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Aeolian environment and sediment transportation over gobi with strong winds

Tao Wang , Benli Liu , Qinghe Niu , Lihai Tan, Jianjun Qu

Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China; wtao1214@lzb.ac.cn, liubenli@lzb.ac.cn, niuqh@lzb.ac.cn, tanlihai09@lzb.ac.cn, qujianj@lzb.ac.cn

SUMMARY:
Aeolian transport driven by strong winds over Gobi may lead to serious environmental issues and direct damage to facilities, but its process and dynamics remain poorly understood. In this study, the aeolian environment and transport over a Gobi were observed in situ in Yandun windy area along the Lanzhou-Xinjiang High-Speed Railway, Northwest China. The results reveal that the maximum height of aeolian sediment transport over this Gobi reaches 9 m, and the sediment flux density decreases exponentially with the increase of height. The vertical profile of median grain size over the Gobi surface is significantly different from that of the sand surface, where grain size increases to a critical altitude before decreasing with height. The annual sediment transport rate (Q) reached 1648.43 kg m^{-1} a^{-1}, which is larger than that of the majority desert regions. The fine sand and total suspended particulate (TSP) components of the wind-blown sand flow, which are primarily impacted by turbulence during strong winds, contribute to approximately 90% of the sediments deposited on the railway subgrade and inhaled by the train. To reduce the aeolian disaster of the Lanzhou-Xinjiang High-Speed Railway, the control of fine particles (TSP and fine sand) must be strengthened.

Keywords: Gobi, Strong winds, Wind-blown sand flow

1. MOTIVATIONS

At present, there are limited studies on the aeolian sediment transport over Gobi with strong winds, and the movement law of wind-blown sand under strong winds is unclear, which hinders the prevention and control of wind-blown sand disasters in the Gobi gale areas. In this study, characteristic parameters of the aeolian environment and sediment transport, such as the saltation threshold, sand drift potential, sediment flux profile, annual sediment transport rate, and sediment grain size properties, were used to investigate aeolian transport over Gobi during strong winds in the Yandun area along the Lanzhou-Xinjiang High-Speed Railway in eastern Xinjiang, China (Fig. 1a).

2. METHODS

2.1. Study area and field observations

The field observations were conducted in Yandun windy area along the Lanzhou-Xinjiang High-Speed Railway (42°18′15″N, 94°1′29″E; Fig. 1a). The wind profile was measured by two 3-D ultrasonic anemometers at heights of 0.30 and 0.83 m above the surface. The saltating particle count profile was measured by a vertical array of seven piezoelectric impact sensors at heights of 0.05, 0.17, 0.31, 0.54, 1.00, 1.47, and 2.14 m above the surface (Fig. 1b). The aeolian sediment flux profile was measured by a vertical array of BSNE sand traps, at inlet heights of 0.12, 0.27, 0.57, 0.87, 1.17, 1.57, 1.97, 2.47, 2.97, 3.47, 3.97, 4.97, 5.97, 6.97, and 8.97 m (Fig. 1c). A meteorological station measured the long-term wind velocity and direction at a height of 2 m (Fig. 1d). Samples of the sediments accumulated on the railway subgrade were collected during the cleaning-up operation at night (Fig. 1e).

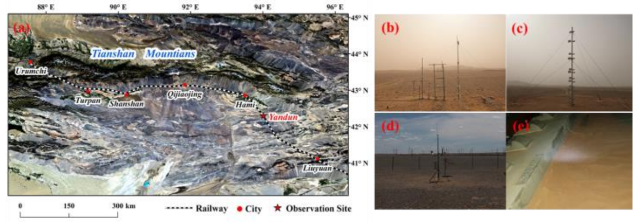

Figure 1. (a) Location map of the Lanzhou-Xinjiang High-Speed Railway and our study area; (b) saltation observation site; (c) observation tower of aeolian sediment transport; (d) meteorological station; (e) sediment samples collected on the railway subgrade.

2.2. Data processing and analysis

High-frequency aeolian saltation was measured from 12:30 to 20:30 on 14 May 2019. The saltation threshold velocity (u_t) was calculated by the time fraction equivalence method (Stout and Zobeck, 1997). The threshold shear velocity (u_{*t}) was calculated by the typical log-law relation:

$$u_{*t} = \frac{u_t k}{\ln(z) - \ln(z_0)} \quad (1)$$

The wind velocity and direction recorded by the meteorological station from September 2020 to August 2021 were used to calculate the sand drift potential (DP), using the method reported by Fryberger and Dean (1979):

$$\mathrm{DP} = 8.95 \times v^2 (v - u_t) t \quad (2)$$

Aeolian sediments were collected by BSNE sand traps at all 15 deployed heights from September 2020 to August 2021. The sediment flux density (q_m) profile describes the variation in sediment transport rate with increasing height above the ground. The grain size distributions of sediments were measured by the sieving method.

3. RESULTS

3.1. Threshold Velocity

The u_t at 0.83 m height during the 8-hr observation period, which was the lowest of 9.46 m s^{-1} during the most intense transport period, and was the maximum of 12.07 m s^{-1} during the least transport period (Fig. 2). The mean value of u_t at 0.83 m was 10.90 m s^{-1}, and the corresponding u_t at 0.30 m was 9.09 m s^{-1}. The u_{*t} was calculated to be 0.71 m s^{-1} by equ.1.

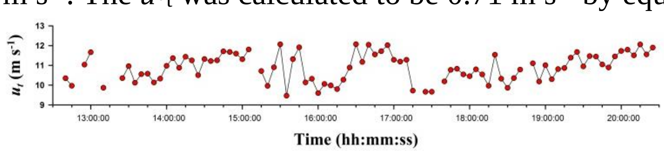

Figure 2. Time series of the 5-min u_t at height of 0.83 m during the 8-hr measurement period.

3.2. Sand Drift Potential

The annual sand-driving wind during the observation period was dominated by E and ENE winds (Fig. 3a).The annual DP and RDP were 416.63 VU and 370.80 VU, respectively (Fig. 3b), indicating a high wind energy environment. The annual RDD was 257.73°, indicating a WSW movement of aeolian sediment.

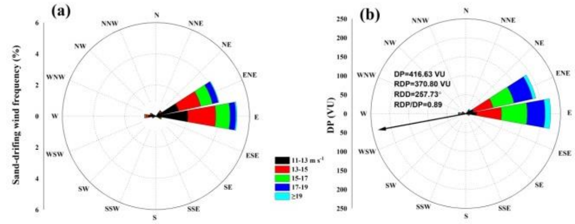

Figure 3. (a) Sand-driving wind rose and (b) sand drift potential rose during the observation period.

3.3. Sediment Flux Profile and Total Transport Quantity

The q_m decreases with increasing height above the Gobi surface, and q_m could be described as an exponential-decay function (Fig. 4a):

$$q_m = q_0 \exp\left(-\frac{z}{z_q}\right) \tag{3}$$

The cumulative frequency of q_m showed 90% of the total sediment flux was concentrated in the layer of 0-0.8 m, and 99% within the range of 0-1.7 m (Fig. 4b).

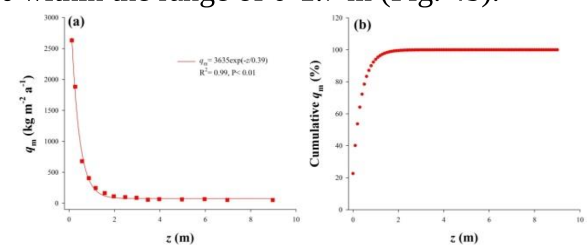

Figure 4. Variation of q_m (a) and cumulative frequency of q_m (b) with height z during the observation period.

The total annual sediment transport quantity (Q) was calculated by integrating the fitted exponential sediment flux density profile during the observation period (Martin and Kok, 2017):

$$Q = \frac{\int_0^\infty q_m dz}{\eta} = \frac{q_0 z_q}{\eta} \tag{4}$$

where η is the collection efficiency of the BSNE sand trap, equal to 0.86 (Fryrear, 1986). Ultimately, the total annual sediment transport quantity over the Gobi is 1648.43 kg m^{-1} a^{-1}.

3.4. Sediment Flux Profile and Total Transport Quantity

The mass percent of saltation particles decreases with height, on the contrary, the mass percent of total suspended particulate (TSP) increases with height (Fig. 5). Saltation particles and TSP accounted for 69.37% and 30.63% of the total sediments, respectively. The d_{50} increases with height at the 0–0.6 m layer, while it decreases above 0.6 m.

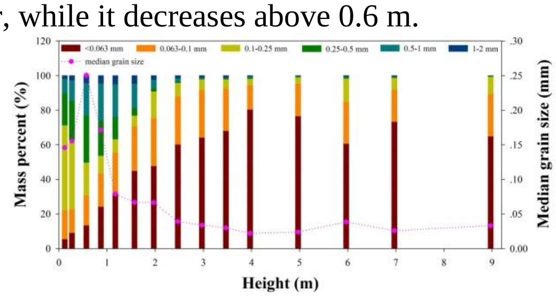

Figure 5. Grain size distribution and median grain size (d50) of sediments collected by BSNE sand traps.

Sediments deposited in the sand control system are mainly saltation particles, accounting for 77.75% (Fig. 6). However, the sediments deposited on the rail track and in the train are mainly TSP and fine sand, accounting for 84.31% and 91%, respectively. The d_{50} of the deposited sediments is 0.27 in the sand control system, 0.12 on the rail track, and 0.10 mm in the equipment bay of the train.

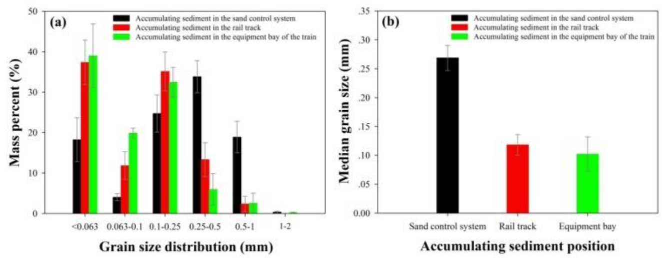

Figure 6. Grain size distribution (a) and median grain size (b) of sediments deposited in the sand control system, rail track, and equipment bay of the high-speed train..

4. CONCLUSIONS

The studied Gobi area belongs to a high wind energy environment with a sand drift potential of 416.63 VU, which is larger than that of most desert regions. The total annual sediment transport quantity reaches to 1648.43 kg m^{-1} a^{-1}, which is comparable to some sandy desert areas. Meanwhile, 69.37% of the blown-sands are saltation particles, and 30.63% are TSP. The maximum height of aeolian sediment transport over the Gobi is 9 m above the surface, and 99% of the sediments were transported in the layer of 1.7 m. The sediment flux density decreases exponentially with height in the field, in contrast to the nonmonotonic flux profiles over Gobi beds measured in wind tunnel studies. The vertical profile of median grain size over Gobi surfaces is significantly different from that of sand surfaces, where grain size grows until a critical altitude (0.6 m in this study) and then decreases with height.

The existing sand control system mainly intercepts the coarse particles of the wind-blown sand, while the TSP and a portion of fine sand overpass the sand control system and wind-break wall, then deposited on the railway subgrade, and are inhaled by the high-speed train. Consequently, the control of fine particles (TSP and fine sand) should be strengthened by increasing the height of the sand fences and preventing dust emission from the Gobi surface to limit the aeolian disaster of the Lanzhou-Xinjiang High-Speed Railway.

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