Fractal Spatial Variability and Its Genesis in Suhongtu Gobi Sediments: Postprint

Authors: Liu Qiya

Date: 2021-03-03T00:00:00+00:00

Abstract

The component structure of Gobi sediments exhibits fractal characteristics; however, current understanding remains insufficient regarding whether these fractal characteristics and their variability can indicate aeolian processes in the formation of Gobi surface sediments. This study calculated fractal dimension values for surface sediments in the Suhongtu Gobi, Inner Mongolia, and analyzed their spatial variability. Results demonstrate that sediment fractal dimension values increase with increasing content of the 0.050~0.179 mm saltation component, and decrease with increasing content of the 0.179~20.919 mm creep and wind-erosion residual component. Wind represents the dominant factor shaping Gobi landforms, with Gobi sediment fractal values being lower than those of debris flow deposits formed under alluvial and diluvial processes (2.630~2.738), yet higher than those of desert and loess deposits dominated by wind action (2.122, 1.930). Wind forces the formation of a "homogeneous surface" on the Gobi, with moderate spatial variability (32.8% spatial correlation): on upwind bare Gobi surfaces, sediments are dominated by creep and wind-erosion residual components (average content 59.88%), with a mean fractal dimension of 2.39; on downwind semi-desert Gobi surfaces, sediments are dominated by saltation components (average content 46.96%), with mean fractal dimension values of 2.45 and 2.48, respectively; and on intermountain sandy gravel surfaces less influenced by the dominant wind, creep and wind-erosion residual components are more abundant (average content 58.22%), with a mean fractal dimension of 2.46. Fractal and variability indicators can reflect aeolian processes in the component changes of Gobi sediments.

Full Text

Fractal Spatial Variability and Its Genesis of Sediments in Suhongtu Gobi

LIU Xiya[12], **WANG Haibing**[12], **ZUO Hejun**[12], **XIAO Jianhua**[3]
[1]College of Desert Control Science and Engineering, Inner Mongolia Agricultural University, Hohhot 010011, Inner Mongolia, China
[2]Key Laboratory of Aeolian Sand Physics and Sand Control Engineering in Inner Mongolia, Hohhot 010011, Inner Mongolia, China
[3]Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, Gansu, China

Abstract

The compositional structure of Gobi sediments exhibits fractal characteristics, yet our understanding of how these fractal features and their variability can indicate the role of wind-blown sand in sediment formation remains insufficient. This study calculated the fractal dimension values of surface sediments in the Suhongtu Gobi of Inner Mongolia and analyzed their spatial variability. Results demonstrate that fractal dimension values increase with higher content of saltation components (0.050-0.179 mm) and decrease with higher content of creep and wind-erosion residual components (0.179-20.919 mm). Wind represents the dominant factor shaping Gobi landforms. Gobi sediment fractal values are smaller than those of debris flow deposits formed under alluvial/pluvial action (2.630-2.738) but larger than desert and loess sediments dominated by aeolian processes (2.122 and 1.930, respectively). Wind action creates a "homogeneous surface" in Gobi regions, with moderate spatial correlation in variability (32.8%). In upwind areas with exposed Gobi surfaces, sediments are dominated by creep and wind-erosion residual components (average content 59.88%), with a mean fractal dimension of 2.39. Downwind semi-desert Gobi surfaces contain predominantly saltation components (average content 46.96%), with fractal dimension means of 2.45-2.48. In intermontane sandy gravel surfaces weakly influenced by dominant winds, creep and wind-erosion residual components are more abundant (average content 58.22%), with a mean fractal dimension of 2.46. Fractal and variability indicators can thus reflect the role of wind-blown sand in altering Gobi sediment composition.

Keywords: sediments; fractal dimension; spatial variability; Gobi

Introduction

Fractal theory describes natural phenomena with self-similar properties, and fractal dimension serves as an effective parameter for characterizing irregular geometric forms and self-similar materials in nature. In the field of soil science, fractal dimension is commonly used to describe soil structural characteristics in desert and loess regions, where its value correlates closely with different particle size fractions—increasing with clay content and decreasing with sand content. Previous research has also suggested that spatial variability of fractal features can indicate regional soil differences. During aeolian processes, differential sorting, transport, and deposition of sand particles create significant compositional variations across different Gobi regions, which substantially influence fractal dimension values. Consequently, sediment fractal dimensions exhibit considerable spatial variability across Gobi landscapes.

Geostatistical theory has proven valuable in soil science for describing the spatial characteristics of soil properties, providing guidance for ecological restoration and agricultural production. For instance, studying spatial variability of soil moisture profiles helps understand deep water distribution patterns, while research on soil salt variability across different layers is crucial for assessing regional salinization levels and rational soil resource utilization. However, whether the spatial variability of fractal characteristics can reveal aeolian processes and sediment genesis in Gobi geomorphology remains understudied.

Gobi represents a major land surface type in arid and extremely arid regions, covering extensive areas in northwestern China (approximately 66.1$×10ˆ{4}$ km^2). Original alluvial-proluvial deposits undergo long-term aeolian modification through erosion, transport, and accumulation, gradually coarsening to form “gravel surfaces.” Unlike the unimodal distribution of desert sands, Gobi sediments typically exhibit polymodal distributions on particle size frequency curves. The Suhongtu Gobi, located in Alxa Left Banner of Inner Mongolia, presents an ideal study area for investigating fractal spatial variability due to its extensive distribution, flat terrain, and scattered sand belts. Bounded by Jiazi Mountain to the southwest, Wuliji Mountain to the south, and Mana Mountain to the southeast, the region forms a semi-closed basin with dried river channels developed along mountain units. Intense aeolian activity provides abundant sandy gravel material, creating diverse landscape types including exposed Gobi, sparsely vegetated semi-desert Gobi, intermontane sandy gravel surfaces, and sand dunes. This study collected surface sediment samples from the Suhongtu Gobi basin to calculate fractal dimension values and analyze how compositional spatial variation influences fractal spatial variability, thereby revealing sediment genesis and aeolian processes in Gobi landform development.

1.1 Study Area Overview

The study area is situated in Suhongtu, Alxa Left Banner, Inner Mongolia, within geographic coordinates of 104°09 37.07 E and 41°14 46.29 N. Elevations range from 810 to 1200 m, with the lowest point in the central region at 810 m. The area experiences a typical continental climate with perennial aridity and minimal precipitation (annual average <100 mm). The mean annual temperature is 7.3°C, with a dominant northwesterly wind direction. The average wind speed is 4.7 $\mathrm{m \cdot s^{-1}}$, reaching maximum speeds of 27.0 $\mathrm{m \cdot s^{-1}}$, and days with gale-force winds (\$ $17m \cdot s$^{-1}\$) average 40.1 days annually. Vegetation is sparse, with dominant species including *Nitraria tangutorum*, *Reaumuria soongorica*, *Haloxylon ammodendron*, and *Zygophyllum xanthoxylum*. Sampling site locations are shown in [Figure 1: see original paper].

The study area exhibits frequent aeolian activity and diverse landscape types: exposed Gobi in the northwest, sparsely vegetated semi-desert Gobi in the northeast and southwest, and intermontane sandy gravel surfaces in the southeast. Gobi landscapes are illustrated in [Figure 2: see original paper].

1.2.1 Soil Sample Collection and Analysis

Sampling commenced from the southwestern part of the study area. At each site, we selected flat, undisturbed natural surfaces and collected surface sediment samples (20 cm × 20 cm × 2 cm) after homogenizing the top layer. A total of 54 samples were collected in self-sealing bags: 16 from northwestern Gobi (sample numbers 1-10, 28-50), 11 from northeastern Gobi (sample numbers 11-16), 17 from southwestern Gobi (sample numbers 17-27), and 10 from southeastern intermontane sandy gravel surfaces (sample numbers 51-54). Samples were numbered, labeled, and transported to the laboratory for processing. After air-drying and grinding, 200 g of each sample was sieved. Following the USDA soil classification standard, we divided particles into 16 size fractions ranging from 0-0.05 mm to 16-32 mm.

1.2.2 Fractal Dimension Calculation

As shown in the particle size frequency distribution curves, Gobi sediment components exhibit a significant two-segment distribution (see [Figure 3: see original paper]). The fractal dimension was calculated using the following formula:

$$Di = 3w(\delta < di - - - - \sum i = 12 + D2$$

where D is the soil particle fractal dimension; Di is the fractal dimension value for each particle size fraction; di is the mean diameter between adjacent sieve sizes *di* and *di+1* (*di* > *di+1*); $w(\delta < di)$ is the cumulative weight of particles smaller than *di*; *dmax* is the maximum particle size; δ is the yardstick; *w0* is the total weight of all particle fractions; and n is the total number of size fractions ($n = 16$ in this study).

1.2.3 Data Processing

Data were processed using Excel 2010 for summary calculations. GS+9.0 software was employed for semivariogram computation and theoretical model fitting. Origin 8.0 and ArcGIS 10.2 were used for mapping and spatial analysis.

---

2 Results and Analysis

2.1 Sediment Component Characteristics The particle size distribution of Gobi sediments is shown in [Figure 3: see original paper], exhibiting a polymodal pattern. The first peak occurs around 0.1 mm, the second around 7.0 mm, with a minor peak in the 0.1-1.0 mm range, indicating complex surface material composition. Significant differences exist among the four study regions in peak characteristics. Based on Wu Zheng's aeolian dynamics theory, different particle size fractions exhibit distinct transport modes: particles <0.050 mm undergo suspension, 0.050–0.179 mm particles saltate, and 0.179–20.919 mm particles creep or form wind-erosion residuals. The four regions show markedly different contents of saltation components and creep/wind-erosion residual components.

2.2 Fractal Characteristics and Their Relationship with Components Calculated fractal dimension values range from 2.30 to 2.64, showing significant correlations with component content. Saltation component content exhibits a strong positive correlation with fractal dimension ($R^2 = 0.730$), with fractal dimension increasing as saltation content increases. Creep and wind-erosion residual components show a significant negative correlation ($R^2 = 0.702$), with fractal dimension decreasing as their content increases. No significant correlation exists between fractal dimension and the minor suspension component ($R^2 = 0.087$). Mean particle size shows an insignificant negative correlation with fractal dimension ($R^2 = 0.179$).

2.3 Spatial Distribution Characteristics of Components and Fractal Dimension Regional differences in component content and fractal dimension are spatially pronounced (see [Figure 5: see original paper]). Saltation components are most abundant in northeastern and southwestern Gobi, while creep and wind-erosion residual components dominate northwestern Gobi and, to a lesser extent, southeastern intermontane surfaces. Each component shows distinct spatial distribution patterns influenced by regional factors. Fractal dimension correlates closely with the contents of saltation components and creep/wind-erosion residual components. Consequently, fractal dimension values are higher in northeastern and southwestern Gobi, lower in northwestern Gobi, and moderate in southeastern intermontane surfaces. The spatial distribution of fractal dimension corresponds closely with the spatial patterns of its related components.

2.4 Spatial Variability Analysis of Components and Fractal Dimension

Semivariogram modeling was performed on three component groups (suspension <0.050 mm, saltation 0.050–0.179 mm, and creep/wind-erosion residual 0.179–20.919 mm) and fractal dimension values. The best-fit models and parameters are presented in . Key parameters include the nugget (C_0), sill (C_0+C), and range (A). The nugget reflects variability at the smallest sampling scale and measurement error, while the sill represents total system variation. The nugget-to-sill ratio indicates spatial correlation strength: <25% indicates strong spatial correlation, 25–75% moderate correlation, and >75% weak correlation.

All three component contents were best fitted by spherical models, with nugget-to-sill ratios of 16.7%, 30.6%, and 29.1%, respectively, showing strong to moderate spatial correlation. This demonstrates their reliability in indicating regional dynamic processes. Fractal dimension was best fitted by a linear model with a small nugget value, indicating minimal random variation from calculation error. Its nugget-to-sill ratio of 32.8% indicates moderate spatial correlation. The range represents the spatial scale of variability, beyond which samples show no spatial correlation. Effective ranges were 2.4 km for major components and 3.9 km for fractal dimension. Overall, the three component contents and fractal dimension values show large determination coefficients, effectively reflecting spatial variability at the study scale.

---

3 Discussion

When wind speed exceeds the threshold velocity, surface particles begin to move. Bagnold' s research identifies three fundamental transport modes depending on wind force and particle mass: suspension, saltation, and surface creep. This study reveals that Gobi sediment fractal dimensions (2.30–2.64) correlate significantly with saltation and creep/wind-erosion residual components. Higher saltation content increases fractal dimension, while higher creep/wind-erosion residual content decreases it, consistent with previous findings.

Different dynamic mechanisms significantly affect fractal dimension values. During rainstorms, loose solid material in debris flow source areas is transported by strong hydraulic erosion to deposition zones, forming debris flow sediments with relatively coarse particle sizes and fractal dimensions averaging 2.630–2.738. Desert sand and loess deposits, shaped by long-term aeolian processes and wind sorting, contain finer particles and lower fractal dimensions (2.122 and 1.930, respectively). Gobi sediments, with a mean fractal dimension of 2.39, fall between these values, reflecting initial dual-phase erosion by wind and water that accumulated substantial material. Subsequent aridification and frequent dust storms made wind erosion the dominant shaping force.

In upwind areas, long-term aeolian transport and dust storm action cause suspension components to abrade and collide while saltation components transport over long distances. Combined with vegetation obstruction and wind energy dissipation, this process enriches sand fractions in northeastern and southwestern Gobi surfaces. These sand-rich surfaces continuously supply fine fractions to desert surfaces during sand-raising events, creating scattered sand belts in the central study area with higher fractal dimension values. The southeastern region, surrounded by mountains and weakly influenced by dominant winds, accumulates more coarse loose material, resulting in larger fractal dimension values.

Thus, the genesis of spatial fractal dimension variation correlates strongly with wind-driven geomorphic distribution patterns. Gobi sediment fractal dimension variability originates from component variability, though Gobi soils are not ideal fractals with self-similarity across all scales. Consequently, fractal dimension shows partial self-similarity with components, exhibiting a larger range than component ranges.

---

4 Conclusions

1) **Significant relationship between fractal dimension and components in Suhongtu Gobi.** Fractal dimension values increase with saltation component content (0.050–0.179 mm) ($R^2 = 0.730$) and decrease with creep/wind-erosion residual component content (0.179–20.919 mm) ($R^2 = 0.702$).
2) **Wind action creates a "homogeneous surface" with moderate spatial correlation.** The sorting, transport, and deposition of sediment components by wind generate spatial differentiation in fractal characteristics (32.8% nugget-to-sill ratio). Upwind areas subject to wind erosion contain high creep/wind-erosion residual components (59.88%) with a mean fractal dimension of 2.39. Downwind areas subject to wind accumulation contain high saltation components (46.96%) with fractal dimension means of 2.45–2.48.
3) **Integrating soil fractal theory with geostatistics provides a novel approach** for revealing Gobi sediment genesis and regional aeolian processes, offering greater simplicity and directness than traditional grain size parameter analysis.

References

[1] Zhuang Yan, Liu Tingxi, Tong Xin, et al. Soil particle fractal dimension in the dune meadow ecotone of the Horqin Sandy Land [J]. Journal of Desert Research, 2016, 36(2): 433-440.

[2] Shi Zhou, Li Yan. Application of geostatistics in soil science[M]. Beijing: China Agricultural Publishing House, 2006: 3-9.

[3] Jia Xiaohong, Li Xinrong, Zhang Jingguang, et al. Spatial heterogeneity analysis of fractal dimension of soil particle for *Ammopiptanthus mongolicus* shrub[J]. Acta Ecologica Sinica, 2006, 26(9): 2827-2833.

[4] Mandelbrodt Benoit B. Fractal geometry of nature[M]. Shanghai: Shanghai Far East Publishers, 1998: 8-11.

[5] Li Baoguo. Application and prospect of fractal theory in soil science[J]. Progress in Soil Science, 1994, 22(1): 1-10.

[6] Zhu Xiaohua, Se Bulima. Fractal analysis applied to fractal character of China desertification land[J]. Journal of Desert Research, 2006, 26(1): 35-39.

[7] Dong Lili, Zheng Fenli. Fractal characteristics of soil particle size distributions in gully hilly regions of the Loess Plateau, north of Shaanxi, China[J]. Soils, 2010, 42(2): 302-308.

[8] Hong L. Fractal dimension of soil particles under different plant communities in mountainous area[J]. IOP Conference Series: Materials Science and Engineering, 2018, 439(3): 032124, doi: 10.1088/1757-899X/439/3/032124.

[9] Ding W F. Fractal dimension features of soil aggregate distribution with the different reclamation years on Loess Plateau[J]. NJAS - Wageningen Journal of Life Sciences, 2014, 6(5): 550-560.

[10] Mohammadi M, Shabanpour M, MohamMadi M H, et al. Spatial variability of soil textural fractions and fractal parameters derived from particle size distributions[J]. Pedosphere, 2019, 29(2): 224-235.

[11] Ma Yuan, Ding Shuwen, Deng Yusong, et al. Study of soil fractal dimension characteristic and spatial variability in collapsing alluvial fan of Wuhua County[J]. Journal of Soil and Water Conservation, 2016, 30(5): 279-285.

[12] Ran Qixiang, Luo Wei, Zhang Xiang, et al. Application of multifractality to evaluation of soil spatial variability[J]. China Rural Water and Hydropower, 2010(7): 5-8.

[13] Scientific Team of Ecological Background in Black Gobi Area of China. A study on the Black Gobi in China[M]. Beijing: Science Press, 2014: 4-5.

[14] Feng Yiming, Zhi Changgui, Yao Aidong. Gobi information extraction based on decision tree classification method[J]. Arid Land Geography, 2013, 36(1): 125-130.

[15] Yin Daiying, Qu Jianjun, Wang Halin. Amount of wind erosion to gravel gobi under different disturbing modes[J]. Arid Land Geography, 2016, 39(3): 495-503.

[16] Su Yongzhong, Zhao Suping, et al. Fractal features of soil particle size distribution in the desertification process of the farmland in Horqin Sandy Land[J]. Acta Ecologica Sinica, 2004, 24(1): 71-74.

[17] Li Y, Huang C M, Wang B L, et al. A unified expression for grain size distribution of soils[J]. Geoderma, 2017, 288: 105-119.

[18] Hossein B, Mostafa R, Mansouri Z M, et al. Particle size distribution models, their characteristics and fitting capability[J]. Journal of Hydrology, 2015, 529(3): 872-889.

[19] Yang Ting, Jing Hang, Yao Xu, et al. Soil particle composition and its fractal dimension characteristics of different land uses in Loess Hilly Region[J]. Research of Soil and Water Conservation, 2016, 23(3): 1-5, 24.

[20] Zhao S W, Jing Su, Yang Y H, et al. A fractal method of estimating soil structure changes under different vegetations on Ziwuling Mountains of the Loess Plateau, China[J]. Agricultural Sciences in China, 2006, 5(7): 530-538.

[21] Liu Xiya, Wang Haibing, Zuo Hejun, et al. Calculation of fractal dimension of gobi sediments and its significance to the effect of wind induced soil erosion accumulation[J]. Journal of Arid Land Resources and Environment, 2019, 33(10): 125-130.

[22] Qiao Jiangbo, Zhu Yuanjun, Jia Xiaoxu, et al. Spatial variability of soil water for the entire profile in the critical zone of the Loess Plateau[J]. Advances in Water Science, 2017, 28(4): 515-522.

[23] Liu Jilong, Liu Lu, Ma Xiaoyi, et al. spatial variability of soil salt in different soil layers at different scales[J]. Journal of Basic Science and Engineering, 2018, 26(2): 305-312.

[24] Liu Tao, Yang Xiaoping, Dong Jufeng, et al. A preliminary study of relation between megadune shape and wind regime in the Badain Jaran Desert[J]. Journal of Desert Research, 2010, 30(6): 1285-1291.

[25] Wu Zheng. Wind sand geomorphology and sand control engineering[M]. Beijing: Science Press, 2003: 31-33.

[26] Lü Zhifa. The comprehensive sequence analysis of size curves and indices and their application in environmental analysis[J]. Coal Geology & Exploration, 1990(2): 12-16, 71-72.

[27] Bagnold R A. The physics of sand and dunes[J]. Nature, 2009, 457: 1084.

[28] Gong Yuanshi, Liao Chaozi, Li Baoguo. Spatial variability and fractal dimension for soil water content and bulk density[J]. Acta Pedologica Sinica, 1998(1): 10-15.

[29] Dong Zhiwang, Liqin, Yang Wenbin, et al. Grain size characteristics of gobi sediment in Ejina Basin[J]. Science of Soil and Water Conservation, 2013, 11(1): 32-38.

[30] Xiong Xin, Wang Haibing, Xiao Jianhua, et al. Particle size distribution models of gobi sediments and its significance to the effect of sorting[J]. Journal of Desert Research, 2019, 39(2): 202-208.

[31] Wang H B, Jia X P, Li Y S, et al. Horizontal wind erosion flux and potential dust emission in arid and semiarid regions of China: A major source area for East Asia dust storms[J]. Catena, 2015(133): 24.

[32] Ni Huayong, Liu Xilin. A preliminary study on debris flow grain size fractal dimension[J]. Research of Soil and Water Conservation, 2006(1): 89-91.

[33] Huang Qi, Chen Ningsheng, Zhu Yunhua, et al. A preliminary study on debris flow grain size fractal dimension[J]. Mountain Research, 2012, 30(5): 578-584.

[34] Chen Dongmei, Mu Guijin. Comparising study of grain size fractal dimensions characteristics between several sediments with different forming environments[J]. Arid Land Geography, 2004, 27(1): 47-51.

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

Source: ChinaXiv —Machine translation. Verify with original.