

Effect of climate on soil salinity in subboreal deserts of Asia

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Abstract

The effect of climate on soil salinity in subboreal deserts was studied on the basis of climatic parameters and data on salt-affected soils in Middle Asia (the Karakum and Kyzylkum deserts and surrounding piedmont plains), China (Xinjiang Uygur Autonomous Region, deserts of Junggar and Tarim basins), and Mongolia (the Gobi deserts). The climatic parameters in the studied subboreal deserts are different, particularly in terms of continentality, aridity, and the amount and seasonal distribution of precipitation. It is shown that there is no correlation between the climate aridity and the area of salt-affected soils. For the automorphic landscapes in subboreal deserts of Asia, the geological history of the territory and the occurrence of salt-bearing deposits are the major factors controlling soil salinity. The eolian transfer of salt-bearing material within deserts is also important. The role of climate is restricted to the redistribution of salts within the soil profiles. A different situation is observed in the soils of hydromorphic landscapes of subboreal deserts. The degree of salinity in the upper horizons of hydromorphic soils and the distribution of salts in the soil profiles largely depend on the climatic parameters. The salinity of hydromorphic soils in deserts can serve as an indicator of climate change.

Key Words

Arid regions, global change, saline soils, Central Asia.

Introduction

Salt-affected soils are obligatory components of arid environments. However, arid lands are subjected to salinization to different extents. They differ in the portion of salt-affected soils and in the degree of salinity, the chemical composition of salts, and their distribution in the soil profiles. According to Ye.V. Lobova and A.V. Khabarov (1977), arid environments occupy nearly 35% of terrestrial surface. The area of salt-affected soils on the Earth reaches 950 million hectares (Szabolcs 1989). The portion of salt-affected soils in arid lands of different continents ranges between 3 to 60% and makes up 22% on the average. The smallest portion of salt-affected soils is observed in South America and Africa; the largest portion - in Australia (Table 1). I. Szabolcs (1989) noted the areas of salt-affected soils on the Earth given by UNESCO are approximate values, because many regions do not have reliable data on salt-affected soils. However, these data suggest that the development of soil salinity in arid environments of the world differs significantly and depends on the particular region.

Table 1. The total area of salt-affected soils (thousand sq. km) and % of salt-affected soils in arid lands.

Continent	Area of arid lands (Lobova and Khabarov 1977)	Area of salt-affected soils (Szabolcs 1989)	% of salt-affected soils in arid lands
Eurasia	17992	3687.5	20.5
Africa	14654.1	805.4	5.5
North America	5771.6	177.0	3.1
South America	3673.4	1291.6	35.0
Australia	6250*	3575.7**	57.1
TOTAL	45395.7	9537.2	22.0

*According to H.E. Dregne (1976) (cited from Deserts 1986).

**The area of salt-affected soils in Australia including Oceania.

What are the reasons for this unevenness and how is it related to modern climate, in particular, to its aridity and continentality? How will soil salinity respond to climate change? These questions have yet to be solved.

In our study, we tried to find answers to them on the basis of data on soil salinity in the deserts of Middle Asia (the Karakum and Kyzylkum deserts and surrounding piedmont plains), China (Xinjiang Uygur Autonomous Region, deserts of Junggar and Tarim basins), and Mongolia (the Gobi deserts). Natural environments were under study.

Materials

Soil salinity in deserts of Mongolia was the subject of our long-term research under the aegis of the Soviet-Mongolian Biological Expedition in 1977-1991 (Soil cover and soils of Mongolia 1984; Pankova 1992). The investigation of deserts in Middle Asia was conducted by us in the 1960s-1990s (Pankova 1992). The deserts of Xinjiang Uygur Autonomous Region (**XUAR**) were studied in detail by the Soviet-Chinese expedition at the end of the 1950s (Natural conditions of Xinjiang 1960; Kunlun and Tarim 1961; Murzaev 1966) and by the authors of this paper in 2006-2008.

Climate of subboreal deserts of Asia

The studied areas belong to the zone of subboreal deserts of Eurasia; in terms of climate, it is subdivided into moderately continental (Middle Asia) and extremely continental (XUAR and Mongolia) facies (Lobova 1965). The area of our study lies within, roughly, 36-43 N and 54-67 E in Middle Asia; 36-46 N and 75-92 E in XUAR, China; and 42-45 N and 92-112 E in Mongolia. The absolute heights are about 200 m (100-400 m) in the deserts of Middle Asia; from 200 to 700 m in the deserts of Junggar basin; from 900 to 1200 m in the deserts of Tarim basin; and above 1000 m asl in Mongolian deserts.

The analysis of some climatic parameters of Mongolian, northwestern Chinese and Middle Asian deserts given in Table 2 reveals that the studied regions are quite different in terms of their climate. The most aridity and the least precipitation are characteristic of extremely arid deserts in the south of Mongolia and in the south of Xinjiang. The least continental and least arid climate is indicative of Middle Asian deserts. The northern deserts of Xinjiang and Mongolia are in the middle. It might seem that from the point of view of climatic aridity, soil salinity should develop to a greater extent in the southern deserts of Mongolia and Xinjiang. However, it is not true, actually.

Table 2. Some climatic parameters of deserts in Central (XUAR China, Mongolia) and Middle Asia (Uzbekistan)

1	2	3	4	5	6	7	8	9	10
Mongolia									
Northern deserts									
+3	-18.7	+23.1	2763	112	78	39	707	281	0.29
True deserts									
+4	-18.2	+24.0	2996	90	77	42	761	303	0.24
Extremely arid (southern) deserts									
+8	-17.0	+28.0	3648	43	31	48	911	309	0.11
Xinjiang Uygur Autonomous Region of China									
Northern deserts (Junggar basin)									
+5.9	-19.4	+24.7	3340	206	58	Not det.	769	302	0.22
Extremely arid (southern) deserts (Tarim basin)									
+11.6	-5.6	+25.0	4304	38	17	Not det.	991	250	0.04
Middle Asia									
Northern deserts									
+8.6	-11.6	+27.0	3710	122	23	48.7	925	260	0.30
Southern (south-Turanian) deserts									
+15.1	-0.6	+29.6	5150	125	2	63.1	1257	229	0.30

1. Mean annual temperature, °C; 2. Mean January temperature, °C; 3. Mean July temperature, °C; 4. Accumulated temperatures above 10°C, degree-days; 5. Mean annual precipitation, mm; 6. Precipitation in June–August, mm; 7. Radiation budget, kcal/cm² per year; 8. Potential evaporation (according to Dimo 1972): $0.72 + 0.23 \cdot (\Sigma t > 10^\circ\text{C})$, where $\Sigma t > 10^\circ\text{C}$ is the accumulated temperatures above 10°C; 9. Continentality factor (according to Ivanov 1948): $A \cdot 100 / (0.33 \cdot \text{lat})$, where A is the annual amplitude of temperatures, °C, lat is the latitude of weather station; 10. Aridity factor (according to Lobova *et al.* 1977): $\text{Pr} / (5.12 + \Sigma t_{\text{IV-X}} + 306)$, where Pr is the mean annual precipitation, mm/year; $\Sigma t_{\text{IV-X}}$ is the sum of the mean monthly temperatures from April to October, °C.

Soil salinity in automorphic (with deep ground water table) landscapes

The soils of automorphic landscapes in Middle Asia are mainly represented by gray-brown soils (Calcisols, Gypsisols), takyrs and takyrs-like soils (Calcisols), and desert sandy (Arenosols) soils. In Mongolia and XUAR, extremely arid stony soils (Leptosols) are found along with Calcisols, Gypsisols, and Arenosols. We restricted ourselves to the analysis of gray-brown and extremely arid soils in this study.

In the gray-brown desert soils of Mongolia, salts and gypsum are mostly absent in the soil profiles and in the underlying rock. Only 10% of the gray-brown soils of Mongolia contain soluble salts; they are mainly

confined to salt-bearing rocks, which are sparse in Mongolia. Extremely arid soils usually contain some amount of soluble salts; their salination originates from the eolian input of salts.

In the XUAR of China, saline and gypsiferous variants of gray-brown desert soils are more frequent than those in Mongolia. According to the Soil map of the P.R.C., 1:10 million (compiled by Ma Yonzhi, V.A. Kovda, N.I. Kondorskaya *et al.* 1959), some 70% of gray-brown soils of Xinjiang are saline or gypsiferous to some degree. There are slightly and strongly gypsiferous soils, the latter being related to paleohydromorphic conditions (Natural conditions of Xinjiang 1960).

Most (90%) of gray-brown desert soils in Middle Asia are salt-affected. Typically, they contain soluble salts in the upper 50 cm (Lobova 1965).

The main (primary) source of salts in the gray-brown soils of subboreal deserts of Asia is the parent material. Therefore, differences in the distribution of salt-affected gray-brown soils are mainly related to the geological features of the particular regions. The eolian input of salts is the secondary source of salinization of automorphic landscapes in the Middle and Central Asia. In Middle Asia, the eolian deposition of salts is most pronounced on coastal plains of the Aral Sea. It can reach 500 kg/ha per year (Kovda 1954); in some areas, the eolian deposition of salts may be up to 2-3 tons/ha per year (Glazovsky 1978). In Xinjiang, the eolian deposition of salts is most active in the areas surrounding drying salt lakes (lakes Ebinur, Aydingkul, Lopnur) and reaches 0.77 tons/ha per year on the adjacent plains (Abuduwaili *et al.* 2008). There are scarce data on the eolian deposition of salts in Mongolian deserts. Obviously, this process is less pronounced in the deserts of Mongolia than in the deserts of Middle Asia and Xinjiang because of the fewer number of the potential sources of salt removal. However, the eolian salinization of automorphic desert soils of Mongolia was described by us in the Trans-Altai Gobi Desert (Deserts of Trans-Altai Gobi 1986; Pankova 1992). It is hardly possible to relate the intensity of the eolian input of salts with the aridity and continentality of modern climate, because this process largely depends on the presence of potential sources of salts (often, the shores of salt lakes), wind conditions, and local geomorphic features in the areas of salt deposition. It is likely that Mongolian deserts are subjected to the active removal of fine earth rather than to its accumulation. The eolian deposition of salts is more intense in the studied deserts of Middle Asia and XUAR.

Soil salinity in hydromorphic (with shallow ground water table) landscapes

As a rule, hydromorphic soils in deserts of Mongolia, Xinjiang, and Middle Asia are saline and subjected to modern salt accumulation. The areas of hydromorphic soils in different regions differ significantly. In Mongolia, such soils occupy insignificantly small areas in comparison with deserts of Middle Asia and Xinjiang.

In contrast to automorphic landscapes, soil salinity in hydromorphic landscapes is closely related to climate, especially to its aridity and continentality. Thus, in extremely arid deserts of south Mongolia and south Xinjiang, "dreadful" solonchaks with salt crusts containing up to 40-60% of soluble salts in the topmost layer are found above the ground water with low solute concentrations (less than 2-5 g/l). In Middle Asia, solonchaks and even salt-affected soils are not developed in the case of such a low salinity of ground water. In Middle Asia, solute concentration of ground water in hydromorphic soils is mainly above 10-20 g/l; in this case, the content of soluble salts in the upper horizons amounts to 2% on the average (maximum 10-20%) and never reaches those high values that are observed in the south of Mongolia and south Xinjiang.

The described regularities of soil salinity in hydromorphic landscapes are governed by precipitation and temperature regimes of soils. In the south of Xinjiang and Mongolia, soils are strongly heated in summer, which leads to enhanced evaporation with accumulation of salts on the soil surface. At the same time, minute amount of precipitation excludes the leaching of salts down the soil profile. The formation of surface salt crusts is also favored by strong soil freezing, which is related to continentality of climate (there is no soil freezing in Middle Asian deserts). As a result, the migration of salts in desert soils of southern Mongolia and southern Xinjiang is unidirectional both in summer (toward the evaporative front) and in winter (toward the freezing front). In Middle Asia, the natural removal of salts from the upper horizons into the ground water takes place during the rainy season in the spring. This results in the increased solute concentrations of the ground water and the desalination of soils.

Conclusions

1. Subboreal deserts of Mongolia (the Gobi deserts), China (Junggar and Tarim basins), and Uzbekistan and Turkmenistan (the Karakum and Kyzylkum deserts and their surroundings) differ significantly in terms of the degrees of continentality and aridity of the climate and the regime and quantity of precipitation. The highest aridity is characteristic of the deserts in the south of Mongolia and south of Xinjiang (extremely arid deserts of Gobi and the Tarim basin), the lowest aridity is observed in Middle Asian deserts. The transitional position is occupied by true deserts of Mongolia and northern Xinjiang (the Junggar basin).
2. A comparison of soil salinity in deserts of Mongolia, northwestern China, and Middle Asia indicates that there is no correlation between the aridity of climate and the areas of salt-affected soils.
3. The differences in soil salinity in the automorphic landscapes of subboreal deserts of Asia are mainly related to the paleogeographic history of the landscapes, the presence of salt-bearing deposits of the past geological epochs, and the activity of the eolian transport of salts from their potential sources (shores of drying salt lakes).
4. The aridity of climate regulates the modern salt accumulation in hydromorphic landscapes: the higher the aridity, the stronger the accumulation of salts in the upper horizons of salt-affected soils.
5. The aridization of the climate may have different effects on the degree of soil salinity and on the distribution of salts in the soil profiles in dependence on their initial salinity and on the degrees of aridity and continentality of the climate and the regime of precipitation. Hydromorphic soils subjected to active modern salinization may be more sensitive indicators of climate changes than automorphic soils.

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