WHY THE AREA OF DEGRADED SOILS AND DESERTIFICATION IS INCREASING IN THE VOLGA DELTA

Anna Fedotova[1,*], Lyudmila Yakovleva[1], Ekaterina Maslova[1], Arstan Utaliev[1]

[1] *Astrakhan State University, Astrakhan, Russia*

* *Corresponding author. E-mail: a.v.fedotova@gmail.com*

ABSTRACT
The article discusses the causes of increasing areas of degraded soils and desertification in the Volga delta, as well as the more frequent occurrence of natural hazards in the form of dust storms. Significant attention is paid to the causes and characteristics of zonal soil degradation in typical delta landscapes. Key areas of zonal soil complexes (ZSC) with visible changes in soil cover (lack of vegetation, changes in salinity, degradation) were under study. It is shown that regular systemic changes related to natural and anthropogenic factors occur in the soil cover. The main mechanisms of soil degradation have been identified: destruction, surface layer deflation, halohydrogenic transformation. A protective shrub shelterbelt and perennial grasses are recommended.

Keywords: *soil degradation, desertification, deflation, salinization, plant communities, pasture digression, dust storms, Volga Delta, Caspian Sea.*

1. INTRODUCTION

The increasing frequency of dangerous natural phenomena in the form of dust storms in the Volga delta, contrasting halomorphic occurrences, increasing areas of degraded soils dictate a new research level of soil cover and degradation processes development mechanisms. The southern arid zone, which includes the Astrakhan region and the Republic of Kalmykia, is one of the most vulnerable to desertification in the Russian Federation. Dust storms of varying intensity are recorded here every 2-3 decades. Dust storms are accompanied by strong winds (up to 25 m/s).

Some sources [1-2] mention earlier recorded large-scale dust storms in the late 1980s. The consequences affected large areas of agricultural land in the region.

In April 2021, the Astrakhan region was again hit by a dust storm, the scale of which far exceeded any previously recorded. Three southern regions of Russia - the Astrakhan region, the Republic of Kalmykia and Dagestan were affected at once. This natural phenomenon is anomalous for this region despite the fact that dust storms are a relatively frequent phenomenon in arid regions. First of all, the area of spread, the volume of particles carried by the wind and the duration.

In general, dust storms are classified as dangerous natural phenomena [3-4]. Sand and dust particles carried by the wind create considerable difficulties for human and animal breathing and reduce visibility to several meters and less. There are often recorded cases of human deaths and injuries. Ground surfaces are buried under layers of sand and dust, the thickness of which depends on the strength and duration of the storm.

This is an emergency situation that significantly complicates livelihoods and causes significant damage to ecosystems. Elimination of the consequences of dust storms is resource-intensive and requires some time. One of the most negative consequences is the intensive development of soil desertification processes, accompanied by the onset of sands, loss of vegetation cover and a significant reduction in arable land.

The overwhelming view of both scientists and administrators is that dust storms in the Astrakhan region, Kalmykia and Dagestan are caused by uncontrolled sheep and goat populations and the drought of 2020 [5-8].

A poor use of pasture has been identified as a key cause of dust storms and desertification. Cattle, goats, and sheep, trample the pastures and eat all the vegetation, while the hot climate and dry winds aggravate the situation. In the Astrakhan region, pasture vegetation cover degradation is also the predominant type of desertification. High pasture use and unsystematic grazing over the years have led to increased degradation and desertification.

According to research by the Scientific Centre for Agroecology, Integrated Reclamation and Protective Afforestation of the Russian Academy of Sciences, degradation of agricultural land in the Astrakhan region has reached almost 50% (1.4 million hectares) [9]. The problem is exacerbated by the increasing open sands area. At present, the total area of degraded pastures affected by wind erosion and desertification of 792,000 ha is more than 20,000 ha of open sands. Due to the abundance of barchans, the southern part of the Astrakhan region and the Republic of Kalmykia increasingly resemble the Sahara.

In our opinion, one of the important factors of the occurring negative changes is the specifics of the processes of soil formation of the territory and the peculiarities of the functioning of soil complexes of different genesis.

High air temperature, extremely low precipitation and the halomorphic nature of the territory create prerequisites for the formation of low fertility soil complexes. Currently changing climatic conditions lead to even sharper contrasts between moisture and evaporation, including due to the increase in the duration of periods with maximum summer air temperatures above 40 °C. As a result, there is a greater drying of soils of automorphic complexes, development of the processes of salinization and disaggregation of soils, change of vegetation towards desert species.

The analysis of the causes, leading to desertification increase and natural complexes degradation in the territory of the Volga delta in general, is of undoubted interest. This is a vivid example of the negative effects of natural and anthropogenic factors on semi-desert landscapes.

Delta ecosystems are among the most vulnerable and unstable. The most vulnerable in the Volga delta's arid climate are brown semi-desert zonal soils, represented on elevated relief elements and isolated from the flood and groundwater influence. In this context, it is of undoubted scientific and practical interest to study the causes of the development of degradation processes in the ZSC soil cover. This will make it possible to predict potential scenarios for soil evolution in the Volga delta and to develop technologies for preventing and stopping degradation processes.

2. MATERIALS AND RESEARCH METHODS

2.1. Research objects

Research objects were selected in accordance with the task set, i.e. to reveal mechanisms of soil degradation and desertification development in the ZSCs of the Volga delta. The study objects were the "key" zones of ZSCs in landscapes typical for the Volga delta and characterized by contrasting changes in the soil cover. The ZSC soil cover is represented by automorphic low-productive saline, solonetzic brown semi-desert soils.

Studies and analysis of stock materials have shown that Baer knolls in the Volga delta are unambiguously the "core" of ecosystems of typical knoll deltaic landscapes. These knoll landscapes are among the most vulnerable ones in the whole ecosystem of the Volga delta. Violation of one ecosystem link inevitably leads to transformation of the whole landscape with development of negative processes in soils.

Two key sites located on Baer knolls with difference in geomorphological position in landscape, structure of plant communities and representation of soil differences have been selected.

Field 1 (Fig. 1). Top of the Baer knoll. The peculiarity is the presence of a takyr-like area (fractured surface crust of heavy granulometric composition). Vegetation communities are represented mainly by desert flora, typical for these habitats.

Field 2 (Fig. 2). Slope of Baer knoll. The peculiarity of the soil cover is the presence of cracks on the soil surface.

Figure 1. Field #1.

The studies conducted by the authors showed [10-12] that the soil cover of the Baer knolls is represented by aridisols, soils of the zonal range - arid brown semi-desert soils and their combinations. As a result, there is a significant heterogeneity and contrast of the soil cover.

Zonal aridisols of the Volga delta (arid brown semi-desert) are usually saline and have heavy granulometric composition. The soils are characterized by loose dried surface, lack of structure or weakly expressed structure, and extremely low humus content. There are compacted horizons in the profile, often with signs of alkalinity.

Figure 2. Field #2.

The surrounding knoll space is characterized by the presence of meadow hydromorphic solonchaks, the genesis of which is based on the salinity of soil-forming rocks and the flooding regime of the territory. The latter determines the structure of the soil profile, mainly consisting of pronounced alluvial layers of different granulometric composition and thickness. These features are directly related to the height and duration of flooding in specific years. Below by geomorphological position, solonchaks are replaced by peat-marsh gley soils, confined to low relief elements (inter-knoll depressions), usually characterized by overwatering and the presence of hydromorphic processes.

2.2. Research methods

Assessment of soil degradation was based on the analysis of changes in the condition of soil and plant communities.

In order to identify areas with maximum variability of soil properties, primarily in the degree of salinity, we conducted an electrophysical study of the soil cover using a portable Land Mapper measuring device. Electrical resistance was measured on a uniform grid at the Baer knoll by vertical electrical probing to a depth of 2 meters and by horizontal electrical profiling to a depth of 1 meter.

After a preliminary field interpretation of the data, the analysis of the results through the dependence of the value of electrical resistivity on the degree of soil salinity revealed the most contrasting areas.

Field studies of soils included morphological analysis of the soil profile, determination of basic soil properties (physical, chemical, physical and chemical) by traditional methods accepted in soil science and ecology, analysis and interpretation of results using methods of mathematical statistics [13].

At the "key" fields, the uniform grid method was used for soil sampling and determination of soil properties, which had proven itself in similar studies earlier [14]; the morphological structure of the transects was studied using the short trench method.

3. OBTAINED RESULTS

The morphological structure of the soil profile of the "key" fields was studied (Table).

In the structure of ZSC soil profile, the presence of salt illuvial horizon, characterized by heavy granulometric composition and a large number of salt efflorescence, is noted. The depth of salt horizon occurrence increases in direct proportion to the increase of its position in the relief. In the near-hill space, the salt horizons are as close to the surface as possible, which determines the salt regime of these soils in conjunction with annual floods. The degree of soil salinization begins to increase as it decreases in the topography. The change of salt horizon thickness has an inverse dependence.

Investigations on the "key" field #1 showed that the greatest amount of salts in the soil profile is confined to the takyr-like area with the absence of vegetation. Laboratory analyses showed that here the value of dense residue increases from 0.8% in the surface layer to 2.3% at a depth of 30 cm. These values correspond to a very highly saline soil. In addition, high contents of Na ions (12-18 mmol/100 g soil), Mg (4-6 mmol/100 g soil) and Cl (16-19 mmol/100 g soil) were recorded in the soil solution.

The peculiarity of the structure of the soil profile of the "key" field #2 is the presence of sediment in the surface horizon from the top of the Baer knoll as a result of water and wind erosion. The thickness of the sediment layer decreases with the lowering of its position in the topography.

New formations along the profile are represented by carbonate accumulations and fragmentary salt inclusions. In the soil profile the illuvial horizon with signs of solonetzicity and a large number of new formations in the form of crystals, powdery forms and salt veins is fixed. Increased salinity is one of the main reasons of low fertility of these soils. In the soil solution the values of sodium ions from 0.15 to 23.29 mmol/100 g of soil, magnesium ions from 0.28 to 6.08 mmol/100 g of soil and chloride ions from 0.14 to 16.97 mmol/100 g of soil (corresponds to the area with strong cracking of surface soil layer) are observed.

Table 1. Morphological structure of the field profile

Field #1, layer, cm	Description
0-3 cm	Loose, light brown, dusty structure, medium/heavy loam, characterised by horizontal stratification, scaly. The transition is clear in density, colour and structure.
3-18 cm	Denser and lighter than the previous one, no grey shades, morphologically diagnosed as sandy loam, stratification exists. The boundary is plane, transition in colour and structure.
18-53 cm	Dark brown with grey abundant spots, much denser than the previous one, the structure is columnar, typical for solonets. The border is not plain, the transition is clear in colour and structure.
53-69 cm	Lighter than the previous one, colour stable, no dark spots, denser than the previous one, less columnar. The border is uneven and the transition is clear with the presence of salts. The border is uneven, the transition is clear by the presence of salts
69-100 cm	Dark brown, heterogeneous colouring, numerous salt stains and efflorescence, pseudomycelium, gypsum and medicinal plant material available. The structure is columnar-prismatic, with vertical fracturing. The boundary is uneven, the transition is gradual in the presence of salts.
100-…cm	Fresh. Light brown. Sandy loam.
Field #2, layer, cm	**Description**
0-14 cm	Dry, dark grey, fine to medium lumpy texture, strongly fissured, cracks 1-5 mm wide, 0.5 to 3 cm deep, rarely up to 5 cm deep, many roots, medium loam, the border is even, the transition is noticeable in colour.
14-33 cm	Dry, light brown in colour with sparse red spots of ironing, humus leaks, fewer roots than in the previous one, clumpy structure when crushed dusty, heavy loam, dense, slightly wavy boundary, transition clear in colouring.
33-65 cm	Dry, light brown, many salt spots, dense, spots of ironing, clumpy structure, heavy loam, gradual transition in colouring and salt presence.
65-100 cm	Dark brown, stains of ironing, gleying, salt efflorescence in the pores, fresh, fine to medium clumpy, compacted, heavy loam

4. RESULTS DISCUSSION

Landscape studies have shown that degradation changes in ZSCs are caused by both climatic and anthropogenic factors.

One of the most important factors is the decreasing water content of the area. It is known that the hydrological regime of the Volga Delta is interdependent with the level of the Caspian Sea. According to Roshydromet data, the Caspian Sea shallowed by 133 cm between 2005 and 2020. According to M. Matthias Prange and his colleagues, [15] the Caspian Sea level is projected to drop by 9-18 meters by the end of the 21st century under medium and high greenhouse gas emission scenarios. This will cause a significant increase in evaporation from the water surface, which will not be counterbalanced by an increase in river flow or precipitation. This will result in the sea floor of the vast northern Caspian Sea shelf and all coastal areas in the middle and southern Caspian Sea being denuded. A 9-metre drop in water level would reduce the Caspian Sea area by 23%, and by 18 meters by 34%.

The Caspian Sea level lowering leads to the ground water depth increase in the Volga delta as well as to the change of flooding regime. As a result, the share of saline low fertility automorphic soils increases. Climatic conditions in the form of high air temperatures and low precipitation contribute to drying of surface layers, destruction of the structure, and, as a consequence, intensive development of deflationary processes. Cut off from the influence of flood waters, SZCs are affected by low precipitation (less than 200 mm per year) and enter the stage of sedimentation.

In general, zonal soils are characterised by unsatisfactory properties: low humus content (about 1.5%). Fulvic acids dominate in humus composition. Soil moisture is at hygroscopic level (3-4 %). Ca2+ and Mg2+ prevail in structure of soil absorbing complex, Na+ content is from 1.3 to 30.0 % of EKO. The ECO value is 8.0-16.4 mg-eq per 100 g of soil, the reaction in the upper horizons is slightly alkaline (pH 7.4-7.6), in the lower ones alkaline (pH 8.2-8.8). Soil density varies from 1.3 g/cm3 on the surface to 1.9 g/cm3 in the illuvial horizon with signs of sedimentation, the moisture content increases uniformly with depth from 4% to 10%. The soils are characterized by the NV value of about 20% for humus horizons and 17% for salt and illuvial horizons. The total projective cover of the plant community does not exceed 15%. The average height of the herbage is 10 cm.

During spring-summer floods, it is on the Baer knolls that significant herds of cattle and small cattle accumulate. Ridge vegetation communities are ecologically vulnerable, especially under grazing loads. Vegetation is eaten almost completely. Intensive degradation of soil and vegetation cover takes place. Long-term pasturage loads cause falling out of the majority of perennial species in the composition of associations. As a result, representatives of poisonous and non-edible species remain. During prolonged floods, cattle eat even those plants which are not edible.

In general, four forms and stages of degradation, including pasture degradation, are characteristic of the surface of the Baer knolls:

1. Change in the structure of the surface soil layer (dispersion, disaggregation);
2. Increased representation of takyr-like habitats;
3. High (more than 1.6 g/cm3) values of density of soil of subsurface horizon;
4. Extremely low (less than 2%) values of soil moisture.

Unnormalized pasture loads, through loss of vegetation cover and soil turbulence lead to intensification of desertification and degradation processes. Destruction of vegetation cover leads, as it was mentioned above, to intensification of soil salinity degree and development of processes of disaggregation and deflation.

The wind regime of the territory contributes to the scattering of surface degraded layers of automorphic soils (aeolian transport). The scale of deflation leads to an increase in massifs of unfixed dispersed soils, which continue to move due to strong winds due to the absence of obstacles in the form of a full vegetation cover.

CONCLUSION

Thus, the cause of desertification and dust storms is complex. The trigger is certainly the lack of strict rationing of grazing of agricultural animals, as a result of which the vegetation cover is destroyed, the destruction of surface soil horizons in the form of destruction of the structure, accompanied by compaction of the underlying horizons.

Regional features of soil formation and soil properties on the background of pasture digression contribute to the destruction of the surface horizons, which are initially characterized by dustiness and lack of structure. As a result, deflation processes develop intensively. The wind regime of the territory and degradation of vegetation contribute to unhindered aeolian transport of dusty and sandy particles.

To prevent further desertification of the Volga delta and the threat of dust storms, it is necessary to implement modern technologies of phytoreclamation everywhere, designed to take into account the characteristics of soils and soil cover, as well as climatic features of a particular territory.

AUTHORS' CONTRIBUTIONS

The authors were directly involved in the planning, organization, and execution of field studies, laboratory analyses and tests, the analysis and interpretation of results, and the development of conclusions and proposals.

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