direction toward the southeast, while the other three seasons are in the northeast direction. Spring and summer show medium wind direction variability, while autumn and winter show low variability.

From the temporal scale of aeolian sand activity intensity in different regions of Wuzhumuqin Sandy Land (Fig. 7), the southern part has the lowest sand transport potential while the northern part has the highest, with the western part greater than the eastern part. All regions show maximum sand transport potential in spring, with annual resultant drift directions concentrated in the northeast and southeast. Both spring and summer belong to medium wind direction variability, while winter shows low variability.

### 2.3 Soil Particle Size Characteristics

As shown in Fig. 8, the sediment grain size curves for Bayan Gol Town, Balagargol Town, and Bayan Hushuo Sumu all show asymmetric bimodal distributions with large differences between primary and secondary peaks. The primary peaks are located at 735–965  $\mu\text{m}$ , belonging to coarse sand fractions. The secondary peaks for Bayan Gol Town and Balagargol Town are at 250–365  $\mu\text{m}$  (medium sand), while Bayan Hushuo Sumu's secondary peak is at 375  $\mu\text{m}$ , representing a mixture of fine and medium sand. Wulan Halaga Sumu's sediment grain size curve shows an asymmetric unimodal distribution with a peak at 250–450  $\mu\text{m}$  (medium sand). Overall, sediment grain size distributions vary unevenly across different regions of Wuzhumuqin Sandy Land, with more complex and coarser particle sizes in the western, northern, and southern parts, and finer, more concentrated particle sizes in the eastern part.

Table 2 shows that Balagargol Town is dominated by coarse sand (30.8% of total samples), followed by fine sand and medium sand at 26.7% and 25.3%, respectively. Clay and very fine sand contents are low at only 6.6%. Bayan Gol Town is dominated by coarse sand (36.4%) and medium sand (31.0%), followed by fine sand at 17.8%, with low silt, clay, and very fine sand contents totaling

14.8%. Bayan Hushuo Sumu is dominated by coarse sand (35.0%), followed by fine sand and medium sand at 23.5% and 16.6%, respectively. Very fine sand and clay contents are minimal at 6.3%. Wulan Halaga Sumu is dominated by medium sand (38.3%), followed by coarse sand and fine sand at 22.3% and 25.6%, respectively. Very fine sand, very coarse sand, and clay contents are lowest, totaling 13.8%.

Overall, the surface layer of Wuzhumuqin Sandy Land is dominated by coarse and medium sand, followed by fine sand, silt, and very coarse sand, with clay and very fine sand having the lowest content. The average grain size in different regions ranges from 0.74–2.60  $\Phi$  (average 1.41  $\Phi$ ), indicating relatively coarse dominant particle sizes. Sediment sorting coefficients range from 0.90–2.51  $\Phi$  (average 1.55  $\Phi$ ), indicating poor overall sediment sorting. Wulan Halaga Sumu has the largest sorting coefficient and poorest sorting, indicating complex sand material components resulting from sand accumulation. Skewness values range from 0.06–0.78, predominantly extremely positively skewed. Higher skewness values in the eastern and northern parts indicate relatively strong aeolian transport capacity and more external sediment components, confirming that sand materials migrate overall toward the east and northeast during aeolian processes.

### 3 Discussion

The results show that southwest winds have the highest frequency in Wuzhumuqin Sandy Land, primarily due to topographic factors. The southern part of the study area consists mainly of mountains and hills, while the northern part is desert grassland, with terrain sloping from southeast to northwest. Influenced by the Mongolian cyclone, upper-level troughs move from west to east, and airflow is channeled into a southwest orientation by hills, resulting in prevailing southwest winds. Additionally, spatial differences in surface vegetation are a major cause of regional wind energy environment characteristics. Lush vegetation can not only reduce wind speed but also increase the threshold wind speed for surface sand particles, thereby reducing sandstorm frequency. Previous research indicates that vegetation coverage in the western and northern parts of Wuzhumuqin Sandy Land is relatively low, resulting in poor windbreak and sand fixation effects, while the eastern and southern parts have good vegetation conditions with a continuous increasing trend in recent years, leading to an overall wind energy environment pattern of high values in the northwest and low values in the southeast.

The main active period for aeolian sand movement in the study area is concentrated in March–May, coinciding with spring when air temperatures are cold and dry, vegetation has not yet greened up, and the surface is essentially bare. Combined with precipitation data, spring rainfall accounts for only 14% of annual rainfall, while evaporation far exceeds precipitation during the same period, leaving soil moisture insufficiently replenished and the soil in a dry, loose state highly susceptible to wind erosion under strong winds. Summer rainfall

accounts for 54% of annual precipitation, and increased rainfall can effectively reduce aeolian sand movement intensity. The temporal difference between the windy season and rainy season intensifies the severity and frequency of aeolian sand disasters, making spring the frequent occurrence period for sandstorms.

Sediment grain size parameters are important criteria for tracing sand source backgrounds. Studying sediment grain size characteristics and their differentiation patterns helps identify surface sand material sources and explore aeolian sand flow movement mechanisms. Significant differences exist in sediment grain size variations across different regions of Wuzhumuqin Sandy Land. The overall coarse sediment grain size indicates that large amounts of fine particles migrate with wind under aeolian action, leaving coarse and medium sand as dominant fractions. The abundance of coarse sand components indicates that the transport medium has relatively low kinetic energy, belonging to a weak wind-energy environment. In aeolian processes, silt is the fine component that can be transported over long distances in dust storms, while fine and medium sand are the main active components of aeolian sand movement and the saltation components of sand materials. The silt content in Balagargol Town and Bayan Gol Town is lower than in Bayan Hushuo Sumu and Wulan Halaga Sumu, primarily due to high-frequency sand-driving wind events that cause large-scale silt migration in the southern and western parts under wind transport. In the northern part, intense aeolian sand erosion causes continuous surface deflation, leading to increased soil silt content. The eastern part has lower coarse and very coarse sand content, higher fine and medium sand content (totaling 60.6%), finer overall sediment grain size, relatively concentrated grain size distribution, poor sorting, and complex components. Combined with wind regime and sand transport potential characteristics, under the influence of high-frequency southwest winds, large amounts of fine sand components are transported eastward and northeastward, causing continuous accumulation of saltation materials in the eastern part during movement and eastward migration, resulting in more external components in eastern sediments.

The sand transport potential of Wuzhumuqin Sandy Land (19.2–193.7 VU) and the Otindag Sandy Land (36.9–174.8 VU) both belong to low wind-energy environments, with resultant drift directions concentrated in the east-northeast direction. The difference is that Wuzhumuqin Sandy Land formed due to rapid population growth and overgrazing in Xilingol Grassland in recent years, which exceeded the natural recovery rate of grasslands, causing “bald patches” and forming numerous scattered, non-contiguous patchy sandy lands. This degradation process is relatively slow. The Otindag Sandy Land formed at least in the Late Tertiary period and represents a natural desertification environment. Degraded grassland restoration has natural advantages over bare sand land restoration. The grassland degradation restoration process can gradually improve soil physicochemical properties, ultimately enabling degraded grassland ecosystems to shift from carbon sources to carbon sinks, thereby increasing the carbon sequestration potential of restored vegetation. Improved grassland carbon storage contributes to regional climate regulation, promotes growth of native grasslands,

and enables rapid restoration of grassland degradation, while excessive degradation accelerates grassland carbon pool loss and disrupts soil organic carbon recovery and accumulation, affecting natural grassland succession. Therefore, it is essential to promptly curb the grassland degradation trend in Wuzhumuqin Grassland to avoid further sand land expansion.

Overall, Wuzhumuqin Sandy Land is currently in a fixed and semi-fixed sand state with relatively light desertification, but the trend of land desertification is evident. Without prevention and control measures, grassland will further degrade and desertify. Therefore, windbreak and sand fixation system design for Wuzhumuqin Sandy Land must adapt to local conditions, focusing on restoring the ecological environment in the northern sandy land through artificial seeding and grazing prohibition measures to rapidly restore grassland vegetation. According to Su Riguga's research, increased shrub encroachment of *Caragana microphylla* in West Wuzhumuqin Grassland leads to decreased clay, silt, and very fine sand content, while increasing fine, medium, and coarse sand content. Combined with the soil particle size distribution characteristics of the study area, planting large amounts of *Caragana microphylla* in the northern sandy land is suitable to reduce dust from silt and other components while preventing high-intensity wind erosion of bare sand surfaces. Additionally, appropriate mechanical sand barriers can be installed in severely desertified areas to increase surface roughness, reduce wind speed, weaken wind erosion intensity, and slow sand land expansion. Zhu Bonian et al. found through sand barrier installation in southern Wuzhumuqin Sandy Land that sand barriers can significantly reduce surface wind speed, with  $1\text{ m} \times 1\text{ m}$  grid barriers providing optimal windbreak and sand fixation effects, suitable for deployment in heavily desertified areas in the northern and western parts where vegetation restoration is difficult. Simultaneously, shelterbelts perpendicular to sand transport direction should be planted in the eastern sandy land to enhance windbreak and sand fixation capacity, prevent continuous eastward sand transport, and avoid damage to excellent eastern grasslands. Selecting dominant grass species for human intervention in severely degraded sandy land areas and forming a management technology system centered on rapid sand fixation and stable vegetation recovery in ecologically fragile areas of Wuzhumuqin Sandy Land can provide scientific foundations for rapid restoration and comprehensive, efficient management of desertified natural grasslands in China.

Studying surface aeolian sand activity intensity and sediment grain size characteristics is key to understanding regional aeolian sand environments. Evaluating regional aeolian sand activity intensity requires not only analysis of wind speed and direction data but also field measurements of aeolian sand flow and consideration of environmental factors such as topography and vegetation coverage. This study only considered wind regime, sand transport potential, and transport direction in Wuzhumuqin Sandy Land, lacking long-term terrestrial observation data and environmental factor considerations. Additionally, soil sampling was conducted in spring when vegetation conditions were still poor, ignoring the effect of vegetation coverage on soil particle size sorting, and with

few sampling points in the sandy land interior, soil samples have certain spatial limitations. Therefore, future research should focus on environmental factor impacts, combine meteorological elements with field aeolian sand flow measurements, enrich surface sediment component data, and comprehensively consider regional aeolian sand activity intensity and depositional environment characteristics to provide scientific foundations for aeolian sand disaster prevention and ecological environment restoration in Wuzhumuqin Sandy Land.

#### 4 Conclusions

- (1) The annual average sand-driving wind frequency in Wuzhumuqin Sandy Land is 33.8%, with average wind speeds of  $3.34\text{--}5.40\text{ m}\cdot\text{s}^{-1}$  and average sand-driving wind speeds of  $6.46\text{--}8.49\text{ m}\cdot\text{s}^{-1}$ . Sand-driving wind frequency and wind speed are higher in the northern and western parts and lower in the southern and eastern parts. All regions show highest values in spring, with annual sand-driving wind directions predominantly from the southwest, and the WSW direction having the highest frequency.
- (2) The annual average sand transport potential in the sandy land is 19.2–193.7 VU, belonging to a low wind-energy environment with predominantly sharp bimodal wind regimes. Sand transport potential is larger in the northern and western parts and smaller in the southern and eastern parts. The southern and northern parts have southwest as the main sand source direction, while the western and eastern parts have both southwest and northwest directions. Sand materials are transported overall toward the east and northeast, with all regions showing maximum sand transport potential in spring.
- (3) The surface layer of the sandy land is dominated by coarse and medium sand, with coarser particle size fractions in the western and southern parts and finer fractions in the eastern part. The eastern region has the poorest soil sorting, while the eastern and northern parts are dominated by extremely positive skewness with more external components, confirming that sand materials accumulate toward the east and northeast.
- (4) Based on analysis of aeolian sand environment characteristics, the northern part of the sandy land has the strongest aeolian sand activity with sufficient sand-driving conditions, making it suitable for artificial vegetation establishment or sand barrier installation to slow surface wind erosion processes and rapidly restore grassland vegetation. Simultaneously, shelterbelts perpendicular to sand transport direction should be planted in the eastern part to prevent continuous eastward sand migration.

#### References

- [1] Liu Hongtao. Environmental killer of long distance migration: sandstorm[J]. Earth, 2004(3): 9-10.

- [2] Chen Zongyan, Dong Zhibao, Wang Qingchun, et al. Characteristics of wind regime and sand drift potential in Qaidam Basin of China[J]. *Journal of Desert Research*, 2020, 40(1): 195-203.
- [3] Liang Xiaolei, Niu Qinghe, An Zhishan, et al. Sand driving wind regime and sand drift potential in the Yardang landform areas of Southern Suoyang Town, Guazhou, Gansu, China[J]. *Journal of Desert Research*, 2019, 39(3): 48-55.
- [4] Zhang Kecun, Niu Qinghe, Qu Jianjun, et al. Analysis of wind blown sand environment in the singing sand mountain & crescent moon spring scenic spot in Dunhuang, China[J]. *Journal of Desert Research*, 2012, 32(4): 896-900.
- [5] Fang Yanjie. Spatial and Temporal Distribution Characteristics of Sand Drift Potential in Taklimakan Desert Based on the Fryberger Method[D]. Chengdu: Sichuan Normal University, 2015.
- [6] Li Zhixing, Li Zhizhong, Jin Jianhui, et al. Spatial temporal variation of drift potential and dune morphology evolution during 2008-2018 in Changli coast of Hebei, China[J]. *Journal of Desert Research*, 2020, 40(3): 94-105.
- [7] Zhang Kecun, An Zhishan, He Mingzhu, et al. Aeolian sand environments and disaster prevention along Zhongwei section of the Wuhai-Maqin Highway[J]. *Arid Land Geography*, 2021, 44(4): 983-991.
- [8] Wang Jinguo, An Zhishan, Zhang Kecun, et al. Surface sand grain characteristics along Zhongwei Section of Wuhai-Maqin Highway[J]. *Research of Soil and Water Conservation*, 2021, 28(6): 183-189.
- [9] Zhu Bonian, Dang Xiaohong, Meng Zhongju, et al. Effects of biodegradable poly lactic acid (PLA) sand barrier on wind prevention and sand fixation in the Urumqin Sandy Land[J]. *Research of Soil and Water Conservation*, 2023, 30(2): 431-437.
- [10] Xing Wenjuan, Lei Jiaqiang, Wang Haifeng, et al. Analysis on wind regime and wind borne sand potential in a desert-oasis ecotone: A case study in Qira County, Xinjiang[J]. *Arid Zone Research*, 2008, 25(6): 894-898.
- [11] Zhou Yanguang, Wang Zhuoran, Qing Damuni, et al. Morphological changes and dynamic mechanism of blowouts on fixed dunes in the Otindag Sandy Land, China[J]. *Chinese Science Bulletin*, 2023, 68(11): 1298-1311.
- [12] Gao Xiaojie, Chen Xiaomei, Han Yijun. Analysis of climate change and sandstorm trends in the Uzhumuqin Grassland[J]. *Journal of Arid Land Resources and Environment*, 2004, 18(1): 266-268.
- [13] Zhao Yuanyuan, Wu Haiyan, Ding Guodong, et al. A review on the aeolian desertification in the Otindag Sandy Land[J]. *Journal of Desert Research*, 2020, 40(5): 101-111.
- [14] Cao Zilong. Basic Studies on Vegetation Restoration of Desertification Grassland in Mid Eastern Inner Mongolia[D]. Beijing: Beijing Forestry University, 2007.

- [15] Huang Haiguang, Han Shiping. Carbon sequestration of Chinese grassland ecosystems: Stock, rate and potential[J]. Chinese Journal of Plant Ecology, 2018, 42(3): 261-264.
- [16] Bai Yongfei, Chen. Carbon sequestration of Chinese grassland ecosystems: Stock, rate and potential[J]. Chinese Journal of Plant Ecology, 2018, 42(3): 261-264.
- [17] Gong Guoli, Liu Jiyuan, Shao Quanqin. Wind erosion in Xilingol League, Inner Mongolia since the 1990s using the revised wind erosion equation[J]. Progress in Geography, 2014, 33(6): 825-834.
- [18] Wang Wenyong, Wang Qiji, Wang Gang, et al. Effects of land degradation and rehabilitation on vegetation carbon and nitrogen content of alpine meadow in China[J]. Journal of Plant Ecology, 2007, 31(6): 1073-1078.
- [19] Jiang Yanfeng, Wang Wei, Wang Lixin, et al. Analysis of soil environmental grain size characteristics in the underlying sandy land of Xiwuzhumuqin Banner, Inner Mongolia[J]. Inner Mongolia Environmental Science, 2007, 19(3): 65-67.
- [20] Hou Jian. The Study of The Causes and Distribution of Sinking Sandy Land in Inner Mongolia Wuzhumuqin Basin[D]. Hohhot: Inner Mongolia University, 2010.
- [21] Wu Zheng. Aeolian Geomorphology[M]. Beijing: Science Press, 1987: 38-39.
- [22] Song Jie, Chun Xi, Bai Xuemei, et al. Review of grain size analysis in China desert[J]. Journal of Desert Research, 2016, 36(3): 597-603.
- [23] Pang Lidong, Liu Guixiang. Grassland landscape structure change and its driving factors during past twenty years in Xiwuzhumuqin, Inner Mongolia[J]. Journal of Arid Land Resources and Environment, 2010, 24(10): 155-160.
- [24] Suriguga, Tonggala, Liu Sujun. Research on the response of grassland thicketization to soil particle size in West Ujimqin Banner[J]. Journal of Inner Mongolia Normal University (Natural Science Edition), 2020, 49(4): 320-326.
- [25] Sun Jiaqi. Wind Regime and Drift Potential in the Badain Jaran Desert Based on Observation[D]. Lanzhou: Lanzhou University, 2020.
- [26] Fryberger S G, Dean G. Dune forms and wind regime[C]//Mckee E D. A Study of Global Sand Seas. Washington: United States Government Printing Office, 1979: 137-169.
- [27] Folk R L, Ward W C. Brazos River bar: A study in the significance of grain size parameters[J]. Journal of Sedimentary Research, 1957, 27(1): 3-26.
- [28] Udden J A. Mechanical composition of clastic sediments[J]. The Geological Society of America Bulletin, 1914, 25(1): 655-744.
- [29] Blott S J, Pye K. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments[J]. Earth Surface Processes and Landforms, 2001, 26(11): 1237-1248.

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

*Source: ChinaXiv — Machine translation. Verify with original.*