

Aeolian salinization of soils on the piedmont plain of Eastern Tian Shan (Lake Ebinur area, China)

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Abstract

This study is focused on the effect of aeolian transport on soil formation and salinization in the piedmont plain of the northern slope of Tian Shan (Xinjiang-Uygur Autonomous Region of China). On the basis of the data on aeolian input of dust and salts (determined by dust collectors) and soil salinity at the 300-km transect it is shown that soil formation and salinization is closely related to aeolian processes. The main source of aeolian material is the dried up bottom of Lake Ebinur (wet playa). Maximum soil salinity (3-6% of salts) is observed in the soils near Jinghe settlement where the maximum aeolian input of salts is also registered. In the soils beyond 100 km from the dried bottom of the lake, salt content is low (0.1-0.4%). Chemical composition of salts in the soils is related to chemical composition of aeolian material. Chloride salts prevail in the soils located in the areas with the high Cl⁻ to SO₄²⁻ ratios (from 0.8 to 1.5) in aeolian salts. In places with a predominance of sulphates in the composition of aeolian salts, soils are characterized by the sulphate type of salinization. Preliminary calculations show that the formation of the modern profile of the studied soils takes about 2000 years.

Key Words

Central Asia, Dzungarian Gate, aeolian genesis of soils, desert soils, Holocene history

Introduction

The genesis of salts in the soils formed on the gravelly deposits of piedmont plains in Central Asia is an argued issue. The influence of two main factors determining the salinity of overwhelming part of salt-affected soils of the world - salinity of parent rocks and ground water - is absent here. The existing hypothesis of aeolian genesis of salts in those soils (Nosin, 1960; Pankova, 1992) has not been supported by experiments.

In this study we have tried to estimate the effect of the aeolian factor on soil salinity in the piedmont plain of the northern slope of Eastern Tian Shan (Xinjiang Uygur Autonomous Region of China) on the basis of the data on the content and composition of salts in aeolian material and soils. This study is the continuation of the series of research devoted to the reasons and influence of Lake Ebinur desiccation on surrounding landscapes.

Materials and methods

The piedmont plains of the northern slope of Tian Shan occupy altitudes from 250 to 700 m a.s.l. They are represented by alluvial and colluvial fans and are mainly composed of coarse gravelly material. In the lower part of piedmont plains (250-350 m a.s.l.), the deposits are often represented by loess of different thickness. Natural vegetation of piedmont plains is sparse, consists of saxaul (*Haloxylon persicum*, *Haloxylon ammodendron*), tamarix (*Tamarix ramosissima*), saltworts (*Kalidium foliatum*, *Kalidium cuspidatum*, *Kalidium caspicum*), wormwood (*Artemisia* sp.). The depth of ground water is 15-30 m and more.

Climate is arid with mean annual precipitation 100-200 mm and potential evaporation 1500-2000 mm. Maximum precipitation falls in summer. Snow cover is shallow, 10-25 cm. Mean July temperature is +27°C, mean January temperature is -17°C. Strong winds are frequent. The amount of days with the winds >8m/s is 164 per year (Guijin Mu et al., 2002). The winds predominantly have northwestern direction; they come to the Dzungarian (or Junggar) Basin in the area of northwestern part of Lake Ebinur from Dzungarian Gate - a relatively narrow pass between the ridges of the Dzungarian Alatau and the Western Dzungarian Mountains (Figure 1).

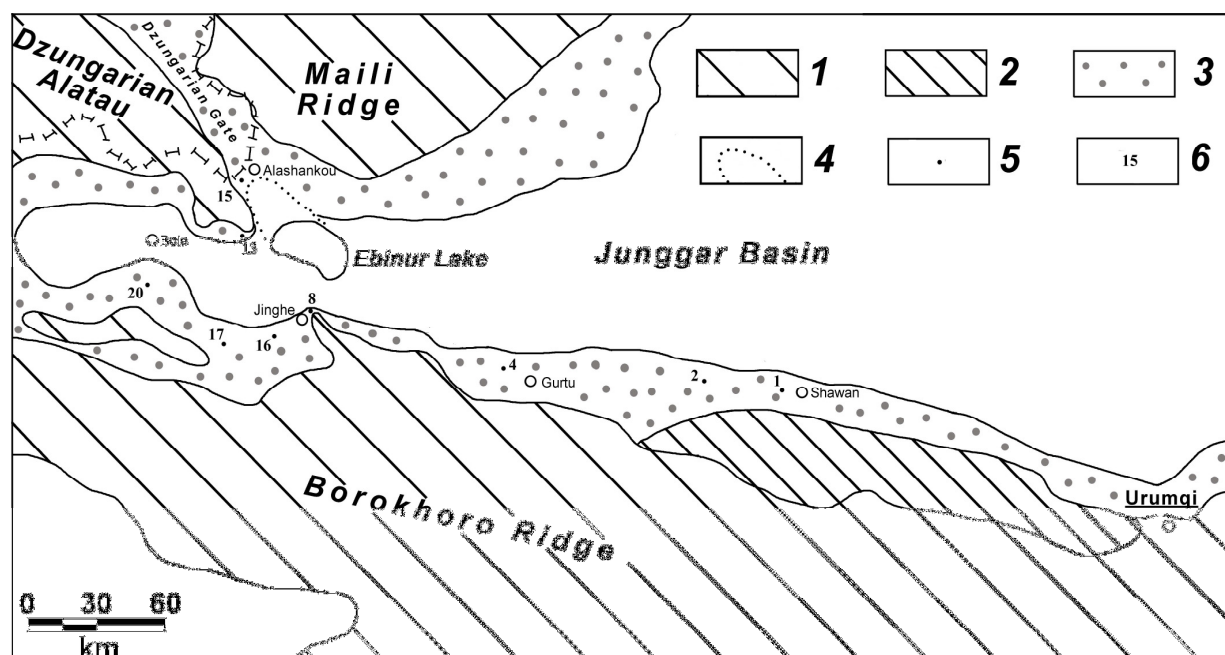


Figure 1. Study area. Legend: 1 - mountains, 2 - outcrops of loose saline Tertiary deposits, 3 - piedmont plain, 4 - dry lakebed, 5 - pits location, 6 - numbers of pits.

Lake Ebinur is located in the northwest of China, in the west of Dzungarian Basin, at the altitudes about 190 m a.s.l. The lake is a closed salt lake with chloride-sulphate composition of water, 80-120 g/l (Fan Zili and Zhang Leide, 1992). The average depth of the lake is 2-3 m, maximum 5 m. In the middle Holocene (some 5000 ago), at the place of the modern salt lake, a fresh lake with the area of 3000 km² and depth of 40 m existed. In the late Holocene, the area of the lake began to decrease due to the decreased surface runoff; by the beginning of the XX century, its area was 1300 km². Since the 1950s, anthropogenic activity (increase in consumption of surface water for irrigation and domestic use) added to the desiccation of the lake. At the beginning of the XXI century, the area of the lake is about 600 km². The surface released from water represents a vast bare wet playa with very high salinity (>40% of salts in the upper 2 cm, 10-30% in the layer of 2-5 cm). The composition of salts is chloride-sulphate with sodium (Abuduwaili Jilili and Guijin Mu, 2006). The northwestern wind blowing from Dzungarian Gate entrains salty dust and transports it to tens and hundreds of kilometres from the lake.

The previous studies have shown that the main source of aeolian material on the piedmont plains is the dried bottom of Lake Ebinur (Guijin Mu et al., 2002; Abuduwaili Jilili and Guijin Mu, 2006; Abuduwaili Jilili et al., 2008). The aeolian transport was studied in 1998-1999 at a 300-km-long transect. At 13 sites including Alashankou, Bortala (Bole), Jinghe, Gurtu, Shawan and several settlements between them, dust collectors were established. Samples were collected each month. It was revealed that the amount of aeolian dust fall is dependent on the position of a sampling site relative to the lake, distance from the lake and the location of the obstacles relative to wind flow. Maximum dust fall (400-600 t/km²/a) is registered in the zone of wind retardation due to a barrier in the form of a bulging ridge of the Tian Shan at the Jinghe sampling site. At the other sites (the farthest one, Shawan, is located 230 km from the lake), aeolian dust fall is 100-200 t/km²/a.

The total amount of salts in the aeolian material is high and reaches 10-25%. Salts are mostly represented by calcium and sodium chlorides and sulfates. The maximum amount of salts (77 g/m²/a) is deposited at Jinghe; at the other sites, the deposition of salts varies from 14 to 27 g/m²/a. The analysis of the chemical composition of salts reveals certain regularity in aeolian transport of salts. At long distances from the source of the eolian material, calcium sulfate predominates in the composition of salts; at closer distances, sodium chloride is actively deposited together with calcium and sodium sulfates.

At different distances and directions from Lake Ebinur, 9 soil pits were studied. According to the Russian and Chinese soil classifications, the soils belong to gray-brown desert type. According to WRB, they are correlated to Calcisols and Gypsisols. For soil samples, the content of Cl⁻, SO₄²⁻, HCO₃⁻, Ca²⁺, Mg²⁺, Na⁺, K⁺ in water extract (1:5), pH, particle-size distribution, humus, gypsum, and carbonate contents were examined.

Results

Soil salinity

The studied soils have the following morphology:

0-3 cm - porous crust, dry, light pale yellow, with gravel, effervescent;

3-10 cm - very fine platy, dry, pale brown, with gravel;

10-25 cm - crumby, pale brown, with gravel;

>25 cm - gravel with gypsiferous "beards" on the lower side of stones, fine earth between the stones.

The depth of fine earth (silt loam) horizons can decrease to 10-12 cm. In pit 15 located in Dzungarian Gate, where predominant removal of loose material takes place, fine earth horizon is absent; fine material is entrapped only between stones. The humus content in soils is low - from 0.3 to 0.9%, 0.4% on average. Soils have high pH - from 9 to 10, rarely from 8 to 9. A horizon of maximum salt accumulation is observed from 3-8 cm and has the total thickness of 5-10 cm (Figure 2). Surface crust (maximum 3 cm) is free from salts.

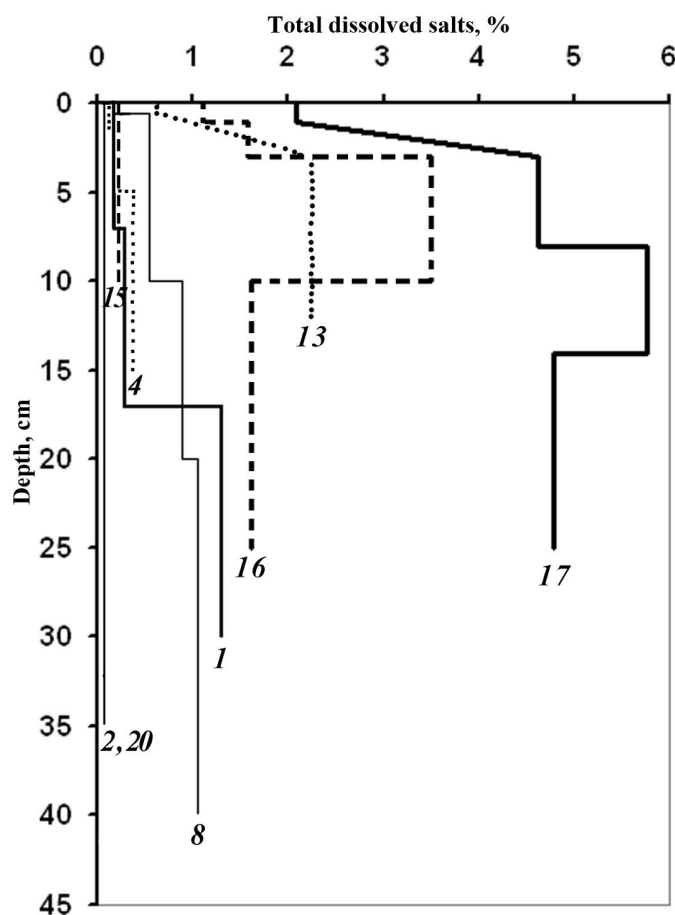


Figure 2. Dissolved salts content in gray-brown desert soils of the piedmont plain of Eastern Tian Shan. Numbers indicate a number of a pit. Pit 1 is underlain from 17 cm by dislocated saline deposits.

The salt content of the studied soils is various and closely related to the input of aeolian salts. Thus, the maximum salinity (3.5-5.8% of salts) is found in Pit 16 and 17 located near Jinghe. As shown above, the maximum aeolian salt input is prominent in this area. Less but still high soil salinity is observed in Pit 13, where aeolian salt input is quite high (about 30 t/km²/a). In Pit 8, which is located close to Jinghe, soil salinity is lower than in the adjacent pits - <1%. This pit, in contrast to other studied soils, is located in the shallow valley of the terminal (seasonal) stream. Thus, spring water removed salts from soil profile. In other soils, the salt content is low - from 0.1 to 0.4%.

Chemical composition of salts in the soils is related to chemical composition of aeolian material. Thus, chloride salts prevail in the soils located at the areas where high Cl⁻ to SO₄²⁻ ratios (from 0.8 to 1.5) in aeolian salts are registered. At the places where sulphates predominate in aeolian salts, soils have a sulphate composition of salts.

Model of aeolian soil formation and salt accumulation

We have tried to estimate approximately the time of the existing soils formation on gravelly deposits due to aeolian input of dust. It was calculated according to the formula of Golovanov et al. (2001), which accounts for transport of particles in soils under the action of water (Formula):

$$t = \frac{\omega(1 + \alpha)}{\alpha V(8\lambda + L)} \left[1 - \sqrt{\frac{L^2}{(8\lambda + L)^2}} \right]$$

where t is the time of penetration of aeolian dust into coarse deposits to the depth of 30 cm, days; α is a factor of fine particles (<0.02 mm) adhesion with the coarse material (equal to 0.01); λ is a factor of hydrodynamic dispersion (characterizes the transport with water in porous media, depends on texture) (equal to 0.001); V – real infiltration rate (equal to 0.000003 m/day); ω – volume water content in the layer of periodical moistening (equal to 0.008); L – the depth of penetration of fine particles (<0.02 mm) (equal to 0.3 m).

After inserting the values into the formula, we get that the formation of existing soils takes about 1850 years. Close figures (about 2000 years) are obtained when calculating the time of salt accumulation from zero to the present values. We realize that the calculated figures are very approximate, but they are quite concordant with paleogeographic data on the lake dynamics in Holocene.

Conclusions

1. Salinity of gray-brown desert soils on the gravelly deposits of the piedmont plain in the northern slope of Tian Shan varies from slight to very strong levels.
2. Soil salinity is related to aeolian input of salts from the dried bottom of Lake Ebinur. The degree of salinization reaches its maximum in the soils where intensive aeolian salt deposition is registered. At the distance beyond 100 km from the dry lakebed, soils are slightly saline.
3. Chemical composition of salts in soils is various - sulphate, chloride-sulphate, sulphate-chloride and chloride. It is related to chemical composition of aeolian material too.
4. According to our calculations, the formation of studied gray-brown desert soils on gravelly deposits took 2000 years. This date is in good correlation with paleogeography of the study area.

Acknowledgment

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