

NAMANGAN DAVLAT
UNIVERSITETI
ILMIY AXBOROTNOMASI, [2026-9]
ISSN:2181-1458
ISSN:2181-0427



03.00.00-BIOLOGIYA
journal.namdu.uz
BIOLOGICAL

ANALYSIS OF SALINIZATION OF IRRIGATED SOILS IN THE URGENCH DISTRICT OF THE KHOREZM REGION

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Abstract: This study analyzes the current state of salinization of irrigated soils in the Urgench district of the Khorezm region, in the lower Amudarya. The analysis is based on large-scale (1:10 000) soil salinity survey data obtained in 2025–2026, with a sampling density of one soil profile per 18 ha and sampling by genetic horizons within the 0–200 cm layer. A salinity map was compiled in ArcGIS 10.8 (Esri Inc.) by spatial interpolation of point data on salinity degree and salt reserves. In total, 14 irrigation tracts of the Urgench district (23,829.3 ha) were characterized. Non-saline soils occupy 33.5% of the surveyed area, whereas slightly, moderately, strongly, and very strongly saline soils account for 39.2%, 16.4%, 7.2%, and 3.7%, respectively (total saline land: 66.5%). The dominant salinity types are sulfate, chloride–sulfate, and sulfate–chloride. Profile-level water-extract analysis of the S. Kalandarov tract ($n = 206$ layers) confirmed that dry residue content and salt reserves differ significantly among the five salinity categories (Welch's ANOVA, $p < 0.001$; $\eta^2 \geq 0.93$ for both indicators). Spatial variation among tracts is attributed to their position within the Amudarya delta and the functioning of the collector-drainage network. The results provide a basis for differentiated planning of leaching norms and reclamation measures across the district. The study was carried out within the framework of the applied project AL-9124093960 "Development of an integrated agrotechnology for combating soil salinization".

Keywords: saline soils; irrigated land; Urgench district; lower Amudarya; large-scale soil mapping; ArcGIS; salinity chemistry; Khorezm region.

XORAZM VILOYATI URGANCH TUMANI SUG' ORILADIGAN TUPROQLARINING SHO' RLANISHI TAHLILI

Annotatsiya: Ushbu tadqiqotda Amudaryoning quyi oqimida joylashgan Xorazm viloyati Urganch tumani sug' oriladigan tuproqlarining hozirgi sho' rlanish holati tahlil qilingan. Tahlil 2025–2026-yillarda tuproq-sho' rlanish kartogramma ma'lumotlariga asoslangan. Bunda har 18 gektarga bitta tuproq kesmasi qo'yilgan va 0–200 sm qatlamlardan hisobiy qatlamlar bo'yicha namunalar olingan. Sho' rlanish xaritasi ArcGIS 10.8 (Esri Inc.) dasturida sho' rlanish darajasi va tuz zaxiralari to'g'risidagi nuqtaviy ma'lumotlarni fazoviy interpolyatsiya qilish yo'li bilan tuzilgan. Urganch tumanining umumiy maydoni 23 829,3 ga bo'lgan 14 ta sug' orish massivi tavsiflangan. Tekshirilgan maydonning 33,5% ini sho' rlanmagan tuproqlar egallaydi. Kuchsiz, o'rtacha, kuchli va juda kuchli sho' rlangan tuproqlar esa mos ravishda 39,2%, 16,4%, 7,2% va 3,7% ni tashkil etadi (jami sho' rlangan yerlar 66,5%). Sho' rlanishning sulfatli, xlorid-sulfatli va sulfat-xloridli turlari ustunlik qiladi. S. Qalandarov massivida kesmalar bo'yicha o'tkazilgan suvli so'rim tahlili ($n = 206$ qatlam) quruq qoldiq miqdori va tuz zaxiralari beshta sho' rlanish toifasi o'rtasida ishonchli farq qilishini tasdiqladi (Uelch dispersion tahlili, $p < 0,001$; ikkala ko'rsatkich uchun $\eta^2 \geq 0,93$). Massivlar o'rtasidagi fazoviy farqlar ularning Amudaryo deltasidagi joylashuvi, kollektor-drenaj tarmog'ining ishlash holati bilan izohlanadi. Olingan natijalar tumanda sho' r yuvish me'yorlari va meliorativ tadbirlarni tabaqalashtirilgan holda rejalashtirish uchun asos bo'lib xizmat qiladi. Tadqiqot AL-9124093960 raqamli "Tuproqlar sho' rlanishiga qarshi kurashishning integratsiyalashgan agrotexnologiyasini ishlab chiqish" amaliy loyihasi doirasida bajarilgan.

Kalit so'zlar: sho' rlangan tuproqlar; sug' oriladigan yerlar; Urganch tumani; Amudaryoning quyi oqimi; yirik masshtabli tuproq xaritalash; ArcGIS; sho' rlanish kimyosi; Xorazm viloyati.

АНАЛИЗ ЗАСОЛЕНИЯ ОРОШАЕМЫХ ПОЧВ УРГЕНЧСКОГО РАЙОНА ХОРЕЗМСКОЙ ОБЛАСТИ

Аннотация: В работе проанализировано современное состояние засоления орошаемых почв Ургенчского района Хорезмской области в низовьях Амударьи. Анализ основан на данных крупномасштабной (1:10 000) почвенно-солевой съёмки 2025–2026 гг., выполненной с плотностью один почвенный разрез на 18 га и отбором образцов по генетическим горизонтам в слое 0–200 см. Карта засоления составлена в ArcGIS 10.8 (Esri Inc.) методом пространственной интерполяции точечных данных о степени засоления и запасах солей. Охарактеризованы 14 массивов орошения Ургенчского района общей площадью 23 829,3 га. Незасоленные почвы занимают 33,5% обследованной площади, слабо-, средне-, сильно- и очень сильнозасоленные – соответственно 39,2%, 16,4%, 7,2% и 3,7% (всего засоленных земель – 66,5%). Преобладают

сульфатный, хлоридно-сульфатный и сульфатно-хлоридный типы засоления. Анализ водной вытяжки по профилям массива им. С. Каландарова ($n = 206$ слоёв) подтвердил, что содержание плотного остатка и запасы солей достоверно различаются между пятью категориями засоления (дисперсионный анализ Уэлча, $p < 0,001$; $\eta^2 \geq 0,93$ для обоих показателей). Пространственные различия между массивами обусловлены их положением в дельте Амударьи и работой коллекторно-дренажной сети. Полученные результаты служат основой для дифференцированного планирования промывных норм и мелиоративных мероприятий в районе. Исследование выполнено в рамках прикладного проекта AL-9124093960 «Разработка комплексной агротехнологии борьбы с засолением почв».

Ключевые слова: засоленные почвы; орошаемые земли; Ургенчский район; низовья Амударьи; крупномасштабное почвенное картирование; ArcGIS; химизм засоления; Хорезмская область.

INTRODUCTION

Salinization of irrigated soils remains one of the most pressing environmental and agronomic problems of the arid territories of Central Asia (Kovda 1968; Qadir et al. 2009). At present, about 53% of the irrigated land of the Republic of Uzbekistan is saline to some degree; on weakly saline soils cotton yield decreases by 20-30% compared with non-saline fertile land, on medium saline soils by 40-60%, and on strongly saline soils by up to 80% (Kuziev and Sektimenko 2009).

The problem of salinization is most acute in the lower reaches of the Amudarya in the territory of the Republic of Karakalpakstan and the Khorezm region owing to the intensification of natural and anthropogenic impacts against the background of the desiccation of the Aral Sea (Micklin 2007). The disruption of the natural balance is accompanied by a rise in mineralized groundwater, intensification of secondary salinization, and the formation of chemistry types of salinization specific to different parts of the region (Pankova et al. 1996; Pankova 2016; Ruzmetov et al. 2019), as well as by the transport of salt-bearing dust from the desiccated seabed in the Pre-Aral zone alone, solonchaks have thus formed over an area of more than 275 thousand ha (Qadir et al. 2009). The mineralization and chemical composition of river and collector-drainage waters of the basin also substantially affect the salt balance of soils in the lower Amudarya (Chembarisov et al. 2013).

The Khorezm region, and the Urgench district in particular, is characterized by considerable spatial heterogeneity of soil salinization, associated with differences in the position of individual irrigation tracts within the delta, hydrogeological conditions, and the state of reclamation systems (Akhmedov and Ruzmetov 2003). A detailed, tract-by-tract quantitative assessment of these differences based on large-scale mapping data has not previously been carried out for the district; a methodological analogue of such a district-level analysis of saline soils is a recent study of the Irkutsk region based on large-scale soil maps (Chernousenko and Koroleva 2025).

The aim of this work is an analysis of the areas of saline soils of different salinity degree in the Urgench district of the Khorezm region, based on materials of a large-scale (1:10 000) soil salt survey of irrigated land carried out in 2026.

OBJECT AND METHODS

The object of the study was the irrigated land of the Urgench district of the Khorezm region, located within the modern and ancient delta of the Amudarya (Fig. 1). The territory is characterized by a sharply continental climate, low precipitation, high evaporation, and strong winds (mean annual wind speed 3.6-5.2 m/s) that promote salt transport and aeolian salinization. Groundwater over most of the irrigated territory occurs at a depth of 1.0-2.5 m and is highly mineralized, creating conditions favourable for secondary soil salinization.

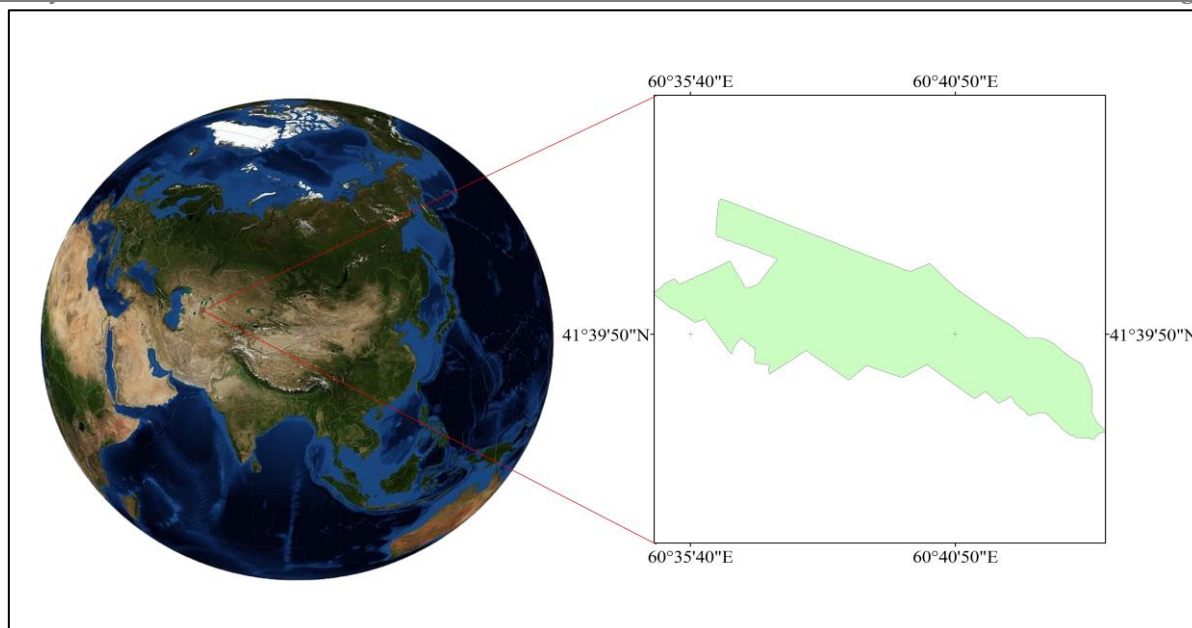


Fig. 1. Location of the Urgench district study area within the lower Amudarya (Khorezm region, Uzbekistan).

The material for the analysis comprised the explanatory note to the soil salinity map of the Urgench district, prepared by the Institute of Soil Science and Agrochemical Research (Tashkent) (Institute of Soil Science and Agrochemical Research 2026a) from field and laboratory-analytical data.

Soil salinity mapping was carried out at a scale of 1:10 000. Given the complexity of the soil cover, one soil profile was laid out per 18 ha of surveyed area, of which 10% were main profiles 2 m deep and 90% were auxiliary boreholes 1 m deep. Samples from the main profiles were taken from the layers 0-30, 30-70, 70-100, 100-150 and 150-200 cm (5 samples), and from the auxiliary boreholes from the layers 0-30, 30-70 and 70-100 cm (3 samples).

At each sampling point, soil material was collected by genetic depth layer as described above. Prior to chemical analysis, samples were air-dried at room temperature for 60 hours, ground using a soil homogenizer, and passed through a 1 mm sieve. Total salt content and individual ion concentrations (HCO_3^- , Cl^- , SO_4^{2-}) were determined from 1:5 soil:water aqueous extracts following standard Central Asian soil science methodology (Arinushkina 1970); salt content is expressed as a percentage of dry soil mass (dry residue, %). For a subset of layers, salinity was additionally assessed from the electrical conductivity of the saturation extract (ECe). Minor discrepancies between total salt content and the sum of measured ion concentrations (generally <5%) are attributed to unmeasured soluble constituents such as K^+ , SiO_2 and NO_3^- in the aqueous extract.

Salt reserves in the soil (A , kg/m^2) were calculated using the formula $A = h \cdot v \cdot B / 10$, where h is layer thickness (cm), v is layer bulk density (g/cm^3), and B is the total salt content (dry residue, %). Salinity degree was classified into five groups non-saline, weakly saline, medium saline, strongly saline, and very strongly saline (including solonchaks) following the threshold system used in the source explanatory note for the surveyed district. For general reference, a widely used classification of saline soils in Russian and Central Asian soil science distinguishes salinity degree by total salt content (%) separately for each chemistry type; for the chloride-sulfate type that dominates in the tracts studied here, the commonly cited thresholds are: non-saline <0.3%, weakly saline 0.3-1.0%, medium saline 1.0-2.0%, strongly saline 2.0-3.0%, and very strongly saline (solonchak) >3.0%.

As shown in Table 2 below, the mean dry residue content of layers classified in the source materials as strongly and very strongly saline (1.62% and 2.55%, respectively) exceeds these general chloride-sulfate thresholds, indicating that the classification actually applied in the source explanatory note uses somewhat higher boundaries appropriate to the specific salt regime of the lower Amudarya. This modified classification, based on salt reserves rather than dry residue content alone, follows Komilov and Akhmedov (1998). For the S. Kalandarov irrigation tract, selected as a detailed case example, salinity was determined for every sampled layer (0-30, 30-70 and 70-100 cm) either by full water-extract analysis (206 layer samples, i.e. about 67% of all analyzed layers) or, for the remaining layers, by ECe (112 layer samples).

Spatial distribution maps of soil salinity and salt reserves for each irrigation tract were generated in ArcGIS 10.8 (Esri Inc., Redlands, CA, USA) using the Inverse Distance Weighting (IDW) deterministic spatial interpolation technique based on georeferenced point data from soil profiles and boreholes at a scale of 1:10 000. The IDW algorithm was applied using a standard power parameter ($p = 2$) and a variable search radius to estimate continuous spatial surfaces of total salt content and salinity classes. This method assumes that the salinization level of unmeasured locations is influenced more strongly

by nearby sampled profiles than by more distant points, accurately reflecting the localized hydrochemical heterogeneity of the study area. As a representative case, the resulting spatial interpolation map of the S. Kalandarov irrigation tract is presented in Figure 3, illustrating distinct salinity contour zones.

On the basis of the field and analytical data, the areas of land by salinity degree were calculated for each irrigation tract of the district and are summarized in Table 1 and Figure 2.

Differences in mean dry residue content and salt reserves among the five salinity-degree categories in the S. Kalandarov tract (Table 2) were tested by one-way ANOVA computed from the reported category-level summary statistics (mean, SD, n; total n = 206 layers). Because sample sizes and standard deviations differed substantially among categories including one category with only three observations the standard (Fisher) ANOVA was supplemented with Welch's ANOVA, which does not assume equal variances and is therefore more robust under this kind of heterogeneity. Statistical significance was set at $p < 0.05$. Effect size was expressed as eta-squared (η^2). Calculations were performed in Python 3 using SciPy 1.17.

RESULTS AND DISCUSSION

In the Urgench district, 14 irrigation tracts were surveyed, with a total area of 23829.3 ha (Table 1). Non-saline soils occupy 7993.9 ha, or 33.5% of the surveyed area. Weakly saline soils account for 9348.1 ha (39.2%), medium saline soils for 3897.2 ha (16.4%), strongly saline soils for 1718.4 ha (7.2%), and very strongly saline soils for 871.7 ha (3.7%). The total area of saline soils is 15,835.4 ha, or 66.5% of the surveyed territory.

Table 1. Distribution of irrigated land of the Urgench district by soil salinity degree (by irrigation tract)

Irrigation tract	Area, ha	Non-saline		Weak		Medium		Strong		Very strong		Saline total	
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
J.Manguberdi	1718.8	676.6	39.4	483.3	28.1	253.4	14.7	196.9	11.5	108.6	6.3	1042.2	60.6
Guliston	1660.0	833.2	50.2	447.5	27.0	307.7	18.5	71.6	4.3			826.8	49.8
Begavot	1465.3	746.4	50.9	501.2	34.2	144.8	9.9	72.9	5.0			718.9	49.1
Durmon	1338.4	434.4	32.5	483.3	36.1	271.5	20.3	89.5	6.7	59.7	4.5	904.0	67.5
S.Kalandarov	1902.7	615.4	32.3	841.3	44.2	199.1	10.5	195.6	10.3	51.3	2.7	1287.3	67.7
Urgench	1331.6	470.6	35.3	232.7	17.5	416.3	31.3	107.4	8.1	104.6	7.9	861.0	64.7
Istiqbol	2618.3	1201.7	45.9	1020.3	39.0	217.2	8.3	71.6	2.7	107.5	4.1	1416.6	54.1
R.Goipov	134.6	120.7	89.7	13.9	10.3							13.9	10.3
A.Temur	2166.8	307.7	14.2	1100.5	50.8	524.9	24.2	143.2	6.6	90.5	4.2	1859.1	85.8
Okhunboboev	1980.3	597.3	30.2	901.7	45.5	362.0	18.3	53.7	2.7	65.6	3.3	1383.0	69.8
Pakhtakor	1947.5	380.1	19.5	1031.2	52.9	367.7	18.9	143.2	7.4	25.3	1.3	1567.4	80.5
Oq Oltin	2849.6	1122.2	39.4	1145.6	40.2	271.5	9.5	161.1	5.7	149.2	5.2	1727.4	60.6
M.Khorazmiy	1127.1	126.7	11.2	537.0	47.6	235.3	20.9	196.9	17.5	31.2	2.8	1000.4	88.8
G' alaba	1588.3	360.9	22.7	608.6	38.3	325.8	20.5	214.8	13.5	78.2	4.9	1227.4	77.3

Irrigation tract	Area, ha	Non-saline		Weak		Medium		Strong		Very strong		Saline total	
		ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Total	23829.3	7993.9	33.5	9348.1	39.2	3897.2	16.4	1718.4	7.2	871.7	3.7	15835.4	66.5

The most salinized irrigation tracts are M. Khorazmiy (88.8% saline land), A. Temur (85.8%) and Pakhtakor (80.5%); the least salinized are R. Goipov (10.3% saline) and Begavot (49.1%).

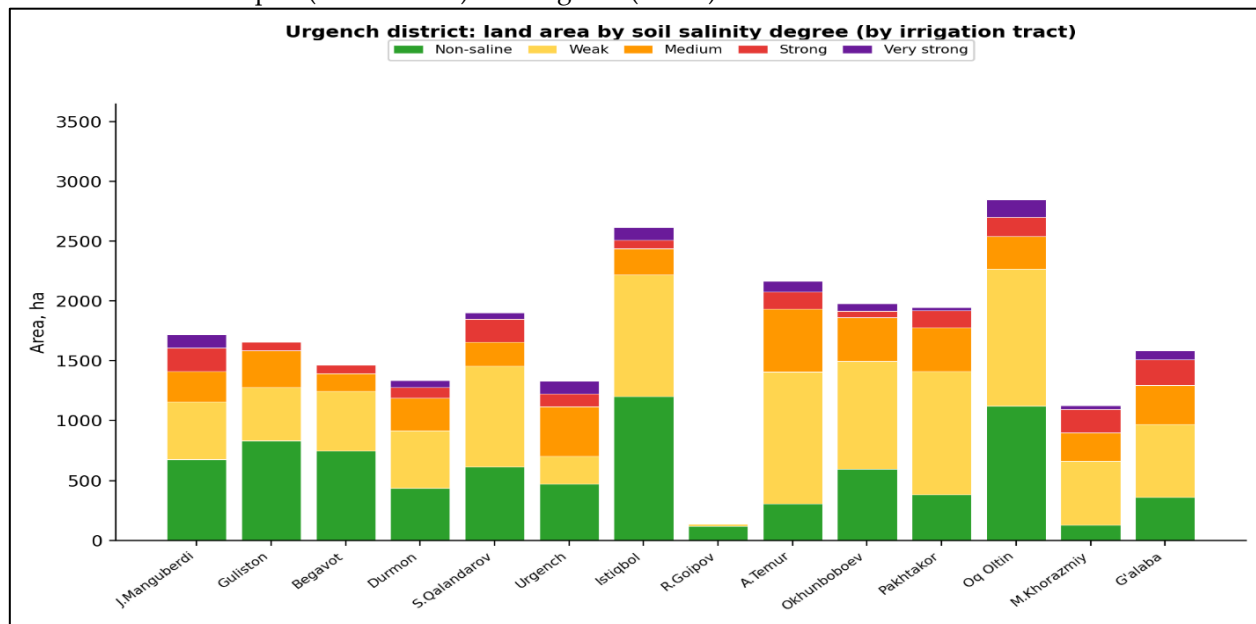


Fig. 2. Land areas of the Urgench district by soil salinity degree (by irrigation tract), compiled in ArcGIS 10.8 by interpolation from the data of Table 1.

As an example, Figure 3 shows the soil salinity map of the S. Kalandarov irrigation tract, compiled in ArcGIS 10.8 by spatial interpolation. On the map, yellow indicates weakly saline, orange medium saline, pink strongly saline, and violet very strongly saline (including solonchak) soil contours.

Fig. 3. Soil salinity map of the S. Kalandarov irrigation tract (Urgench district), compiled by the IDW interpolation method in ArcGIS 10.8.

To validate the cartogram-based area statistics at the profile level, all sampled layers (0-30, 30-70 and 70-100 cm) of the S.

Kalandarov irrigation tract were additionally examined by

full water-extract chemical analysis or by E_{ce} measurement (Institute of Soil Science and Agrochemical Research 2026b). Of the samples with a full water-extract analysis, the chloride-sulfate type ($Cl^- > SO_4^{2-}$ dominance pattern typical of the lower



Amudaryya) accounted for 95.1% of layers, with the sulfate type making up the remainder (4.9%). Average dry residue content, chloride and sulfate percentages, and salt reserves (0-100 cm) by salinity degree are summarized in Table 2.

Table 2. Average salt content and salt reserves by salinity degree in the S. Kalandarov irrigation tract (Urgench district), based on water-extract analysis of individual soil layers (n = 206 analyzed layers)

Salinity degree	n	Dry residue, % (mean±SD)	Cl ⁻ , % (mean)	SO ₄ ²⁻ , % (mean)	Salt reserve, t/ha (mean±SD)
Non-saline	67	0.096±0.074	0.010	0.045	4.15±0.95
Weak	89	0.223±0.105	0.024	0.108	10.12±4.15
Medium	28	0.579±0.212	0.081	0.259	26.35±9.97
Strong	19	1.616±0.181	0.233	0.706	76.02±13.85
Very strong	3	2.553±0.265	0.337	1.631	119.27±25.19

The data in Table 2 show a consistent, monotonic increase in dry residue content and salt reserves from non-saline to very strongly saline categories, confirming the internal consistency of the salinity-degree classification applied. Averaged over all analyzed layers, the S. Kalandarov tract shows a mean dry residue content of 0.392% and a mean salt reserve of 18.2 t/ha in the 0-100 cm layer, with values increasing consistently across salinity classes from 0.096% and 4.15 t/ha for non-saline layers to 2.553% and 119.27 t/ha for very strongly saline layers. This profile-level result provides independent chemical confirmation of the cartogram-based distribution of salinity degrees shown in Table 1: the non-saline category accounted for 32.4% of the analyzed S. Kalandarov layers, broadly consistent with the 33.5% non-saline share found at the tract-area level district-wide.

The differences among the five salinity-degree categories were statistically significant for both indicators. For dry residue content, Welch's ANOVA the primary test, given the unequal variances and unequal group sizes among categories gave $F(4, 13.5) = 353.9$, $p < 0.001$; the standard ANOVA gave a consistent result, $F(4, 201) = 795.8$, $p < 0.001$, with salinity degree accounting for the great majority of the variance in dry residue content ($\eta^2 = 0.94$). Salt reserves showed the same pattern (standard ANOVA: $F(4, 201) = 643.8$, $p < 0.001$; $\eta^2 = 0.93$). These results confirm, at a high level of statistical confidence, that the five-category salinity classification used in the source explanatory note corresponds to genuinely distinct, non-overlapping levels of soil salt content and salt reserve in the S. Kalandarov tract, rather than an arbitrary subdivision of a continuous gradient.

More broadly across the district, the explanatory note indicates that the dominant salinity chemistry types are sulfate, chloride-sulfate and sulfate-chloride, more rarely chloride-sulfate-magnesium, which is typical of the lower Amudaryya as a whole (Pankova et al. 1996) and is related to the composition of river and collector-drainage waters of the region (Chembarisov et al. 2013) consistent with the profile-level chloride-sulfate dominance quantified above for the S.Kalandarov tract. No qualitative difference in salinity chemistry type was found among the irrigation tracts of the district; the differences are predominantly quantitative, both in area (Table 1) and in salt content per profile (Table 2).

The differences in salinization degree among the irrigation tracts of the Urgench district appear to be related primarily to their position within the Amudaryya delta and their distance from the desiccated bed of the Aral Sea. Tracts situated closer to the more recent part of the delta are subject to greater aeolian salt transport from the desiccated seabed under the region's strong winds, a mechanism described in detail in the literature (Micklin 2007; Qadir et al. 2009). Tracts located further from the desiccated seabed, in the older part of the delta, show comparatively lower exposure to this factor, given a broadly similar depth of groundwater occurrence across the district (1.0-2.5 m).

An additional factor behind the observed differences among irrigation tracts is likely the condition of the collector-drainage network: as noted for the Khorezm oasis generally (Akhmedov and Ruzmetov 2003; Ruzmetov et al. 2019), irrigation tracts with a well-functioning collector network and adequate groundwater outflow show a substantially lower degree of salinization than poorly drained irrigation tracts. This is consistent with the pronounced contrast observed within the district itself: R.Goipov, with only 10.3% saline land, and Begavot (49.1% saline) contrast sharply with heavily salinized tracts such as M.Khorazmiy (88.8%), A.Temur (85.8%) and Pakhtakor (80.5%). Confirming the role of drainage condition conclusively will require additional data on the technical state of the collector-drainage network for each irrigation tract.

The results obtained are consistent with the general pattern noted for the lower Amudaryya as a whole (Pankova 2016) — an intensification of soil salinization with proximity to the Aral Sea and a decrease with distance from it upstream — which confirms the need for differentiated planning of the volumes and timing of land leaching across the irrigation tracts of the district.

CONCLUSION

1. According to the 2026 large-scale (1:10 000) soil salt survey, the irrigated soils of the Urgench district of the Khorezm region show considerable spatial heterogeneity in salinization: saline land accounts for 66.5% of the surveyed area (15,835.4 ha of 23,829.3 ha), while non-saline soils occupy 33.5%.

2. Among saline soils, weakly saline land predominates (39.2%), followed by medium saline (16.4%), strongly saline (7.2%), and very strongly saline including solonchaks (3.7%); together, strongly and very strongly saline soils account for 10.9% of the surveyed area.

3. The dominant salinity chemistry types are sulfate, chloride-sulfate and sulfate-chloride, typical of the lower Amudarya.

4. The differences in salinization degree among irrigation tracts are attributed to their position within the modern and ancient parts of the Amudarya delta, proximity to the desiccated bed of the Aral Sea, and, presumably, the condition of the collector-drainage network; additional data are needed to clarify the role of the latter factor.

5. Full water-extract chemical analysis of the S. Kalandarov irrigation tract independently confirms the cartogram-based findings at the profile level: dry residue content and salt reserves increase consistently from non-saline (0.096%; 4.15 t/ha) to very strongly saline (2.553%; 119.27 t/ha) categories, and the chloride-sulfate chemistry type dominates (95.1% of analyzed layers). The differences among the five salinity-degree categories are statistically significant and account for the great majority of the observed variance (Welch's ANOVA, dry residue: $F(4, 13.5) = 353.9$, $p < 0.001$, $\eta^2 = 0.94$; salt reserve: $F(4, 201) = 643.8$, $p < 0.001$, $\eta^2 = 0.93$), confirming that the salinity classification applied corresponds to genuinely distinct salt-content levels rather than an arbitrary gradient subdivision.

6. The materials obtained can be used for differentiated planning of the volumes, timing and frequency of leaching of saline land across the irrigation tracts of the Urgench district.

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