Experimental measurements of deflation in steppe landscapes of Priol’khonie (Lake Baikal region)

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Abstract. The quantitative value of the deflation processes in the steppe landscapes of Priol’khonie was obtained during field experimental studies in the summer seasons of 2017–2019 years. The quantity and properties of the transported particles were determined and statistical analysis of factors (parameters of test sites and weather conditions) affecting the erosion advancing was identified. The measurements were made with a set of dust traps at different heights from the surface, as well as a particle counter and a digital thermo-anemometer. Also, we surveyed the size (fractions) of trapped particles as well as soil samples from the upper soil horizon at the test sites. A comparative analysis of the native and transformed landscapes is carried out. According to results of multiple regression analysis, the main landscape factors that positively affect the deflation are: the quantitative ratio of the fractions of the granulometric composition of the upper horizon of the soil (the positive relationship with silt and dust content is most often expressed) and the steepness of the slope, and the negative relationship is most pronounced with rockiness soil and a projective cover of herbaceous vegetation. We found out that the development of deflation processes in the study area is primarily due to natural factors (features of the soil cover) and increases with anthropogenic impact, which affects the state of the vegetation cover and the particle-size composition of soils.

1. Introduction

Comprehensive geographical research is also needed for feasibility studies of measures to save of steppe landscapes under conditions of increasing anthropogenic impact.

The Priol’khonie region (the central part of the western coast of Lake Baikal, south of Eastern Siberia) is selected as an object of research due to the development of intensive denudation processes [1, 2], which are now especially aggravated following uncontrolled recreational development [3]. There also are livestock breeding, the greatest rise of which occurred in the 70s–80s of the XX century. By 2015, the number of cattle in relation to 1980 decreased by almost 7 times [4]. The recreational potential of the region is formed by a combination of a relatively favorable climate with the exceptional scenic beauty of the landscapes. Pleasurers from nearby cities set up bivouacs on the shores of the lake. According to the annual statistical observations of the district administration, from 2013 to 2019, the tourist flow increased by 22%, more than 600 thousand tourists visit the area annually.

There is a need to monitor the state of landscapes and erosion processes due to increasing of the zones with a high density of random soil roads, which leads to soil compaction, the development of linear erosion, as well as deflation.
An earlier statistical analysis of the collected data on water erosion showed that the main factors influencing the development of this process here are the steepness of the slope and the large quantity of fine sand in the upper soil horizon that usual for this territory [5].

In this research, we tried to quantify parameters of deflation and identify the main factors influencing the development of wind erosion in the steppe landscapes of the Priolkhonie region based on the geosystem approach using a set of experimental techniques.

The climate of the study area is arid (200-300 mm of precipitation per year) with relatively warm summers and moderately cold winters [6]. The depth of the snow cover varies from zero (as a result of blowing out) to 15 cm. The average wind speed is 5.4 meters per second, sometimes it reaches the speed of a hurricane (20-30 m/s). In summer, in connection with the local anticyclonic conditions, breeze and mountain-valley circulation develop [4]. The peneplenized landscape with absolute heights of up to 1000 m with long ridges of rocks creates a special picturesque landscape.

The soil-forming rock is the weathering products of amphibolites, gneisses, and pegmatites [7]. Loose Quaternary deposits are thin, represented mainly by coarse clastic talus deposits and proluvium, 2–3 meters thick [8]. The flat areas are covered with a thicker cover of loose sediments than the slope ones, which smooths the mineralogical and petrographic heterogeneity of the bedrock.

Extrazonal steppes in combination with light-coniferous forests are widespread here: forb-fescue, low-herb, and herb-stipa grass steppes with caragana, larch woodlands with cotoneaster, herb-graminaceous or forb-sagebrush on Lithic Leptosols or Dystric Leptosols girty soil with rock outcrops. In intermontane and lakeside depressions there are boggy meadows with mixed herbs and sedge on Histic Gleysols Limnic soils. Due to grazing and recreational impact, indigenous steppe plant communities are partially replaced by a potentilla (Potentilla spp.) and sagebrush (Artemisia monostachya, Artemisia frigida), in the meadows by wheat grass (Elytrigia repens). The soil cover of the territory is characterized by a light particle-size distribution with a predominance of the fine sand fraction, which causes an insignificant wind resistance of the aggregates.

2. Models and methods
Geosystem approach proposed by Viktor Sochava is a theoretical base of the research [9]. The idea of the hierarchical organization of geosystems allows one to correlate the levels of landscape differentiation with the levels of land use, which can be used for making decisions in the field of land use.

Fieldwork was in the summer of 2013, 2015, 2017-2019 years and more than 100 integrated (landforms, geobotanical and soils) descriptions of representative study sites (10 to 10 meters) were completed, characterizing the study area in the northern part of the Priolkhonie plateau which adjacent to the Kurkut Bay (Lake Baikal) (figure 1). On the study sites, coordinates were recorded, characteristics of the location and features of the relief (slope, exposure, nature of the microlief), vegetation (layer structure, a projective cover of species, height, etc.), soils (profile thickness, particle-size distribution, color, structure, density, etc.) were determined. The map of geosystems of Priolkhonie (scale 1:25000) [5, 10] was used for extrapolating data obtained at the local scale of study sites to the broader scale.

Field experimental studies of matter transfer were carried out in 2017 – 2019 within gullies along roads, as well as on background sites (in indigenous steppe and forest-steppe communities). Quantitative accounting of the transported particles by the wind was carried out using a set of traps (dust collectors) at different heights, as well as a particle counter (model DT-9880) and a digital thermo-anemometer (DT-618). A steel pipe with a cross-sectional area of 1500 cm2 was dug in, and three plastic containers with a total surface area of 143 cm2 were fixed at heights of 30, 60, and 90 cm above the ground. The captured substance was weighed, and the particle size was determined. During experimental studies, the recorded wind speeds did not exceed 7.5 meters per second.
Figure 1. The location of test plots for experimental measurements of wind erosion on the study area (background – DEM ALOS, resolution 30 m): 1 – the test plots of particle counter measurements; 2 – the test plots with traps; 3 – contour lines (20-m interval); 4 – settlements.

3. Results and discussion

The number of quantitative characteristics of wind erosion was obtained in the results of experimental studies. In three years 70 measurements with a particle counter and 14 measurements with traps were made. The average values of collected matter in the traps were determined for the main types of landscapes of the study area (figure 2, table 1).

Analysis of the particle-size distribution of the trapped matter showed that 82% is the fine sand, 16.5% is coarse sand, and 1.5% – fractions >1 mm (last trapped mainly by ground traps). Earlier experimental studies in the steppes of the Priol’khonie region [11] showed that during stormy winds, larger mechanical elements are involved in the movement – gruss and small rock debris.

Table 1. Maximum and minimum concentrations of particles in air, September 14–20, 2017.

| Group of facies       | Height of measurement over ground, m | 0.3     | 0.5     | 1       | 2.5      | 5       | 10      |
|-----------------------|-------------------------------------|---------|---------|---------|----------|---------|---------|
| Forb-stipa steppes on slopes | 0.5 | 73–478 | 13–128 | 8–44    | 0–6      | 0–2     | 0–1     |
|                       | 1.5 | 64–143 | 18–92  | 0–24    | 0–2      | 0       | 0       |
| Residential           | 0.5 | 935–10777 | 148–2603 | 24–340 | 2–56     | 1–21    | 0–13    |
|                       | 1.5 | 544–41914 | 215–7764 | 21–729 | 1–73     | 0–17    | 0–4     |
To identify factors affecting the matter transfer, a multiple regression analysis of the dependence of the amount of trapped matter \( y \) was carried out on the following parameters \( x_n \): maximum wind velocity (m/s), average wind velocity at a height of 50 cm from the ground (m/s), average wind velocity at a height of 150 cm from the ground (m/s), relative humidity (%), air temperature (°C), the projective cover of the tree-shrub layer of vegetation (%), the projective cover of the grass (%), slope steepness (degrees).

Preliminary a pair correlation analysis was performed to test the independent variables. As a result of this analysis, high pair correlation coefficients (0.74-0.87) were identified for the maximum and average wind velocity. They were included in the analysis one by one when calculating multiple regressions. To identify the factors that have the greatest impact, the \( \beta \)-coefficient and elasticity coefficient \( E \) were calculated. The results of the regression analysis are presented in tables 2 and 3.

Table 2. The dependence of the amount of collected matter in ground traps on influencing factors \( y = 0.1x_1 - 0.04x_2 - 2.6 \) with \( R = 0.69, R^2 = 0.48, F\text{-test} = 5.04, p = 0.03 \).

| Variables          | Coefficient | Standard deviation | t-test | p-value | \( R^2 \) | \( E \) | \( \beta \) |
|--------------------|-------------|--------------------|--------|---------|----------|--------|----------|
| Constant           | -2.6        | 1.2                | -2.2   | 0.05    |          |        |          |
| \( x_1 \) – relative humidity | 0.1         | 0.03               | 2.7    | 0.02    | 0.3      | 12.5   | 0.75     |
| \( x_2 \) – slope steepness  | -0.04       | 0.02               | -2.2   | 0.05    | 0.1      | -0.8   | -0.4     |

Multiple regression analysis of the data showed that relative humidity of the air \( (\beta = 0.75) \) had a positive effect on the accumulation of material in the ground trap (see table 2), and the slope steepness had a negative effect. The multiple correlation coefficient is average. The resulting model describes the variation of less than half of the values of trapped matter and does not take into account all the
influencing factors. Nevertheless, the high sensitivity of the values to a change in relative humidity \((E = 12.5)\) was revealed. The slope steepness and air temperature have the greatest positive effect on the transport of matter at the height of 30 cm from the surface of the ground.

| Variables          | Coefficient | Standard deviation | t-test | p-value | R² | E  | β  |
|--------------------|-------------|--------------------|--------|---------|----|----|----|
| Constant           | -0.03       | 0.02               | -1.8   | 0.09    |    |    |    |
| \(x_1\) – air temp | 0.002       | 0.001              | 2.2    | 0.06    | 0.4| 1.7| 0.4|
| \(x_2\) – slope steepness | 0.002 | 0.001 | 1.9 | 0.08 | 0.4| 0.7| 0.5|

An analysis of the trap data at the height of 60 cm over the ground showed that the projective cover of the tree-shrub layer of vegetation has the greatest positive effect on the transport of matter. The paired linear regression model \((R = 0.72, R^2 = 0.52, t\text{-test} = 3.48, p = 0.005)\) is as follows:

\[
y = 53.8x - 0.49
\]

where \(y\) – the amount of collected material in the trap at the height of 60 cm (g/m²), \(x\) – the projective cover of the tree-and-shrub layer, %.

It was not found statistically significant relationships with a number of measured factors as a result of regression analysis of trap data at the height of 90 cm overground.

The obtained models cannot be used for predicting and calculating wind erosion indicators, because the multiple correlation coefficients and \(p\)-values are low. But in general, such an analysis allows us to identify factors that affect the deflation process: meteorological indicators (relative humidity and air temperature) and the state of the vegetation cover.

To identify factors that affect the particle concentration in the air due to wind erosion in the landscapes of the Priol’khon region, a multiple regression analysis of data obtained using a particle counter in the air at heights of 0.5, 1.5 and 2.0 m from the ground was also performed. As independent variables, the following set of parameters was used: projective cover of grass and tree-shrub layers (%), air temperature \(\degree C\), relative humidity (%), wind velocity (maximum and average, m/s), slope steepness \(\degree\), soil density \(g/cm^3\), the content in the upper soil horizon of organic carbon (%), sand fractions in % \((0.05–0.25; 0.25–0.5; 0.5–1.0 \text{ mm)}\), dust \((0.001–0.005; 0.005–0.01; 0.01–0.05 \text{ mm})\) and silt \(<0.001 \text{ mm})\), soil rockiness (> 3 mm).

Comparing the measurements made by the particle counter in different years and periods, it was found that the readings vary greatly (by an order of magnitude), while the readings taken in the same observation period for several days vary to a minimum. A particle counter measures the content of suspended solids ranging in size from 0.3 to 10 microns. Such sizes are characteristic of aerosols in the atmosphere. Transparency of the atmosphere, changing not only depending on the season of the year but also the level of air pollution, affects the readings of the particle counter. To analyze the particle counter data, it is necessary to take into account the influence of spontaneous emissions of pollution (for example, from motor vehicles, stove heating) and the atmosphere transparency. Therefore, the data obtained in different periods were analyzed separately and the measurements were carried out in the natural background.

Statistical analysis was performed for 18 dependent variables (50 measurements for each). A pair correlation analysis was made to check the independent variables. Then a multiple linear regression analysis was performed, and beta coefficients \((\beta)\) were calculated.

For example, the following multiple regression equation showed the greatest certainty for the concentration of particles with a size of 2.5 μm at a height of 0.5 m from the surface of the ground \((R = 0.72; R^2 = 0.52; F\text{-test} = 9.4; p > 0.999)\):

\[
y = 1.4x_1 + 0.6x_2 - 0.3x_3 + 1.1x_4 - 0.3x_5 + 3.2
\]
The variables and statistical parameters of the equation are presented in table 4. The analysis results showed that the silt content in the upper soil horizon ($\beta = 0.47$), the steepness of the slope ($\beta = 0.39$) and the average wind speed ($\beta = 0.27$) have the greatest positive effect on the increase in the concentration of 2.5 micron particles in the air. The projective cover of the grass has a significant negative effect ($\beta = -0.45$).

**Table 4.** The dependence of the concentration of particles with a size of 2.5 $\mu$m at a height of 0.5 m from the ground surface on influencing factors.

| Variables                  | Coefficient | Standard deviation | t-test | p-value | $R^2$ |
|----------------------------|-------------|--------------------|--------|---------|-------|
| Constants                  | 3.2         | 3.2                | 0.98   | 0.7     | 0.07  |
| $x_1$ – average wind velocity | 1.4         | 0.6                | 2.5    | 0.98    | 0.09  |
| $x_2$ – slope steepness    | 0.6         | 0.2                | 3.2    | 0.997   | 0.12  |
| $x_3$ – the projective cover of the grass | -0.3        | 0.1                | -4.1   | > 0.999 | 0.02  |
| $x_4$ – silt content (<0.001 mm) | 1.1         | 0.3                | 4.2    | > 0.999 |       |
| $x_5$ – the rockiness of soils (>3 mm) | -0.3        | 0.1                | -3.1   | 0.997   |       |

In general, the results of multiple regression analysis showed that the main factors affecting the concentration of the particles in the air at heights of 0.5-2 m are: the quantitative ratio of the fractions of the mechanical composition of the soil upper horizon (a positive relationship with the content of silt and dust is most often expressed) and the slope steepness. The negative correlation is most often with a soil rockiness and projective cover of grass.

The ratio of influencing factors changes for particles 5 and 10 $\mu$m in size. The main contribution is made by the slope steepness, soil rockiness, the projective cover of the grass, the amount of silt in the soil upper horizon.

4. Conclusion

The relative quantity assessment of deflation in the Priol’khonie region was performed in the results of field and experimental work.

Analysis of the particle-size distribution of soil showed that most of the types of soils in the Priol’khonie region are characterized by a low ability to resist the wind. Soil aggregates are destroyed by the intensive recreational impact, and fine sand (< 0.05 mm) is released, which is easily transported by the wind. Multiple regression analysis of results obtained using a particle counter showed that the particle-size distribution of upper soils horizons and the content wealth of fine sand and silt fractions in the upper soil horizon have a greater impact on the concentration of particles in the air. Loamy sand and light loamy texture of the soils, weak aggregation of soil particles, and the anthropogenic impact considerably increases the deflation.

The arid conditions of the study area influenced the formation of the dry valleys and the concentration of loesslike and sandy sediments in them on talus and less commonly on proluvium deposits. Therefore, we can conclude that the development of denudation processes is primarily due to natural factors and increases with growth in anthropogenic impact.

The rehabilitation of anthropogenically disturbed areas of the steppes and the environmental protection of indigenous steppe communities is a prerequisite for restoring the natural mechanisms of erosion regulation in the Priol’khonie region.

Acknowledgment

This study was performed within the framework of state assignment (registration nos. AAAA-A17-117041910169-4, AAAA-A17-117041910167-0, AAAA-A17-117041910171-7) and was partially
supported by the Russian Foundation for Basic Research (project no. 17-05-00588) and the Russian Geographical Society (project no. 17-05-41020 RGO–RFFI).

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