

## Spatial Variation of Grain Size in Surrounding Sediments and Identification of Dust Emission Source Areas in the Badain Jaran Desert (Post-print)

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### Abstract

To reveal the sediment grain size characteristics of the areas surrounding the Badain Jaran Desert and identify potential dust emission source areas, this study collected 110 surface layer (0-2 cm) and subsurface layer (10-20 cm) sediment samples from seven typical regions around the desert periphery (Wentugaole Gobi, Alatengaobao Gobi, Yabulai Gobi, Alatenchaoke Gobi, Dingxin-Dongfeng Gobi, Gurina dry lake area, and Juyanhai dry lake area) in August 2023. The grain size composition was analyzed using a combination of sieving method and laser particle size analysis, and the potential erosion-accumulation rate and potential PM10 emission rate were quantified using a sediment erosion-accumulation model. The results show that: (1) Due to the superposition of fluvial processes and aeolian modification, surface sediments exhibit a trimodal distribution pattern of fine sand (2-3  $\Phi$ ), fine gravel (-3 to -1  $\Phi$ ), and very fine silt (8-9  $\Phi$ ), while the subsurface layer shows quadrimodal distribution characteristics (with a coarse silt peak). The proportion of sand particles in the surface layer (58.23%-84.60%) is significantly higher than that in the subsurface layer (30.87%-81.20%), and the sand fraction shows an increasing trend from Dingxin-Dongfeng Gobi to Yabulai Gobi, while the proportions of gravel, silt, and clay show a decreasing trend. (2) The surface fine particle loss is significant in Dingxin-Dongfeng Gobi and Gurina dry lake area, with the highest potential erosion-accumulation rate (7.82%) and potential PM10 emission rate (4.01%), while Yabulai Gobi shows the lowest values (0.15% and 0.02%). (3) The dry lake areas are dominated by lacustrine fine-grained deposits, while the Gobi areas are controlled by alluvial-proluvial processes with poor sorting; wind sorting in the high wind energy area of Dingxin-Dongfeng Gobi leads to surface coarsening, and the spatial variation of erosion intensity is significant. The study confirms that Dingxin-Dongfeng Gobi and Gurina dry lake area are

the most important potential dust emission source areas around the Badain Jaran Desert, and their surface protection is of critical significance for regional sand fixation and desertification control as well as transboundary dust transport management.

## Full Text

### Spatial Variations in Sediment Grain Size and Identification of Dust Emission Source Areas Around the Badain Jaran Desert

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## Abstract

To elucidate the sediment grain size characteristics and identify potential dust emission sources in the regions surrounding the Badain Jaran Desert, 110 surface (0–2 cm) and subsurface (10–20 cm) sediment samples were collected in August 2023 from seven typical areas: Wentugaole Gobi, Alatengaobao Gobi, Yabulai Gobi, Alatengchaoke Gobi, Dingxin-Dongfeng Gobi, Gurinai Dry Lake, and Juyanhai Dry Lake. The grain size composition was analyzed using a combination of sieving and laser particle size analysis. A sediment erosion-deposition model was employed to quantify potential erosion-deposition rates and PM<sub>10</sub> emission rates. The results indicate: (1) Surface sediments exhibited a triple-peak distribution pattern, while subsurface layers showed a quadruple-peak distribution (with an additional coarse silt peak). The sand fraction in surface layers (58.23%–84.60%) was significantly higher than in subsurface layers (30.87%–81.20%), with sand content increasing progressively from the Dingxin-Dongfeng Gobi toward the Yabulai Gobi, while gravel, silt, and clay proportions decreased correspondingly. (2) The Dingxin-Dongfeng Gobi and Gurinai Dry Lake experienced the most pronounced loss of fine surface particles, exhibiting the highest potential erosion-deposition rates (7.82%) and PM<sub>10</sub> emission rates (4.01%). In contrast, the Yabulai Gobi showed the lowest values (0.15% and 0.02%, respectively). (3) The dry lake areas were dominated by fine-grained lacustrine deposits, whereas the Gobi regions were controlled by alluvial-proluvial processes with poor sorting. The Dingxin-Dongfeng Gobi, a high wind-energy zone, showed surface coarsening due to wind sorting, with significant spatial heterogeneity in erosion intensity. This study confirms that the Dingxin-Dongfeng

Gobi and Gurinai Dry Lake constitute the primary potential dust emission sources around the Badain Jaran Desert, and that surface protection in these areas is critical for regional sand control and transboundary dust transport management.

**Keywords:** grain size characteristics; dust emission potential; potential erosion-deposition rate; sedimentary environment; Badain Jaran Desert

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Grain size, as a fundamental property of sediment particles and an important structural characteristic of clastic deposits, serves as a key physical indicator for discriminating depositional environments. As a core parameter for characterizing natural sediments, grain size distribution not only determines the chemical, physical, and biological properties of sediments but also correlates closely with parent material sources, climatic conditions, and geomorphological evolution. In Quaternary terrestrial sediment research, grain size composition records the synergistic effects of provenance properties, transport dynamics, and depositional environments, providing an effective proxy for reconstructing climate change and environmental evolution. Consequently, grain size analysis has become a classical method for analyzing aeolian geomorphology, depositional environments, dynamic mechanisms, sorting processes, and developmental stages, playing an irreplaceable role particularly in revealing dust emission potential and wind erosion response mechanisms in arid regions.

Dust emission represents a critical environmental process in arid zones, exacerbating soil degradation and air pollution while influencing global biogeochemical cycles through long-distance transport. Relevant studies indicate that areas surrounding deserts are primary dust sources, with their emission potential closely related to sediment grain size characteristics. The Badain Jaran Desert, as China's second-largest desert, has long been considered a potential dust source. Previous grain size studies have shown that the desert interior contains significantly lower dust content than surrounding potential dust emission surfaces such as Gobi and dry lake basins. In contrast, Gobi and dry lake basin sediments are rich in fine-grained deposits that are more susceptible to dust release under strong winds. However, existing research has primarily focused on single surface types, lacking comparative analysis across multiple source areas, and the spatial differentiation of specific source areas and emission mechanisms remain controversial. Therefore, clarifying the grain size characteristics of sediments around the Badain Jaran Desert and their response to wind erosion processes is essential for accurately identifying potential dust emission sources.

Based on this, our study focuses on the Gobi and dry lake geomorphology surrounding the Badain Jaran Desert. Through stratified sampling and grain size analysis, combined with calculations of potential erosion-deposition and emission rates, we aim to: (1) analyze the spatial differentiation patterns of grain size composition and parameters in surface and subsurface sediments; (2) reveal the influence of hydraulic-aeolian coupling on sediment sorting and coarsening;

and (3) quantify dust emission potential in key source areas to precisely identify dominant sources. The research findings can provide a scientific basis for optimizing regional sand control engineering and managing transboundary dust transport.

## 1.1 Study Area Overview

The study area is distributed around the Badain Jaran Desert, bordering the piedmont Gobi of the Altai Mountains to the north, the Beida and Longshou Mountains to the south, adjacent to the Yabulai Mountains in the east, and neighboring the Gurinai Lake and Ejin Gobi in the west [Figure 1: see original paper]. The terrain gradually rises from northwest to southeast, with primary geomorphological types including alluvial-proluvial fan groups, lacustrine basins, and Gobi. The region experiences 50-100 windy days annually, with prevailing northwesterly winds. The mean annual temperature ranges from 5-10 °C, and potential evapotranspiration exceeds 2500 mm. Surface vegetation is dominated by *Nitraria tangutorum* and *Haloxylon ammodendron*, with local distribution of *Phragmites australis* and *Populus euphratica* in dry lake areas.

## 1.2 Sample Collection

In August 2023, surface (0-2 cm) and subsurface (10-20 cm) sediment samples were collected from seven typical areas around the Badain Jaran Desert: Wengugaole Gobi, Alatengaobao Gobi, Yabulai Gobi, Alatengchaoke Gobi, Dingxin-Dongfeng Gobi, Gurinai Dry Lake, and Juyanhai Dry Lake. Sampling was conducted at 5-10 km intervals, with approximately 500 g of sediment collected from each layer at each site and sealed in polyethylene bags. A total of 110 surface and 110 subsurface samples were collected.

## 1.3 Grain Size Measurement and Analysis

After natural air-drying, the samples were analyzed in August 2023 at the Key Laboratory of Aeolian Sand Physics and Sand Control Engineering in Inner Mongolia. Grain size determination employed a combination of sieving (for particles  $\geq 2$  mm) and laser diffraction (for particles  $< 2$  mm). The sieving equipment conformed to GB/T6003.1-2012 standards, with 100 g subsamples used. Samples were separated into seven grain size fractions:  $\geq 2$  mm, 2-4 mm, 4-8 mm, 8-16 mm, 16-32 mm, and  $< 2$  mm. The  $< 2$  mm fraction was weighed and analyzed using a Fritsch Analysette 22 Next laser particle size analyzer. Following and HCl to remove organic matter and carbonates, then dispersed with  $(\text{NaPO}_3)_6$  before measurement. After measurement, volume percentage data were converted to mass percentages. Classification adopted the Udden-Wentworth scale, converting grain size values to  $\Phi$  units using the formula:

$$\Phi = -\log_2 d$$

where  $d$  is particle diameter (mm). Sediments were classified into four primary grades (gravel, sand, silt, clay) and eleven secondary grades. Grain size parameters including mean grain size ( $Mz$ ), sorting coefficient ( $\sigma$ ), skewness ( $Sk$ ), and kurtosis ( $Kg$ ) were calculated using the Folk and Ward graphical method.

#### 1.4 Calculation of Sediment Potential Erosion-Deposition Rate and $PM_{10}$ Potential Emission Rate

Based on aeolian dynamics principles, sediment particles move via creep, saltation, or suspension. According to these transport modes, particle components were defined as: suspension component ( $Ep$ ) for long-distance transport, creep-saltation component ( $Dp$ ) for short-distance transport, and residual component ( $Rp$ ) that remains in place.  $Ep$ ,  $Dp$ , and  $Rp$  values were determined by analyzing the grain size probability cumulative curve distributions of different components in surface and subsurface sediment samples.

This study assumes the subsurface layer represents the original soil layer, while the surface layer represents the disturbed layer. The original soil layer undergoes erosion or deposition under external disturbance, but the residual component in the original layer remains unchanged in mass. Based on the law of mass conservation, formulas for potential erosion-deposition rate and  $PM_{10}$  emission rate were derived as follows:

$$\text{Potential erosion-deposition rate} = \frac{Q_{\text{original}} - Q_{\text{disturbed}}}{Q_{\text{original}}} \times 100\%$$

$$PM_{10} \text{ emission rate} = \frac{PM_{10} \text{ in original layer} - PM_{10} \text{ in disturbed layer}}{PM_{10} \text{ in original layer}} \times 100\%$$

where  $Rp$  is the weight of the residual component in the original soil layer (g),  $Q$  is the sampling weight of the original soil layer (g),  $Rp'$  is the residual component in the disturbed surface layer (g),  $Q'$  is the sampling weight of the disturbed layer (g),  $\Delta Q$  is the potential erosion-deposition amount (g), and  $T$  is the potential erosion-deposition rate (%).

#### 2.1 Sediment Grain Size Distribution Characteristics

The average grain size frequency distribution curves of surface sediments from various Gobi and dry lake areas showed similar patterns, with certain differences in peak component proportions, exhibiting triple-peak distributions with the main peak in fine sand (2-3  $\Phi$ , 0.125-0.25 mm), secondary peaks in fine gravel (-3 to -1  $\Phi$ , 2-8 mm) and very fine silt (8-9  $\Phi$ , 0.002-0.004 mm). Subsurface layers showed quadruple-peak distributions with an additional coarse silt peak (4-5  $\Phi$ , 0.031-0.063 mm) [Figure 2: see original paper]. The mixing of coarse and fine particles in the study area, with significantly lower proportions of fine

particles in surface layers compared to subsurface layers, indicates that these sediments originated from hydraulic deposition and were subsequently modified by aeolian processes.

Comparative analysis across regions (Table 2) revealed that dry lake areas had lower gravel proportions but higher silt and clay contents compared to Gobi areas. Specifically, the Gurinai Dry Lake surface sand fraction reached 80.32%, with silt and clay contents of 14.41% and 1.91%, respectively—higher than other areas, reflecting lacustrine fine-particle enrichment. The Dingxin-Dongfeng Gobi showed a 27.36% increase in surface gravel proportion and a 20.94% increase in sand fraction compared to its subsurface layer, with the most significant loss of silt and clay, indicating the strongest aeolian modification.

## 2.2 Sediment Grain Size Parameter Characteristics

Analysis of grain size parameters (FIGURE:3) showed no consistent differentiation patterns between dry lake and Gobi areas except for skewness. Specifically, surface sediments were coarser than subsurface layers, with mean grain size fining progressively from the Dingxin-Dongfeng Gobi toward the Yabulai Gobi, while subsurface layers showed the opposite trend—resulting from aeolian modification of surface sediments. Sorting was generally poor across the study area, though it improved gradually from the Dingxin-Dongfeng Gobi to the Yabulai Gobi. Surface layers showed coarse skewness, while subsurface layers in the Wentugaole Gobi and Dingxin-Dongfeng Gobi were coarse-skewed and other areas fine-skewed. Kurtosis values ranged from 1.22 to 2.15, between narrow and very narrow distributions. The Yabulai and Wentugaole Gobi subsurface layers were narrower than their surface layers, while other areas showed the opposite pattern, indicating that aeolian sorting concentrated surface grain sizes.

From the Dingxin-Dongfeng Gobi to the Yabulai Gobi, surface sand fractions increased from 58.23% to 84.60%, gravel decreased from 10.05% to 1.61%, and silt and clay decreased from 25.95% and 5.12% to 11.80% and 0.22%, respectively. Subsurface sand fractions (30.87%–81.20%) were significantly lower than surface layers, while silt and clay proportions were higher. The highest subsurface sand fraction occurred in the Dingxin-Dongfeng Gobi (52.31%). This demonstrates that strong wind erosion from northwest to southeast caused progressive fine-particle loss in the study area.

## 2.3 Sedimentary Environment and Spatial Differentiation of Transport Components

Probability cumulative curves consist of multiple line segments with different slopes; inflection points (where slope changes abruptly) indicate the percentage content of suspension, saltation, creep, and corresponding components, with relationships between different transport modes reflecting depositional environment characteristics. The grain size probability cumulative curves of surface sediments from all areas around the Badain Jaran Desert showed highly similar

morphologies, with continuous, smooth saltation component curves and good sorting, plus low fine-particle component content—indicating aeolian sand-type depositional environments.

Spatial distribution of specific components showed: suspension component content peaked in the Dingxin-Dongfeng Gobi (15.70%) and dry lake areas (16.19%–16.44%), decreasing progressively toward the Yabulai Gobi; saltation components followed the same spatial trend as surface layers; creep and larger components enriched in the Wentugaole and Alatengaobao Gobi, with lowest contents in the Dingxin-Dongfeng Gobi and dry lake areas. Thus, strong wind erosion from the Dingxin-Dongfeng Gobi to the Yabulai Gobi caused gradually decreasing fine-particle loss across the study area.

Subsurface sediment grain size characteristics differed significantly from surface layers (FIGURE:4). All regional curves showed poor sorting, with Gobi areas showing obvious slope inflections around 4–5  $\Phi$  while dry lake saltation segments remained smooth. This suggests the Dingxin-Dongfeng and Wentugaole Gobi subsurface layers likely formed in alluvial-proluvial environments dominated by diluvial processes, other Gobi areas primarily by alluvial processes, and dry lakes in typical lacustrine depositional environments. Component distribution showed suspension component contents higher than surface layers (e.g., Dingxin-Dongfeng Gobi 21.68%, dry lake areas 18.44%–20.31%), decreasing toward the Yabulai Gobi; saltation components increased along the same direction; creep and larger components were highest in the Wentugaole Gobi and Dingxin-Dongfeng Gobi, significantly lower in dry lake areas.

## 2.4 Identification of Potential Dust Emission Source Areas

Based on calculations of potential erosion-deposition rates and PM<sub>10</sub> emission rates (FIGURE:5, FIGURE:6), the study area contained both erosion and deposition zones, with erosion zones far more extensive. Deposition zones were scattered in wind-eroded residual mountain areas of the Alatengaobao Gobi, the border region between Yabulai and Alatengchaoke Gobi, the center of Gurinai Lake, southern Juyanhai, and the Ejin Populus euphratica forest area.

Within erosion zones, potential erosion-deposition rates and PM<sub>10</sub> emission rates decreased from the Dingxin-Dongfeng Gobi toward the Yabulai Gobi. The Dingxin-Dongfeng Gobi showed the highest potential erosion-deposition rate (7.82%) and PM<sub>10</sub> emission rate (4.01%), followed by the Gurinai Dry Lake (2.66% and 0.87%), while the Yabulai Gobi had the lowest values (0.15% and 0.02%). This indicates that the Dingxin-Dongfeng Gobi and Gurinai Dry Lake are strong erosion zones with prominent dust emission risks.

### 3.1 Spatial Patterns and Genesis of Sediment Grain Size Differentiation

Based on the controlling effects of different transport mechanisms and dynamic types, sediments exhibit multi-component grain size distributions. This study found similar average grain size frequency curve morphologies between surface and subsurface sediments, indicating overall consistency in regional depositional environments. However, the proportions of very fine silt and coarse silt peaks decreased significantly in surface layers, while the double peaks of fine sand and fine gravel remained prominent. The loss of fine particles can be explained by: sediments originally formed by hydraulic processes were subsequently modified by aeolian processes, with fine components gradually lost through dust transport. This conclusion aligns with Dong Zhibao et al.'s wind tunnel experiments revealing Gobi dust transport patterns. Although natural soils undergo dynamic deposition, the consistency of depositional environments between surface and subsurface layers in this study indicates no significant later modification, validating the scientific reliability of using subsurface layers as reference layers.

Sediment grain size components showed significant spatial differentiation. Surface sediment grain size ratios decreased progressively from the Dingxin-Dongfeng Gobi to the Yabulai Gobi, with synchronous fining of mean grain size, while subsurface sediments showed the opposite trend. This spatial pattern is comparable to existing research in northwestern Chinese Gobi desert regions. The genesis mechanism can be summarized as: (1) Weathering of regional bedrock and continuous supply of fluvial clastic materials from large mountains around the Badain Jaran Desert under seasonal flooding created poorly sorted, coarse alluvial-proluvial deposits typical of fan margins; (2) Under prevailing westerly wind systems, high wind-energy zones like the Dingxin-Dongfeng and Wentugaole Gobi experienced intense wind erosion and sorting, leaving coarse particles as residual components. As transport distance increased, wind capacity decay caused medium-coarse sand deposition in the Badain Jaran Desert, while fine components continued transporting toward the Yabulai Gobi. Superimposed secondary aeolian erosion ultimately created surface sediments with concentrated grain sizes, sharp peaks, and optimized sorting.

### 3.2 Influence of Hydraulic Deposition and Aeolian Modification on Sedimentary Environments

Probability cumulative curves can reveal sediment transport modes and thereby infer depositional environments. Subsurface sediments, less affected by external forces than surface layers, retain more original grain size compositions. This study found all regional average grain size probability cumulative curves exhibited three-segment patterns: dry lake subsurface layers formed in lacustrine environments, Gobi subsurface layers in alluvial-proluvial environments, while surface sediments displayed aeolian sand-type characteristics. Combined with Zhang et al.'s research on depositional environments in the Hexi Corridor, we

infer that the Hei River system historically carried clastic materials from the Qilian and North Mountains into the Gurinai and Juyanhai lakes, where fine particles deposited to form the fine-grained dry lake sediments. The substantial clastic materials provided to Gobi areas through alluvial-proluvial processes were poorly sorted and coarse-grained. The discrepancy between surface and subsurface depositional environments confirms that aeolian erosion caused fine-particle loss from surface layers.

### 3.3 Driving Factors of Dust Emission Potential and Surface Processes

The Badain Jaran Desert periphery exhibits dual characteristics as both a dust deposition zone and emission source area. Deposition zones are mainly distributed in oasis areas where favorable moisture conditions enhance soil particle aggregation and vigorous vegetation reduces wind speed, protecting surface sediments from erosion while capturing 外来物质. This result aligns with Li Kuan et al.'s findings on dust emission from the Ejin Oasis. The potential dust emission rate is a primary indicator of soil dust release capacity. Within erosion zones, the Dingxin-Dongfeng Gobi and Gurinai Dry Lake represent high-potential dust emission sources, showing a spatial pattern of high rates in the northwest and low rates in the southeast. This pattern was confirmed by Zhang Ye et al.'s research on dust sources and high-frequency dust activity areas in northwestern China. In major dust source areas, silt and clay contents are relatively low because these fine particles constitute the material basis for dust emission. The Badain Jaran Desert periphery shows decreasing wind energy from northwest to southeast; the Dingxin-Dongfeng Gobi and Gurinai Dry Lake, with high fine-particle content and severe wind erosion, provide sufficient material for regional dust emission, making them high-frequency dust release zones. Additionally, complex aeolian processes occur on Gobi surfaces: in high-velocity sand flows, collisions and abrasion between sand particles and gravel cause compression and shearing, leading to fragmentation or surface cleaning that releases smaller particles from larger grains, generating new dust particles and enhancing emission efficiency. Therefore, strengthening surface protection in the Dingxin-Dongfeng Gobi and Gurinai Dry Lake is strategically important for dust control in northern China.

## 4 Conclusions

Through multi-scale sediment grain size analysis and dynamic modeling, this study identified key dust emission source areas around the Badain Jaran Desert. The main conclusions are:

- (1) Subsurface sediments in dry lake and Gobi areas around the Badain Jaran Desert exhibited quadruple-peak distributions, while surface sediments showed triple-peak patterns due to superimposed hydraulic and aeolian modification. Spatially, surface sand fractions increased progressively

from the Dingxin-Dongfeng Gobi to the Yabulai Gobi (58.23%-84.60%), while gravel, silt, and clay decreased, with subsurface layers showing the opposite trend. The Dingxin-Dongfeng Gobi displayed typical fine-particle loss characteristics under strong wind erosion.

- (2) Dry lake and Gobi areas around the Badain Jaran Desert showed significant differences in depositional environments. Dry lake areas were dominated by fine-grained lacustrine deposits, while Gobi areas were influenced by alluvial-proluvial processes with poor sorting and coarse grain sizes. Aeolian modification homogenized surface sediments, making them coarser than subsurface layers and gradually fining from the Dingxin-Dongfeng Gobi to the Yabulai Gobi.
- (3) The study area exhibited significant spatial differentiation in potential erosion-deposition rates and PM<sub>10</sub> emission rates. The Dingxin-Dongfeng Gobi and Gurinai Dry Lake are high-potential dust emission source areas, where the combination of fine-particle enrichment and strong wind erosion intensifies dust emission risk. The Yabulai Gobi has the lowest emission potential due to wind energy attenuation and enhanced surface stability.

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