Multifractal Characteristics of Surface Sediments on Both Banks of the Ulan Buh Desert Reach of the Yellow River and Their Indicative Significance (Postprint)

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Abstract

To investigate the differences in aeolian sedimentary environments between the two banks of the Yellow River' s Ulan Buh Desert section and the provenance of sand materials on the east bank, multifractal theory was applied to analyze the multifractal characteristics of grain-size distributions in surface sediments across different underlying surfaces on both banks. The results indicate that, with the exception of grassland areas, the modal grain-size range of sediments is 189.13-212.20 m on the west bank and 133.89-168.56 m on the east bank, with generally finer surface particles and weaker wind-energy environments on the east bank. Multifractal parameters (D0, D1, D2, , f) all demonstrate east bank > west bank, reflecting a broader grain-size distribution range and stronger local superposition degree in east bank sediments, which further signifies greater heterogeneity in particle properties, wider source areas, more complex depositional processes, and more diverse sedimentary environments on the east bank. Various multifractal parameters exhibit significant correlations with the contents of particles in the 2–50 m and 100–250 m size fractions; based on the transport patterns of aeolian sand particles and in conjunction with the topography and geomorphology of both banks, this study preliminarily reveals that the upwind Ulan Buh Desert constitutes one of the primary source areas for the 2–50 m suspended particles on the east bank of the Yellow River.

Full Text

Multifractal Features and Their Significances of Surface Sediments along Both Banks of the Yellow River Reach in the Ulanbuh Desert

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Abstract: This study employs multifractal theory to analyze the sand particle size distribution of land surface sediments, demonstrating the variation in wind-induced sedimentary environments along both banks of the Ulanbuh Desert reach of the Yellow River and identifying the sand source region on the east bank. Results showed that sand particle size ranged from 189.13 to 212.20 m on the west bank and from 133.89 to 168.56 m on the east bank, indicating that surface particles were finer and wind energy was weaker on the west bank compared to the east bank. Multifractal spectrum parameters D , D , D , Δ , and Δf for the east bank were higher than those on the west bank, the particle size range on the east bank was wider than that on the west bank, and local sediment particles on the east bank were more overlapped than those on the west bank. These findings further demonstrate significant differences in particle properties, wider range of particle sources, complex sedimentary processes, and diverse sedimentary environments on the east bank. Significant correlations existed among the aforementioned parameters and the contents of particle sizes ranging from 2 to 50 m and 100 to 250 m. According to the law of wind-induced sand migration and the landforms on both banks, it was preliminarily revealed that the upwind Ulanbuh Desert was one of the main source regions of 2–50 m suspended sand particles over the east bank of the Yellow River.

Keywords: sediment; particle size; multifractal parameter; sedimentary environment; Ulanbuh Desert; Yellow River

1 Introduction

The Ulanbuh Desert, located in the northern part of the Hetao Plain along the Yellow River, represents a critical region for studying aeolian sediment transport and riverbank geomorphology. Previous research has extensively documented the desert' s sediment characteristics and their environmental significance [?]. Studies have investigated underlying surface characteristics and blown-sand movement observations [?], dune morphology and migration patterns [?], and land-use changes in the watershed area [?]. The multifractal characteristics of sediments have been analyzed to understand particle size distributions and their relationships with soil physical properties [?, ?, ?].

The particle size distribution of sediments serves as a fundamental indicator of sedimentary environments and transport mechanisms. Coarser particles typically indicate higher wind energy, while finer particles suggest weaker transport forces. The multifractal approach provides a robust framework for quantifying complex particle size distributions and their scaling properties, offering insights into the heterogeneity of sediment sources and transport processes [?, ?, ?].

2 Methods

2.1 Study Area and Sample Collection

The study area encompasses both banks of the Yellow River within the Ulanbuh Desert region. Surface sediment samples were systematically collected from representative sites on the east and west banks. The sampling strategy considered variations in land cover types, including *Nitraria tangutorum*, *Sarcoxygium xanthoxylon*, *Haloxylon ammodendron*, *Artemisia ordosica*, and *Ammopiptanthus mongolicus* communities [?].

2.2 Multifractal Analysis

The box-counting method was employed for multifractal analysis of particle size distributions. The mathematical framework is defined as follows:

For a normalized measure $p_i(\varepsilon)$ partitioned into boxes of size ε, the partition function is given by:

$$u_i(q,\varepsilon) = p_i(\varepsilon)^q$$

where q represents the moment order. The scaling exponent $\tau(q)$ is obtained from:

$$\tau(q) = \lim_{\varepsilon\to 0} \frac{\log \sum p_i(\varepsilon)^q}{\log \varepsilon}$$

The generalized dimension $D(q)$ is calculated using:

$$D(q) = \frac{\tau(q)}{q-1} \quad (q \neq 1)$$

For $q = 1$, the information dimension is:

$$D_1 = \lim_{\varepsilon\to 0} \frac{\sum p_i(\varepsilon) \log p_i(\varepsilon)}{\log \varepsilon}$$

Specific dimensions of interest include D_0 (capacity dimension), D_1 (information dimension), and D_2 (correlation dimension) [?]. When $q < 0$, the method emphasizes regions with low particle concentration; when $q > 0$, it highlights high-concentration regions [?].

The singularity strength $\alpha(q)$ and multifractal spectrum $f(\alpha)$ are derived from:

$$\alpha(q) = \frac{d\tau(q)}{dq}$$

$$f(\alpha) = q\alpha(q) - \tau(q)$$

The width of the multifractal spectrum $\Delta\alpha = \alpha_{\max} - \alpha_{\min}$ reflects the heterogeneity of the particle size distribution, while the difference in fractal dimensions $\Delta f = f(\alpha_{\min}) - f(\alpha_{\max})$ indicates the proportion of maximum and minimum probability subsets [?]. When $\Delta f < 0$, the distribution is dominated by small probability events, typical of coarse sediments; when $\Delta f > 0$, large probability events dominate, characteristic of fine sediments.

2.3 Data Processing

Particle size analysis was performed using standard sieving and laser diffraction techniques. The multifractal parameters were calculated for particle size fractions ranging from 2–50 m and 100–250 m, as these ranges are particularly sensitive to wind transport processes. Statistical analysis included correlation tests between multifractal parameters and particle size fractions.

2.4 Software

Data processing and analysis were conducted using Excel 2010 for basic calculations, Origin 2017 for graphical representations, and SPSS 24.0 for statistical analyses. The multifractal algorithm was implemented with q values ranging from -10 to 10 at integer intervals.

3 Results and Discussion

The multifractal analysis revealed distinct differences between the east and west banks of the Yellow River in the Ulanbuh Desert region. The east bank exhibited higher values for all multifractal parameters (D_0, D_1, D_2, $\Delta\alpha$, and Δf), indicating a more complex sedimentary environment with wider particle size ranges and greater overlap among local sediment populations.

The significant correlations between multifractal parameters and specific particle size fractions (2–50 m and 100–250 m) demonstrate the sensitivity of the method to different transport modes. The 2–50 m fraction, representing fine suspended particles, showed particularly strong relationships with multifractal parameters, suggesting that the upwind Ulanbuh Desert serves as a primary source region for these aerosolizable particles that affect the east bank.

The west bank' s coarser particle sizes (189.13–212.20 m) and lower multifractal parameter values reflect weaker wind energy and more localized sediment sources. In contrast, the east bank' s finer particles (133.89–168.56 m) and higher parameter values indicate stronger aeolian activity and more diverse sediment provenance.

These findings align with previous research on sediment transport in arid regions [?, ?, ?] and demonstrate that multifractal analysis provides a powerful tool for distinguishing sedimentary environments and identifying source-sink relationships in complex geomorphic systems.

4 Conclusion

The multifractal characteristics of surface sediments along the Ulanbuh Desert reach of the Yellow River reveal significant differences between the east and west banks. The east bank exhibits more complex sedimentary patterns, wider particle size ranges, and greater heterogeneity, reflecting stronger wind energy and diverse sediment sources. The upwind Ulanbuh Desert is identified as a major source of fine suspended particles (2–50 m) affecting the east bank. These results highlight the utility of multifractal analysis in characterizing aeolian sedimentary environments and have implications for understanding dust emission sources and riverbank evolution in arid regions.

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