Post-print: Analysis of Near-surface Sand Transport Flux Under Photovoltaic Facility Disturbance in Sandy Areas

Authors: Tang Guodong, Meng Zhongju, Gao Yong, Zheng Haifeng, Jia Ruiting, Shitao, Meng Zhongju

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Abstract

To reveal the characteristics of sand transport and the development and evolution processes of landform morphology following the construction of photovoltaic power stations in sandy areas, this study quantitatively analyzed the sand transport characteristics at different positions of photovoltaic panels, surface wind erosion conditions, and flow field distribution patterns in the hinterland region of a 200 MWp photovoltaic power station in the Kubuqi Desert under the main wind direction condition (photovoltaic panels facing due south, wind direction from the west, i.e., the angle between the photovoltaic facility arrangement direction and wind direction is 0°). Results show: The sand transport rate at different parts of the photovoltaic panels increases with wind speed. Under different wind speeds, the average sand transport rates follow the order: between panels (1.17 $g \cdot cm^{-2} \cdot min^{-1}$) > behind panels (0.86 $g \cdot cm^{-2} \cdot min^{-1}$) > in front of panels (0.65 $g \cdot cm^{-2} \cdot min^{-1}$). On the 0-30 cm vertical profile, more than 90% of the sand transport rate at different positions is concentrated within the 0–8 cm height range, and more than 95% is concentrated within the 0–11 cm height range. The distribution of sand transport rate with height in the sand-laden airflow follows an exponential decay law [WTBX] ($R^2 \geq 0.98$). The average saltation height of sand particles follows the order: in front of panels > behind panels > between panels, and is positively correlated with wind speed. Analysis of the wind-sand flow flux coefficient indicates that wind-sand flow between and behind panels is concentrated in the near-surface layer, while wind-sand flow in front of panels tends to move toward higher layers. The friction wind speed at different positions of photovoltaic panels follows the order: in front of panels (0.5620~0.596 0 $m \cdot s^{-1}$) > behind panels (0.331 2~0.436 0 $m \cdot s^{-1}$) > between panels (0.3252~0.3632 $m \cdot s^{-1}$). Moreover, the thickness of the dry sand layer in front of panels is significantly higher than at other positions, increasing soil erodibility. Under the combined effects, strong undercutting erosion occurs in

front of panels, with wind erosion depth reaching up to 12.44 cm during the observation period. This study can provide theoretical support for the scientific prevention and control of wind-sand hazards within photovoltaic power stations in desert regions.

Full Text

Preamble

TANG Guo-dong[1], MENG Zhong-ju[1], GAO Yong[1], ZHENG Hai-feng[2], JIA Rui-ting[1], SHI Tao[1]

[1]Desert Science and Engineering College/Key Laboratory of Aeolian Sand Physics and Sand Control Engineering in Inner Mongolia, Inner Mongolia Agricultural University, Hohhot 010011, Inner Mongolia, China
[2]Shenhua Group Zhungeer Energy Co., Ltd, Ordos 010300, Inner Mongolia, China

Abstract: This study assesses the characteristics of sand transport, morphological development, and their evolution after the construction of a photovoltaic (PV) power station in a sandy area. Field wind flow, sediment transport, and surface elevation changes were analyzed in the hinterland of a 200 MWp PV power station in the Hobq Desert, where the angle between the arrangement of the PV facilities and wind direction is 0° (i.e., the PV panels face south and the wind direction is west). The results show that: (1) The total sand transport rates around the PV panels were highest in the zones between panels (1.17 $g \cdot cm^{-2} \cdot min^{-1}$), followed by the zones behind panels (0.86 $g \cdot cm^{-2} \cdot min^{-1}$), and finally the zones in front of panels (0.65 $g \cdot cm^{-2} \cdot min^{-1}$). Sand transport rate was also found to decrease with increasing height. On the vertical section of 0–30 cm, more than 90% of the total sand transport flux was distributed within the height 0–8 cm, and over 95% of the total sand transport flux was distributed within the height 0–11 cm. The sediment discharge over three typical photovoltaic panel positions decreased with height and conformed to an exponential function distribution ($R^2 \geq 0.98$). (2) The average saltation height was positively correlated with wind speed; saltation height was, in order from highest to lowest, in front of panels > behind panels > between panels. The sand flux coefficient of wind-sand flow was also analyzed, and it was found that sand flux tends to be highest in front of panels, whereas between and behind panels, the flux was mostly concentrated in the near-ground layer. (3) Under the interference of PV panels, shear velocities were 0.5620–0.5960, 0.3312–0.4360 $m \cdot s^{-1}$, and 0.3252–0.3632 $m \cdot s^{-1}$ for the zones in front of, behind, and between panels, respectively. The thickness of the dry sand layer of the zones in front of panels was also significantly higher than at other locations, increasing soil erodibility. A stronger erosion occurred in the zones in front of panels by comprehensive action, and wind erosion depth reached 12.44 cm during the observation period. This study provides a better technical scheme for wind-sand hazards for the case of solar PV power stations in order to ensure their stable and safe operation.

Keywords: sand transport; aeolian sediment flux structure; fitted model; wind profile; photovoltaic power station; Hobq Desert

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1 Study Area

1.1 Site Description

The study was conducted at a 200 MWp photovoltaic power station located in the Hobq Desert. The site is situated between 37°20 -39°50 N and 107°10 -111°45 E. The region has a temperate continental climate, with an average annual temperature of 5-8°C, annual precipitation of 258.3 mm, annual evaporation of 2400 mm, and total annual solar radiation of 597.9 kJ · cm^{-2}. The area experiences 149 windy days per year, primarily during spring (March-May), with 25-35 days of strong winds ($ $5m \cdot s^{\{-1\}}).TheprevailingwinddirectionisNW - ES, withwindspeedsrangingfrom10–60m \cdot s${-1}$. The terrain consists of mobile and semi-mobile dunes with slopes of 10%-30%, and dune heights of 10-60 m. The underlying surface is primarily composed of fine sand.

1.2 Experimental Design and Methods

1.2.1 Measurement Setup and Instrumentation Wind speed was measured at three heights: 1 m, 2 m, and 3 m above the surface using automatic anemometers. Sediment transport was measured using vertical sediment traps with a collection opening of 2 cm × 1 cm, installed at heights of 0-30 cm at 2 cm intervals, with 15 sampling levels total. The experiment was conducted from March 25-27, 2019, under wind speeds of 7.79 m · s^{-1}, 8.43 m · s^{-1}, and 8.80 m · s^{-1}. Measurements were taken at three typical positions: in front of panels, between panels, and behind panels. Each measurement lasted 1 hour, with three replicates for each wind speed condition.

[FIGURE 1] Wind erosion surface under the interference of PV panels
[FIGURE 2] Smoothing underlying surface to test
[FIGURE 3] Schematic diagram of the experimental layout

At wind speeds of 7.79 m · s^{-1}, 8.43 m · s^{-1}, and 8.80 m · s^{-1}, sand transport rates were measured at heights of 0-30 cm at 2 cm intervals. The results showed that sand transport rates varied significantly by position. At 7.79 m · s^{-1}, the rates were: between panels (0.953 g · cm^{-2} · min^{-1}) > behind panels (0.570 g · cm^{-2} · min^{-1}) > in front of panels (0.496 g · cm^{-2} · min^{-1}). At 8.43 m · s^{-1}: between panels (1.074 g · cm^{-2} · min^{-1}) > behind panels (0.655 g · cm^{-2} · min^{-1}) > in front of panels (0.602 g · cm^{-2} · min^{-1}). At 8.80 m · s^{-1}: between panels (1.470 g · cm^{-2} · min^{-1}) > behind panels (1.348 g · cm^{-2} · min^{-1}) > in front of panels (0.847 g · cm^{-2} · min^{-1}). Averaged across all wind speeds, the sand transport rates were: between panels (1.17 g · cm^{-2} · min^{-1}) > behind panels (0.86 g · cm^{-2} · min^{-1}) > in front of panels (0.65 g · cm^{-2} · min^{-1}). The zones in front of and behind panels showed 55.62% and 73.58% lower transport rates, respectively, compared to between panels.

The vertical distribution of sediment flux was analyzed using Origin 2017 software. The results showed that sediment discharge decreased with height and followed an exponential function distribution: q = ae^(-bh), where q is sediment flux, a and b are regression coefficients, and h is height. The coefficient of determination (R^2) was $ $0.98 for all positions.

[FIGURE 4] Mass flux density profiles at the different positions and velocity of PV panels
[FIGURE 5] Cumulative percentage of sand transport rate at the different positions and velocity of PV panels

The regression coefficients varied by position: coefficient a ranged from 0.3008 to 0.9208, with the highest values between panels, followed by behind panels, and lowest in front of panels. Coefficient b ranged from 0.2793 to 0.4540. At wind speeds of 7.97 $m \cdot s^{-1}$ and 8.43 $m \cdot s^{-1}$, b values were highest in front of panels, indicating greater attenuation of sediment flux with height. At 8.80 $m \cdot s^{-1}$, b values were highest between panels, suggesting more concentrated near-surface transport.

2.2 Sand Flux Coefficient Analysis

At 8.80 $m \cdot s^{-1}$, the sand flux coefficient λ showed distinct patterns: between panels (1.05), behind panels (0.67), and in front of panels (0.98). The saltation height was positively correlated with wind speed, with the highest saltation occurring in front of panels, followed by behind panels, and lowest between panels. The shear velocities measured were 0.5620–0.5960 $m \cdot s^{-1}$ in front of panels, 0.3312–0.4360 $m \cdot s^{-1}$ behind panels, and 0.3252–0.3632 $m \cdot s^{-1}$ between panels.

[FIGURE 6] Wind velocity profiles at the different positions and velocity of PV panels
[FIGURE 7] Wind velocity profiles at the different positions and velocity of PV panels

The dry sand layer thickness varied significantly by position: 10.17 cm in front of panels (increasing erodibility by 0.65), 25.57 cm behind panels (increasing erodibility by 1.00), and 13.73 cm between panels (increasing erodibility by 2.07). The comprehensive wind erosion depth reached 12.44 cm in front of panels during the observation period.

4 Conclusions

(1) At the 200 MWp PV power station in the Hobq Desert, sand transport rates around PV panels followed the sequence: between panels > behind panels > in front of panels. Over the 0–30 cm vertical profile, more than 90% of sand transport occurred within 0–8 cm height, and over 95% within

0–11 cm. The vertical distribution of sediment flux followed an exponential function ($R^2 \geq 0.98$).

(2) Saltation height was positively correlated with wind speed and varied by position: highest in front of panels, intermediate behind panels, and lowest between panels. The sand flux coefficient analysis revealed that sand flux was concentrated in the near-surface layer, particularly between and behind panels.

(3) Under the interference of PV panels, shear velocities were 0.5620–0.5960 $m \cdot s^{-1}$ in front of panels, 0.3312–0.4360 $m \cdot s^{-1}$ behind panels, and 0.3252–0.3632 $m \cdot s^{-1}$ between panels. The dry sand layer thickness was significantly greater in front of panels, increasing soil erodibility. Comprehensive wind erosion depth reached 12.44 cm in front of panels during the observation period.

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