

Postprint: Aeolian Sand Transport Characteristics in Desert Photovoltaic Power Plants

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Abstract

Taking the sandy-area solar photovoltaic power field of Wuhai Shenghui Energy Technology Company as the research object, observations were conducted on wind-sand transport at the leading edge, trailing edge of photovoltaic panels, and the aisles of photovoltaic arrays within the photovoltaic matrix to investigate the wind-sand flow transport patterns in sandy-area photovoltaic power plants. The research indicates: The sediment transport rate at all observation points exhibits a decreasing trend with increasing height. The optimal fitting equations for sediment transport rate as a function of height at the leading edge, trailing edge, and aisles of photovoltaic panels are all polynomial functions, with R^2 values exceeding 0.95, indicating reliable fitting results. The wind-sand flow structure characteristic values at the leading and trailing edges of photovoltaic panels are greater than 1, indicating an unsaturated wind-sand flow state with surface wind erosion. The wind-sand flow structure characteristic values at the aisles of the power field matrix are all less than 1, indicating a saturated wind-sand flow state with surface accumulation. Due to the guiding effect of photovoltaic panels on wind-sand flow, an airflow acceleration zone forms beneath the panels, resulting in undercutting phenomena; therefore, the area beneath photovoltaic panels constitutes a key region for wind-sand control within the field. The sediment transport rates at all observation points inside the photovoltaic matrix are lower than those in open fields, and gradually decrease with deeper penetration into the power station. The critical location for controlling sand hazards in sandy-area photovoltaic power plants is the windward edge of the station.

Full Text

2.2.1 Sand Transport at 0-50 cm Height (Q0-50)

The sand transport rate at photovoltaic plate eaves decreased with increasing height. Polynomial functions provided the best fit for sand transport rates at

observation points along both front and back eaves as well as array roadways, with R^2 values exceeding 0.95, indicating reliable model fit [Figure 1: see original paper]. According to Goovaerts [12-13], when the eigenvalue > 1 , wind-drift sand flow is unsaturated and transport rate increases with wind speed; when < 1 , flow is saturated and transport rate remains constant regardless of wind speed. For positions A1-A5, eigenvalues at front eaves (MN and ON) approximated 1, with correlation coefficients reaching significance ($P < 0.05$). In contrast, the eigenvalue at back eaves (RS) was 0.78, also statistically significant ($P < 0.05$). Further analysis revealed significant differences in sand transport rates among the five front-eave observation points, with A1 differing significantly from A2, A4, A3, and A5 ($\alpha = 0.05$).

Sand flow structures at different heights of back eaves of photovoltaic plates

Position	Sand transport rate ($\text{g} \cdot \text{min}^{-1} \cdot \text{cm}^{-2}$)	0-1 cm	2-10 cm
A1	$0.817 \pm 0.07\text{a}$	0.254	0.471
A2	$0.617 \pm 0.06\text{b}$	0.222	$1.85 \pm 0.03\text{a}$
A3	$0.595 \pm 0.08\text{c}$	0.210	0.344
A4	$0.341 \pm 0.06\text{d}$	0.110	$1.55 \pm 0.05\text{b}$
A5	$0.267 \pm 0.01\text{e}$	0.089	0.288
			$1.37 \pm 0.03\text{c}$
			0.192
			$1.76 \pm 0.01\text{d}$
			0.152
			$1.71 \pm 0.07\text{e}$

[Figure 6: see original paper] shows sand transport rates from 0-50 cm heights at front eaves of photovoltaic plates. The relationship between transport rate and height followed a polynomial function, with significant correlations ($P < 0.05$). At front eaves, sand transport was concentrated in the 0-2 cm layer, accounting for over 62% of total transport, while the 2-10 cm layer contributed approximately 38%.

2.2.2 Front Eaves

Sand transport at front eaves occurred primarily within the 0-2 cm layer [Figure 6: see original paper]. Polynomial fitting of transport rates for A1-A5 yielded $R^2 = 0.96$ [Figure 4: see original paper]. The sand transport rate at A1 was $0.282 \text{ g} \cdot \text{min}^{-1} \cdot \text{cm}^{-2}$ [Figure 5: see original paper]. Compared with control values, sand transport rates at A1-A5 showed reductions of 92.91%, 95.63%, 96.75%, 97.29%, and 97.91%, respectively. Eigenvalue analysis indicated > 1 for front eaves, confirming unsaturated flow conditions. Pairwise comparisons revealed significant differences between A1 and A2, A4, as well as between A2 and A4, and between A3 and A5 ($\alpha = 0.05$).

2.2.3 Back Eaves

Sand transport at back eaves also concentrated in the 0-2 cm layer [Figure 7: see original paper]. Polynomial fitting for A1-A5 produced $R^2 = 0.97$ [Figure 6: see original paper]. The flow structure at back eaves differed markedly from front eaves, forming a wind shadow zone where airflow velocity decreased significantly, promoting sand deposition [17-18]. This velocity reduction created saturated flow conditions ($\lambda < 1$) conducive to sand accumulation. The back-eave environment thus represents a critical area for sand control measures.

4 Conclusions

- (1) Sand transport rates varied significantly by position within the photovoltaic array, with front eaves (MN, ON) showing unsaturated flow characteristics ($\lambda > 1$) and back eaves (RS) exhibiting saturated flow ($\lambda = 0.78$). All differences were statistically significant ($p = 0.05$).
- (2) The photovoltaic plate structure creates distinct aerodynamic zones: an acceleration zone at front eaves enhancing sand transport, and a deceleration zone at back eaves promoting deposition. These findings align with previous research on wind flow modification by engineered structures [7-9]. Consequently, both the windward margin and plate bottom areas require prioritized erosion control interventions.

Abstract: A photovoltaic power station in a sandy area was studied to investigate wind-drift sand transport at front and back eaves of photovoltaic plates and array roadways, aiming to understand sand migration patterns at different spatial positions within the photovoltaic electric field. Results showed: Sand transport rate decreased with height at all measurement positions, with polynomial functions providing optimal fit ($R^2 > 0.95$); Eigenvalues of wind-drift sand flow exceeded 1 at plate eaves (unsaturated flow) but were below 1 at array roadways (saturated flow), indicating the plates' guiding effect on sand transport with acceleration zones at plate bottoms creating erosion hotspots; Transport rates within arrays were lower than in open fields, identifying the windward marginal zone as the key area for erosion prevention.

Keywords: photovoltaic array; spatial position; transport rate; wind-sand flow structure characteristic value; Inner Mongolia

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