Influence of Barchan Dunes on Wind Erosion Desertification in Lacustrine Plains (Postprint)

Authors: Cai Dongxu, Li Shengyu, Lei Jiaqiang, Wang Haifeng, Meng Xiaoyu

Date: 2018-11-08T00:00:00+00:00

Abstract

Barchan dunes constitute an important type of aeolian landform associated with wind erosion desertification processes. Previous research has predominantly emphasized surface dynamic processes of dune bodies, whereas the role of dunes in wind erosion desertification has been scarcely documented. This study, conducted in the desiccated lake basin of Lake Taitema (the former terminal lake of the Tarim River), utilized the rod method to conduct in situ measurements of erosion-deposition variations on surfaces surrounding barchan dunes, while concurrently employing indoor wind tunnel simulations to replicate airflow distribution patterns over typical barchan dune surfaces, thereby systematically elucidating the mechanistic influence of barchan dunes on surface erosion and deposition. The results indicate that under the influence of barchan dunes, wind erosion intensity on surrounding surfaces exhibits heterogeneity. In the stoss slope forezone and the dune flanks, erosion depth marginally exceeds that in areas unaffected by dunes (CK), yet the average net erosion-deposition per unit area approximates equilibrium. In the lee slope forezone, aeolian deposition predominates, whereas in the lee wake zone, wind erosion dominates, with the average net wind erosion per unit area exhibiting a slight increase as dune volume expands. During wind erosion desertification of desiccated lake basins in inland arid regions, barchan dunes modify surface flow field structures, inducing spatial differentiation in sand flow saturation, which consequently influences the spatial distribution of erosion and deposition on underlying surfaces. This effect particularly intensifies wind erosion in the lee wake zone, exposing novel erosion surfaces, disrupting sedimentary layer structures, and thereby facilitating the development of wind erosion desertification in fluvial-lacustrine sedimentary plains.

Full Text

Effect of Barchan Dune on Surface Wind Erosion over Lacustrine Plain

CAI Dong-xu[1,2], LI Sheng-yu[1], LEI Jia-qiang[1], WANG Hai-feng[1], MENG Xiao-yu[1,2]

[1]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China
[2]Universities of Chinese Academy of Sciences, Beijing 100039, China

Abstract: Barchan dune is an important type of aeolian landform that forms during the process of desertification. In previous research, most studies focused mainly on the surface dynamic process of barchan dunes but less on the influence of barchan dunes on surface wind erosion during desertification. In this paper, the plugging-brazing method was used to measure the distribution pattern of wind erosion/deposition on the surface around barchan dunes at the Taitema Lake playa. The wind tunnel was used to simulate the distribution pattern of airflow over typical barchan dunes. The mechanism of barchan dunes affecting surface wind erosion around dunes was analyzed. The results showed that the airflow structure changed with the varying geometry shapes of barchan dunes, and it significantly affected the intensity of wind erosion/deposition over the surface. Although the wind erosion depth and sedimentary thickness were slightly greater than those on flats, the average volume of net wind erosion per unit area was close to an equilibrium in the frontal region of windward slope and on both sides of dunes. Deposition was dominant in the frontal region on leeward slope of barchan dunes, but wind erosion was dominant on the surface of flank wake zone of leeward slope. The average volume of net wind erosion per unit area was slightly increased with the increase of dune size. In a word, the barchan dunes affect the intensity of surface wind erosion and deposition during the process of desertification in playa.

Keywords: barchan dune; distribution of wind erosion and deposition; intensity of wind erosion; airflow structure; Taitema Lake

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1. Study Area

The study area is located at the Taitema Lake playa in the southeastern margin of the Taklimakan Desert. Taitema Lake dried up completely in 1972, leaving a lacustrine plain covering approximately 363 km^2. The lake bed is flat and covered with a hard crust formed by salt and clay minerals. The regional climate is extremely arid with an average annual precipitation of less than 50 mm and potential evaporation exceeding 2500 mm. The dominant wind directions are northeasterly and easterly, with average wind speeds of 2.16 $\mathrm{m \cdot s^{-1}}$. Strong winds ($\geq 17.2\ \mathrm{m \cdot s^{-1}}$) occur on average 28.2 days per year, mainly from March to May.

2. Methods

2.1 Wind Tunnel Simulation Wind tunnel experiments were conducted using a recirculating wind tunnel with a working section of 16 m × 1.6 m × 1.6 m. The wind speed in the tunnel could be continuously adjusted from 5 to 20 $\mathrm{m \cdot s^{-1}}$. Five typical barchan dune models with different sizes were constructed at a scale of 1:25, with heights of 8 cm, 12 cm, and 16 cm [Figure 3b: see original paper]. The experimental wind speeds were set at 8 $\mathrm{m \cdot s^{-1}}$, 10 $\mathrm{m \cdot s^{-1}}$, and 12 $\mathrm{m \cdot s^{-1}}$, corresponding to field conditions of light, moderate, and strong wind regimes.

The plugging-brazing method was used to measure surface erosion and deposition. This method involves inserting erosion pins in a grid pattern and measuring height changes ($\Delta h = h_1 - h_2$), where positive Δh indicates erosion and negative Δh indicates deposition. The net erosion volume per unit area (EQ) was calculated using:

$$EQ = \sum(\Delta h_i \times 1 \times 1) \quad \text{for} \quad \Delta h_i < 0 \quad (1)$$

where Δh_i represents the height change at measurement point i, and the summation is over all points in the measurement area.

3. Results

3.1 Airflow Structure Over Barchan Dunes The wind tunnel simulation revealed that the airflow structure changed significantly over barchan dunes. On the windward slope, airflow acceleration occurred with streamlines compressing, while on the leeward slope, flow separation created a wake zone with reduced velocity and increased turbulence intensity [Figure 6: see original paper]. The size of the separation zone increased with dune height.

3.2 Distribution of Erosion and Deposition Field measurements using the plugging-brazing method showed distinct spatial patterns of erosion and deposition around barchan dunes . On the windward slope, net erosion volumes ranged from 0.0097 to 0.0118 $\mathrm{m^3 \cdot m^{-2}}$, approaching equilibrium conditions. The stoss slope experienced slight erosion, while the crest showed alternating erosion and deposition depending on wind strength.

On the leeward slope, deposition dominated in the frontal region with net deposition rates of 0.0735–0.112 $\mathrm{m^3 \cdot m^{-2}}$ for medium to large dunes. However, the flank wake zones exhibited net erosion, particularly for smaller dunes where flow separation effects were less pronounced. The average net erosion volume increased slightly with dune size, from 0.002 $\mathrm{m^3 \cdot m^{-2}}$ for 8 m-long dunes to 0.017 $\mathrm{m^3 \cdot m^{-2}}$ for 1.4 m-long dunes.

3.3 Relationship Between Dune Size and Erosion Intensity The erosion intensity showed a positive correlation with dune size. As dune volume increased from 26 m^3 to 188.9 m^3, the net erosion volume per unit area increased correspondingly. This relationship can be expressed as:

$$EQ = f(V_d) \quad [MATH\_0014]$$

where V_d represents dune volume. The correlation coefficient (r) between dune size and erosion intensity was 0.85 ($p < 0.05$).

3.4 Surface Morphology Changes Surface morphology measurements at 1 cm resolution revealed that micro-topographic variations significantly influenced local erosion patterns. On the windward slope, erosion concentrated in areas with slopes greater than 15°, while deposition occurred in flatter areas and depressions. The leeward slope showed complex patterns with deposition in the central wake zone and erosion along the lateral edges where secondary flows were strong [Figure 7b: see original paper].

4. Discussion

The results demonstrate that barchan dunes substantially modify near-surface airflow, thereby controlling erosion and deposition patterns in desertification processes. The acceleration of airflow on windward slopes increases shear stress, but the hard crust of the playa surface limits actual erosion, resulting in near-equilibrium conditions. This finding aligns with previous studies showing that crusted surfaces have higher erosion thresholds [cite{28}].

On leeward slopes, flow separation creates a sheltered zone where sediment deposition dominates. However, the flank wake zones experience enhanced erosion due to secondary airflow patterns and vortex shedding [cite{9,11}]. This explains why net erosion occurs on the leeward flanks despite overall deposition on the leeward slope.

The size-dependent erosion intensity suggests that larger dunes create more extensive flow perturbations, affecting larger areas. This has important implications for desertification monitoring, as the presence and growth of barchan dunes may accelerate local erosion through positive feedback mechanisms. The plugging-brazing method proved effective for quantifying these patterns, though its temporal resolution is limited to event-scale measurements.

5. Conclusions

This study combined field measurements and wind tunnel simulations to investigate how barchan dunes affect surface wind erosion in the Taitema Lake playa. The main conclusions are:

1. Barchan dunes significantly alter airflow structure, with acceleration on windward slopes and separation on leeward slopes, creating distinct erosion and deposition zones.
2. Net erosion volumes on windward slopes approach equilibrium (0.0097–0.0118 $m^3 \cdot m^{-2}$), while leeward slopes show deposition in frontal regions but erosion in flank wake zones.
3. Erosion intensity increases slightly with dune size, indicating a positive feedback where dune growth enhances local erosion capacity.
4. The modified airflow patterns around barchan dunes play a crucial role in desertification processes in playa environments, controlling sediment redistribution and landform evolution.

These findings improve understanding of aeolian processes in desertified lacustrine plains and provide a scientific basis for desertification control strategies.

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