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Disruption of Ecological Systems Caused by Soil Salinization in the Aral Sea Region

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Abstract
This article examines the disruption of ecological systems resulting from soil salinization in the Aral Sea region. The study focuses on the physicochemical and agrochemical characteristics of irrigated meadow–alluvial soils, with particular attention to the degree and types of salinity. The findings reveal that soil salinization varies significantly across different territories and soil depths. These variations contribute to the deterioration of soil fertility and adversely affect the stability and functioning of local ecosystems. The results highlight the growing environmental challenges associated with salinization and emphasize the need for sustainable soil management strategies in the region.

Keywords: Aral Sea Region, Ecological Disruption, Meadow–Alluvial Soils, Soil Fertility, Soil Salinization

Introduction

Soil is one of the most important natural resources for humanity, as it supports plant growth, regulates water circulation, contributes to the carbon cycle, and sustains biodiversity. However, in recent decades, soil degradation driven by human activities has accelerated significantly. Among the major forms of degradation, soil salinization is a critical factor that directly disrupts ecological systems.

Salinization refers to the accumulation of soluble salts—primarily sodium, magnesium, and calcium—in the soil. Saline soils not only reduce agricultural productivity but also negatively affect vegetation, fauna, and soil microorganisms.

Central Asia, particularly the Republic of Uzbekistan and the Republic of Karakalpakstan, is among the regions most severely affected by salinization. As a consequence of the Aral Sea crisis, hundreds of thousands of hectares of land have become saline, leading to a significant decline in soil fertility.

Review of Related Literature

Research on soil salinization and degradation in the Aral Sea region and Karakalpakstan highlights both local and global perspectives. Saidova and Usmonova (2019) examined the agrochemical indicators of saline irrigated soils in Karakalpakstan, noting the negative impact of salinity on soil fertility and crop productivity. Similarly, Nauryzbaeva (2021) analysed degraded soils in Karakalpakstan, emphasizing the urgent need for restoration measures to sustain agricultural development in the region.

Global studies provide a broader framework for understanding salinization. The FAO (2021) published a global map of saline soils, identifying salinity as a widespread challenge affecting food security and sustainable land use. Lal (2015) argued that restoring soil quality is essential to mitigate degradation, linking soil health to broader sustainability goals. Qadir et al. (2014) explored the economic dimensions of salt-induced land degradation, showing that salinity not only reduces productivity but also imposes significant financial burdens on communities and nations.

The ecological consequences of salinization are closely tied to the Aral Sea disaster, as described by Micklin (2007), who documented how water mismanagement and environmental decline accelerated soil degradation in the region. More recent work by Otenova and Mambetullaeva (2024) provided an ecological assessment of soil salinization in the southern Aral Sea region, highlighting the ongoing environmental risks and the need for sustainable management strategies.

Taken together, the literature demonstrates a dual focus: localized studies in Karakalpakstan that detail the chemical and ecological impacts of salinization, and global research that situates these challenges within broader environmental, economic, and sustainability contexts. This convergence underscores the importance of integrating soil restoration, salinity management, and sustainable land use to address the pressing issue of soil degradation in the Aral Sea region and beyond.

Figure 1. Synthesized image from NASA satellite data (1989–2014)

Objectives

This study aims to investigate the impact of soil salinization as a critical form of degradation that disrupts ecological systems and agricultural productivity. Since soil is one of humanity’s most vital natural resources—supporting plant growth, regulating water circulation, sustaining biodiversity, and contributing to the carbon cycle—the objective is to analyze how the accumulation of soluble salts such as sodium, magnesium, and calcium alters soil quality and reduces its ecological and economic value.

Another objective is to explore the broader consequences of salinization on vegetation, fauna, and soil microorganisms. By examining these interconnected effects, the study seeks to highlight the urgent need for sustainable soil management practices. Ultimately, the research intends to provide insights into strategies for mitigating salinity, restoring soil health, and ensuring the long-term resilience of ecosystems and agricultural systems in vulnerable regions.

Methodology

The research was conducted in the central and southern regions of Uzbekistan, which are characterized by an arid climate and shallow groundwater levels. Soil samples were collected from depths of 10 cm and 30 cm in field conditions, and their physicochemical properties were analysed in the laboratory.

The study employed the following methods: physicochemical analysis, measurement of pH and electrical conductivity (EC), and statistical analysis. Additionally, irrigation practices and groundwater levels were monitored during the research. These approaches enabled the assessment of soil salinity levels, the distribution of chemical elements, and their variation under environmental influences.

Analysis

Analysis of soil salinity demonstrated that both the degree and type of salinity vary across locations and soil depths.

- In irrigated soils of the experimental farm of the Karakalpak Research Institute of Agriculture (Section 1), salinity levels were generally low. Within the 0–50 cm soil layer, salt content remained relatively low, and pH values were around 8.0, indicating an alkaline environment. The dominant salinity types were sulfate and chloride–sulfate.
- In the irrigated soils of the “Kenges” massif (Section 2) in the Chimbay district, salinity levels were also low, with minimal salt accumulation across all depths. The pH remained approximately 8.0, and the predominant salinity type was chloride–sulfate.
- In the soils of the “Tazajol” massif (Section 3), salinity levels were higher, reaching moderate levels. Salt accumulation was particularly pronounced in the 10–30 cm layer. The dominant salinity type was chloride–sulfate, and vertical accumulation processes were evident in the soil profile.

Findings and Discussion

The results indicate that several regions in Central Asia exhibit high levels of soil salinity, with the most severe conditions observed in the Republic of Karakalpakstan and the Khorezm region.

Field studies conducted on meadow–alluvial soils in the Chimbay district of the Republic of Karakalpakstan revealed that the genetic characteristics of these soils are closely linked to fluvial deposition processes, relief, parent material, vegetation cover, climatic conditions, groundwater depth, and salinity level. Significant changes in the agrochemical and physicochemical properties of soils under the influence of salinization were observed.

Table 1 Salinity Status of The Studied Soils

S e ct	de pt	Dr y re	Total HCO_3	Cl^-	SO_4	Ca	Mg	Anion	Na+K		sum of com	pH	Salinity

ionnumber	h cm	maining part	%/mg/eq	% / mg/eq					mg/eq	%	ponents		type	level
Irrigated soils of the experimental farm of the Karakalpakstan Scientific Research Institute of Farming														
1	0-10	0,430	0,029	0,021	0,226	0,016	0,001	5,78	4,88	0,112	0,405	8,0	-S-	low
			0,48	0,6	4,7	0,8	0,1	0,9						
	10-20	0,482	0,027	0,028	0,254	0,020	0,004	6,54	5,24	0,121	0,454	8,0	-S-	low
			0,44	0,8	5,3	1,0	0,3	1,3						
	20-30	0,928	0,032	0,028	0,533	0,016	0,004	9,42	9,32	0,260	0,873	8,0	-S-	low
			0,52	0,8	1,1	0,8	0,3	1,1						
	30-50	0,179	0,037	0,014	0,072	0,008	0,012	2,5	1,1	0,025	0,168	8,0	X-S	low
			0,6	0,4	1,5	0,4	1,0	1,4						
Irrigated soils of the "Kenges" massif of Chimbay district														
2	0-10	0,280	0,015	0,028	0,139	0,012	0,007	3,94	2,74	0,063	0,264	8,0	X-S	average
			0,24	0,8	2,9	0,6	0,6	1,2						
	10-20	0,180	0,019	0,043	0,058	0,018	0,012	2,72	0,82	0,019	0,169	8,0	X-S	low
			0,32	1,2	1,2	0,9	1,0	1,9						
	20-30	0,2487	0,019	0,035	0,110	0,014	0,015	3,62	1,72	0,040	0,233	8,0	X-S	low
			0,32	1,0	2,3	0,7	1,2	1,9						
	30-50	0,263	0,019	0,035	0,115	0,010	0,006	3,72	2,72	0,063	0,248	8,0	X-S	average
			0,32	1,0	2,4	0,5	0,5	1,0						
Irrigated soils of the "Tazajol" massif of Chimbay district														
3	0-10	0,421	0,032	0,057	0,182	0,028	0,009	5,92	3,82	0,088	0,396	8,0	X-S	average
			0,52	1,6	3,8	1,4	0,7	2,1						
	10-20	0,564	0,039	0,064	0,264	0,026	0,017	7,94	5,24	0,121	0,531	8,0	X-S	average
			0,64	1,8	5.5	1,3	1,4	2,7						
	20-30	0,554	0,037	0,043	0,283	0,026	0,017	7,7	5	0,115	0,521	8,0	X-S	average
			0,6	1,2	5,9	1,3	1,4	2,7						

	30 - 50	0,352	0,044	0,035	0,149	0,016	0,006	4,82	3,52	0,081	0,331	8,0	X-S	average
			0,72	1,0	3,1	0,8	0,5	1,3						

Overall, the degree of salinity in the studied soils ranged from low to moderate, varying by location and depth. Across all sites, alkaline conditions (pH ≈ 8.0) prevailed, and sulfate as well as chloride–sulfate salinity types were dominant.

Conclusion

The study demonstrates that soil salinity in the investigated regions varies from low to moderate levels, with sulfate and chloride–sulfate types predominating. Salinization significantly alters the physicochemical properties of soils, leading to reduced fertility and destabilization of ecosystems. Therefore, the development and implementation of effective measures to control and prevent soil salinization are of critical importance.

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