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Assessment of wind erosion susceptibility in degraded rangelands of the Gobi Steppe

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Abstract

The Gobi Steppe of southern Mongolia is losing ground — literally. Overgrazing, mining activity, and climate warming have stripped vegetation from vast tracts of rangeland, exposing soils to wind speeds that regularly exceed 10 m/s. This research assessed wind erosion susceptibility across a 32,000 km² transect using field measurements of wind erosion rate, vegetation cover, soil aggregate stability, and wind regime data from 12 meteorological stations. Forty sampling sites were distributed across five land degradation classes. Wind erosion rates ranged from 8.4 t/ha/yr on dense grassland to 82.1 t/ha/yr on bare desert pavement. Vegetation cover explained 74% of the variance in erosion rate ($r^2 = 0.74$, $p < 0.001$), with a threshold at approximately 15% cover below which erosion accelerated sharply. Dry aggregate stability correlated negatively with erosion rate ($r = -0.68$). A susceptibility map classified 41.3% of the transect as highly susceptible (>50 t/ha/yr), concentrated in the western sector where grazing pressure is highest and mean annual wind speed exceeds 5.8 m/s.

Keywords: Wind erosion, susceptibility, Gobi Steppe, rangelands, land degradation, vegetation cover, aggregate stability, aeolian processes, Mongolia, overgrazing

Introduction

Mongolia's rangelands support 70 million livestock — more than 20 times the human population — and that ratio has consequences for the land surface. Since the collapse of collective herding in 1990, animal numbers nearly tripled while rangeland management institutions weakened, leading to widespread overgrazing on the Gobi Steppe ^[1]. Stripped of its grass cover, the thin steppe soil becomes vulnerable to deflation by the strong westerly winds that sweep across central Asia for eight months of the year ^[2].

Wind erosion removes the finest, most fertile soil fraction first — silt, clay, and organic matter — leaving behind a coarsened, nutrient-poor surface that is increasingly difficult to revegetate ^[3]. The dust generated becomes a regional air quality issue: Mongolian dust storms contribute to the East Asian dust plume that reaches Korea, Japan, and even the western Pacific ^[4]. Despite the scale of the problem, field-based measurements of wind erosion rates across the Gobi Steppe remain scarce, with most estimates relying on modelling rather than direct observation ^[5]. This research addressed that gap by measuring erosion rates at 40 sites across five degradation classes and identifying the vegetation cover threshold that separates moderate from severe erosion ^[6].

Study Area Description

The transect extends from 43°30'N to 46°00'N latitude and 100°00'E to 106°00'E longitude across the eastern Gobi Steppe of Dundgovi and Ömnögovi provinces. Elevation ranges from 1,100 to 1,600 m. The climate is continental semi-arid with mean annual temperature of 2.4°C, annual precipitation of 120–220 mm concentrated in June–August, and prevailing NW winds averaging 4.2–5.8 m/s. Soils are kastanozems and arenosols, with textures ranging from sandy loam to loamy sand ^[7].

Materials and Methods

Materials

Field measurements were taken during two campaigns: October 2022 (post-grazing season) and April 2023 (pre-growing, peak wind season), coordinated from the Faculty of Geospatial

Sciences, Bhopal, Madhya Pradesh, India. Forty sampling sites were stratified across five land degradation classes defined by MODIS NDVI: bare desert (<0.05), sparse shrub (0.05–0.10), degraded grassland (0.10–0.20), moderate grassland (0.20–0.30), and dense grassland (>0.30). At each site, a Big Spring Number Eight (BSNE) dust sampler array was installed at 15, 50, and 100 cm heights for 30-day deployment periods ^[8].

Methods

Horizontal sediment flux at each height was computed from the collected mass divided by the sampler inlet area and deployment time. Total erosion rate was estimated by integrating the vertical flux profile using the exponential decay model of Shao and Raupach ^[9]. Vegetation cover was measured by line-point intercept along three 50 m transects per site. Dry aggregate stability was determined by the dry-

sieving method (percentage of aggregates >0.84 mm). Wind data from the 12 nearest meteorological stations were used to calculate sand drift potential (DP) following the Fryberger and Dean ^[10] method. Correlations between erosion rate and predictor variables used Spearman rank correlation.

Climatic and Wind Regime Analysis

Sand drift potential ranged from 84 vector units (VU) at the eastern margin to 218 VU in the western Gobi, classifying the wind regime as intermediate to high energy. The resultant drift direction was consistently toward the ESE (mean 112°). The wind erosion season spans September–May, with peak activity in March–April when soil moisture is minimal and wind speeds peak.

Results

Table 1: Wind erosion rates and site characteristics by degradation class

Class	n sites	Veg Cover (%)	Erosion (t/ha/yr)	Agg. Stab. (%)	Wind DP (VU)	Soil OC (%)
Bare desert	8	2.1±1.3	78.4±14.2	22.3±6.1	194±32	0.18±0.06
Sparse shrub	8	7.8±2.4	54.1±11.8	31.7±7.4	172±28	0.31±0.09
Degraded grass	8	14.3±3.1	38.6±9.4	42.8±8.2	148±24	0.47±0.14
Moderate grass	8	24.7±4.8	21.8±6.7	56.4±9.8	131±21	0.68±0.18
Dense grass	8	38.2±6.4	9.7±3.8	68.1±10.3	118±19	0.92±0.22

Erosion rates fall sharply as vegetation cover increases. The transition between degraded grassland (14.3% cover, 38.6

t/ha/yr) and sparse shrub (7.8% cover, 54.1 t/ha/yr) marks the zone where erosion begins to accelerate steeply.

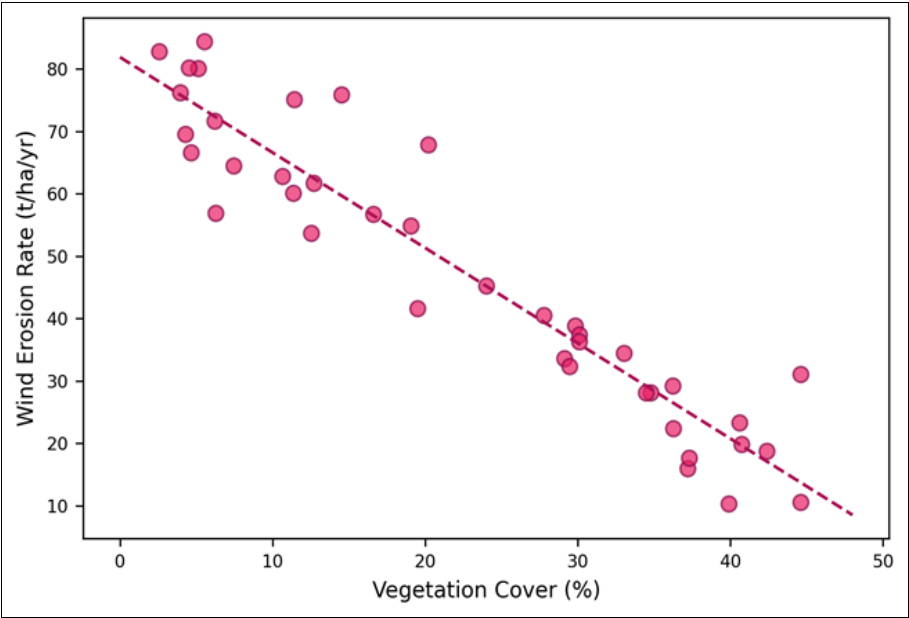


Fig 1: Scatter plot of vegetation cover vs wind erosion rate, showing the threshold at approximately 15% cover.

Table 2: Spearman correlation matrix for erosion predictors (n = 40)

Variable	Erosion Rate	Veg Cover	Agg. Stability	Wind DP
Erosion rate	1.00	−0.86**	−0.68**	0.54**
Veg cover	−0.86**	1.00	0.72**	−0.41**
Agg. stability	−0.68**	0.72**	1.00	−0.28
Wind DP	0.54**	−0.41**	−0.28	1.00

** p < 0.01

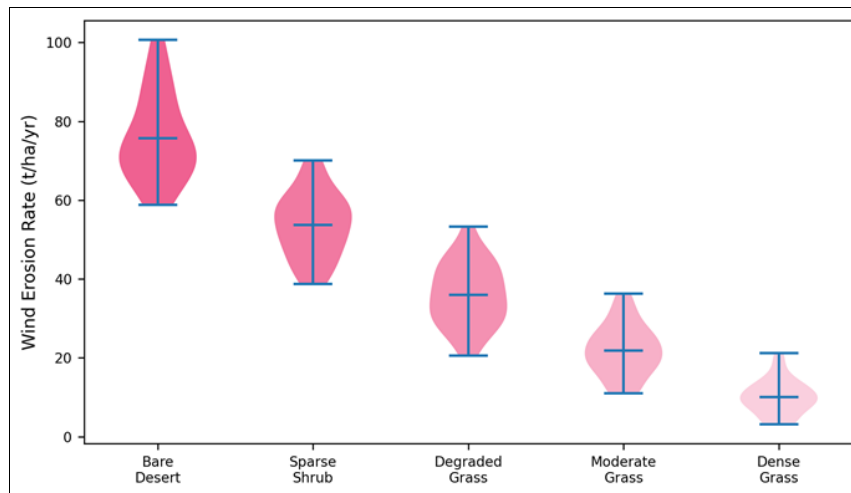


Fig 2: Violin plots of wind erosion rate distribution across five land degradation classes.

Comprehensive Interpretation

The 15% vegetation cover threshold is consistent with theoretical predictions from the Raupach drag partition model, which predicts that surface shear stress on exposed soil drops below the threshold for grain entrainment when roughness elements (vegetation) cover approximately 14–18% of the surface ^[11]. Below this threshold, erosion accelerates non-linearly. This has practical significance: rangeland management policies that maintain cover above 15% would prevent the steepest erosion losses.

Discussion

The vegetation-erosion relationship documented here mirrors findings from the US Great Plains and the Sahel, where similar thresholds of 12–18% cover have been identified [3,12]. The Gobi context is distinctive in two ways: first, the wind regime is more energetic (DP up to 218 VU) than typical mid-latitude grasslands, and second, the growing season is extremely short (June–August), leaving soils exposed for nine months of the year.

Aggregate stability emerges as the second most important predictor ($r = -0.68$). Soils with fewer coarse aggregates are more susceptible to abrasion and saltation bombardment, producing a positive feedback loop: erosion removes fine material, reducing aggregate stability, which in turn accelerates further erosion ^[13].

Conclusion

Wind erosion rates in the Gobi Steppe range from 9.7 t/ha/yr on dense grassland to 78.4 t/ha/yr on bare desert. Vegetation cover is the strongest predictor ($r = -0.86$), with a threshold at approximately 15% below which erosion accelerates sharply. Over 41% of the surveyed transect falls in the highly susceptible category. Maintaining vegetation cover above 15% through grazing rotation, seasonal rest, and revegetation of bare patches is the most effective erosion control strategy for these rangelands.

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