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ANTHROPOGENIC IMPACT ON THE SOIL SALINIZATION AND ITS MANAGEMENT IN IRRIGATED AREAS OF THE MUGHAN PLAINS, AZERBAIJAN

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SUMMARY

The Mughan Plain irrigation has existed since ancient times in Azerbaijan, but no known organized and sufficient data are available on such activity. The presented study aimed to assemble the detailed information on the processes that occurred in the irrigated and raw soils of the Mughan Plain and quantify a system of complex measures to improve degraded soils resulting from anthropogenic effects in the recent era. Research showed that in Mughan Plain, the non-salinized soils were predominant in areas with a better collector-drainage system with proper agrotechnical and land reclamation measures. In those areas, the salts varied between 0.108% and 0.250%, while in some parts, the saline soils also appear. Weakly salined soils were also evident in satisfactory areas of collector-drainage systems, and the level of salts ranged between 0.26% and 0.50%, with the chemical composition as chloride-sulfate, sulfate, and sulfate-chlorine. Moderately saline soils mainly have a distribution in municipal lands and in the areas used for cotton crop up to some extent.

Keywords: Anthropogenic effects, granulometric composition, meadow-gray soils, alluvial-meadow soil, saline soils, groundwater and mineralization, land reclamation measures

Key findings: Anthropogenic effects caused variations in the research area soil, which led to variations in the humus, total nitrogen, and phosphorus content. In an investigation of the 40-year period, the absorbed bases and salts in meadow-gray and alluvial-meadow soils and an increase and decrease in their content were notable.

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INTRODUCTION

Recent research revealed that in the Kur-Araz Lowland, improper use of agricultural lands, ineffective operation of collector-drainage systems, and non-compliance with irrigation norms have led to a rise in groundwater levels and varying degrees of soil salinization (Aliyev, 2000). This, eventually, led to a considerable deterioration in the soils' ecological and reclamation status and an intensification of desertification processes in arid areas. Improving the soil's reclamation status, which has been subjected to varying degrees of salinization and used in crop rotation, has emerged as crucial. Past studies enunciated soils exposed to salinization reduce the productivity of agricultural crops, resulting in 18%–26% crop losses (Azizov, 2006; Mustafayev, 2006, 2014a, b; Volobuyev, 1965).

Soil salinization has considerable association with crop production, including the deterioration of nutrients (through nitrogen absorption processes) and the decline in the development of crop plants (Zhapayev *et al.,* 2023). About 635,800 hectares of irrigated land (43.8%) were predominantly saline to varying degrees, wherein 429,800 hectares (67.60%) were slightly saline, 139,800 hectares (21.99%) were moderately saline, and about 66,200 hectares (10.41%) were severely saline in the Azerbaijan (Volobuyev, 1967; Mammadov, 2007, Mustafayev, 2020). For salinization, the soils of the Kur-Araz Lowland emerged as most sensitive, especially for the soils of the Mughan Plain. Various efforts have been ongoing through protection and restoration measures in the territory's soils over the past decades.

MATERIALS AND METHODS

The aqueous extract of the soils and mineralization of the groundwater when determined used the generally accepted methodology of Arinushkina (1970): CO_3^- and HCO_3^- ions by titration with sulfuric acid; CI^- by Mohr's argentometric method; the sum of Ca^{+2} and Mg^{+2} ions by trilonometric method; and SO_4^{-2} by volume and Na^+ + K^+ by the difference of the sum of cations and anions. The soil bulk density detection engaged the method of Kachinsky; the specific gravity employed the method of Dolgov; particle size distribution used the pipette method with the treatment of 1.0 NaCI; humus utilized the method of Tyurin; and the pH was by the potentiometric titration. The absorbed bases composition underwent determination by extracting absorbed Ca and Mg from the soil using the method of Ivanov, and volumetric sodium was according to Gedroits. Moreover, assessing the soils' salt content and types succeeded (Figure 1) (Volobuyev, 1965).

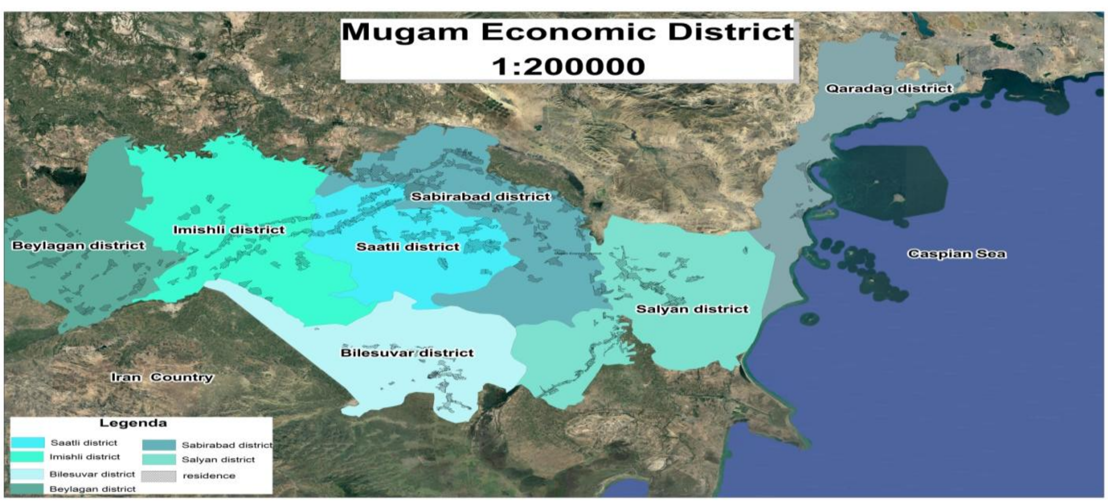

Figure 1. Mugam Economic District.

RESULTS AND DISCUSSION

In the Mughan Plain, meadow-gray soils are widespread, spreading over an area of 3,855.02 ha in the central, northern, and northeastern parts of the territory. Meadow-gray soils have medium humus, ranging from 1.64% to 3.67% in the upper layers and from 0.69% to 1.21% in the one-meter soil layer. Accordingly, the total nitrogen content fluctuates between 0.15% and 0.26% in the upper layer and 0.12% and 0.15% in the middle layers. The absorption capacity of these soils ranged from 21.30 to 39.00 mg-eq in the upper layers, with a decrease observed toward the lower layers. The absorbed Mg^{2+} cations' increase was up to 16.5 mg-eq, and the absorbed Na+ cations was up to 4.1 mg-eq (10.5%). The composition of absorbed bases revealed that weak and moderately saline variants of soils were also widespread in that area. The pH indicator appeared to be weakly alkaline (7.7–7.8); however, it gradually increased with the depth in the meadow-gray soil profile. The carbonate content varies between 5.98% and 13.51% in the upper layers, and an enhancement (15.6%) was evident in the illuvial layer, while a decrease (9.38%) occurs again toward the depth.

According to the granulometric composition, meadow-gray soils were clayey, the particles (<0.002 mm) in the upper layers were 67%–81%, the signs of clay formation increased further toward the lower layers (90.44%), and the particles (0.05–0.002 mm) were 25%–38%. Hygroscopic moisture indicators varied between 4.2% and 5.2%. In alluvial-meadow soils, the humus as determined ranged from 1.51% to 2.81% in the upper layers and from 0.42% to 0.83% in the soil layers below one meter. Similarly, the detected total nitrogen occurred to be 0.14%–0.21% in the upper layer and 0.04% in the one-meter layer (Table 1). The supply of absorbed bases for alluvial-meadow soils was moderate in the soil (23.70–32.70 mg-eq). Alluvial-meadow soils were visibly moderately carbonated, constituting 7.51%–10.40% in the upper layers, while in irrigated soils, the carbonates accumulated more in the illuvial layer (11.4%–14.15%). Alluvial-meadow soils were heavy loamy and clayey for granulometric composition, with a physical clay content of 47.25%–71.72%. The clay content decreases along the profile, varying between 40% and 63%. The amount of salt particles manifested to be 19.23%–37.80% in the upper layers, and a decline was prominent toward the lower layers (13%–33%).

The Mughan Plain is one of the regions where anthropogenic impact was constantly increasing, and the problem of soil salinization is of great importance. The salt content and their composition in the meadow-gray and alluvial-meadow soils underwent studies in the presented research (Table 2). In the meadow-gray soils, the salts ranged from 0.264% to 1.254%, and the observed salt increase was along the profile in the half-meter layer (0.281%–1.506%). For meadow-gray soils planted with cereal crops, the salts had ranges from 0.23% to 0.26%, while in raw soils, the salts were maximum (1.25%–1.46%). In alluvial-meadow soils, the salts in the upper layer of the profile were 0.202%–0.651%, and their minimum content resulted in the half-meter layer (0.187%–0.453%). In the alluvial-meadow soils under vegetables, the salt content ranged from 0.356% to 0.363%, in cereals (0.202%–0.220%), and under alfalfa (0.472%–0.651%).

Past research showed the Cl^- and SO_4^{-2} ions predominate in the soils of the Mughan Plain, including in areas with high salinity (Alimov, 2001). According to present analyses, in the meadow-gray soils, the Cl^- content varied from 0.009% to 0.068%, while in alluvial-meadow soils, it was from 0.021% to 0.228%. The obtained SO_4^{-2} ions ranged from 0.102% to 0.795% in meadow-gray soils and 0.042%–0.192% in alluvial-meadow soils (Huseynova, 2012, 2016a, b, c; Mustafayev, 2014a, b, 2020). In the non-saline soils of the Mughan Plain, the Cl^- ion content varied between 0.009% and 0.058%, and the amount of SO_4^{-2} ions diverged between 0.011% and 0.085%. In the weakly salinized soils of the area, the Cl^- ions ranged from 0.008% to 0.462%, and the SO_4^{-2} ions' range was 0.047%–0.422%. As salinization increases,

Table 1. Fertility indicators of meadow-gray and alluvial-meadow soils of the Mughan Plain.

Sections	Depth (cm)	Humus (%)	Total nitrogen content (%)	Hygroscopic moisture (%)	pH	Absorbed bases (mg.eq in 100 g soil)			Absorbed bases (mg.eq in 100 g soil)	CO_2 (%)	$CaCO_3$ (%)	Granulometric soil texture (%)	
						Ca	Mg	Na				0.05-0.002 mm	< 0.002 Mm
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gray-meadow soils													
1	0-15	1.64	0.15	4.20	7.6	13.20	6.15	1.95	21.30	5.92	13.51	25.87	67.15
	15-29	1.91	0.14	4.19	7.7	12.60	7.70	1.90	22.20	5.80	13.42	28.13	72.32
	29-63	1.51	0.12	4.12	7.7	10.75	8.00	2.15	20.90	6.16	14.18	25.03	66.35
	63-92	1.23	0.11	4.10	7.6					6.50	14.75	27.47	70.16
	92-122	0.69	0.07	4.14	7.7					6.56	14.91	29.13	73.42
2	0-13	2.87	0.21	5.24	7.7	18.40	16.50	4.10	39.00	4.38	9.82	32.96	78.43
	13-32	2.38	0.19	5.21	7.6	18.50	16.10	3.90	38.50	2.77	6.25	40.15	88.65
	32-61	1.31	0.15	5.19	7.7	22.15	12.20	3.75	38.10	3.25	7.32	40.03	88.14
	61-86	1.15	0.12	4.18	7.7					6.12	13.91	44.54	89.44
	86-105	0.59	0.09	3.96	7.8					5.54	12.85	41.38	74.50
3	0-16	1.71	0.16	4.23	7.7	16.50	5.30	2.15	23.95	5.58	12.55	27.34	62.10
	16-31	1.58	0.15	4.15	7.8	15.70	11.20	2.45	29.35	5.81	13.23	29.77	66.86
	31-57	1.38	0.12	4.07	7.7	15.30	12.30	2.30	29.90	6.43	14.65	28.50	67.65
	57-90	1.15	0.11	4.13	7.6					6.28	14.38	32.21	70.82
	90-104	0.79	0.11	4.04	7.7					6.25	14.36	40.32	84.16
	104-115	0.41	0.09	4.05	7.6					5.21	11.90	38.65	77.54
4	0-17	2.94	0.22	4.82	7.7	16.10	5.50	2.70	24.30	3.77	8.55	37.90	81.14
	17-28	2.25	0.18	4.71	7.8	15.90	7.30	2.85	26.05	3.51	8.26	43.57	87.15
	28-53	1.67	0.15	4.73	7.9	14.60	7.90	3.15	25.65	5.44	12.36	44.01	87.82
	53-79	1.57	0.15	3.90	7.9					4.85	10.97	45.95	90.44
	79-101	0.92	0.12	4.31	7.8					5.09	11.47	44.73	87.20
	101-117	0.71	0.10	4.10	7.6					4.17	9.38	44.98	88.55
5	0-14	2.48	0.20	4.75	7.7	15.40	7.20	2.75	25.35	2.65	5.98	38.66	72.42
	14-27	1.69	0.17	4.53	7.8	12.80	10.60	3.10	26.50	4.18	9.25	37.90	72.16
	27-52	1.30	0.12	4.30	7.9	10.30	8.80	3.15	22.25	5.51	12.35	38.12	75.62
	52-67	0.84	0.09	4.12	7.8					6.14	13.97	40.05	81.43
	67-106	0.69	0.07	3.96	8.0					5.15	11.74	38.81	76.61
	106-132	0.54	0.07	3.61	7.9					5.19	11.78	36.43	75.45
6	0-13	3.67	0.26	4.31	7.8	17.50	11.70	2.45	31.65	5.96	13.42	32.45	67.10
	13-27	2.90	0.22	4.16	7.7	12.30	14.70	2.30	29.30	6.59	14.85	31.29	63.58
	27-47	2.47	0.18	4.07	7.6	14.10	12.00	2.10	28.20	6.81	15.60	36.18	71.39
	47-71	1.93	0.15	4.01	7.7	14.70	11.20	2.00	27.90	6.52	14.81	35.88	69.27
	71-97	1.21	0.13	3.98	7.7					6.69	14.95	35.12	68.10
	97-118	0.81	0.11	3.75	7.8					5.58	12.69	39.90	78.62
Alluvial-meadow soils													
7	0-17	1.61	0.15	4.87	7.5	21.95	8.20	2.55	32.70	4.45	10.21	37.80	71.72
	17-31	1.35	0.14	4.75	7.6	15.30	5.10	2.15	22.55	4.18	9.39	32.17	62.10
	31-53	1.14	0.09	4.34	7.7	16.90	9.50	2.20	28.60	5.00	11.40	32.84	62.57
	53-89	0.95	0.07	4.10	7.6					3.91	8.87	25.36	54.80
	89-102	0.71	0.04	3.95	7.7					4.65	10.55	30.44	61.26
	102-141	0.42	-	4.14	7.7					3.97	8.98	32.15	63.07
8	0-23	1.51	0.14	4.58	7.6	13.50	7.10	3.10	23.70	4.55	10.40	19.23	47.25
	22-60	1.30	0.13	4.71	7.7	16.00	8.20	3.05	27.25	3.69	8.35	21.36	50.72
	60-85	1.00	0.10	4.29	7.8					4.14	9.58	13.88	40.56
	85-115	0.83	0.09	3.94	7.9					4.43	10.25	13.05	40.10
9	0-29	2.68	0.17	4.45	7.7	16.20	7.50	2.00	25.70	5.23	12.15	29.18	65.40
	29-51	2.41	0.14	4.43	7.6	15.80	4.60	1.95	22.35	6.03	13.01	27.03	61.88
	51-64	1.55	0.13	4.28	7.6					6.16	14.15	23.55	58.72
	64-97	1.10	0.10	4.40	7.7					5.62	12.06	23.41	58.27
	97-112	0.75	0.07	4.37	7.6					4.43	10.61	25.16	59.65
10	0-27	2.81	0.21	5.19	7.7	18.80	6.10	3.20	28.10	3.88	7.51	32.10	71.05
	27-53	2.37	0.15	5.16	7.8	18.20	11.50	2.85	32.55	4.72	9.29	31.15	70.90
	53-78	1.63	0.12	4.97	7.8					5.52	11.63	34.52	76.10
	78-94	1.18	0.11	4.86	7.6					4.60	10.90	30.88	65.23
	94-116	0.81	0.08	5.03	7.6					3.62	8.97	32.40	68. 07
	116-123	0.67	0.05	5.24	7.7					3.01	7.21	33.61	70.16

Table 2. Fertility indicators of meadow-gray and alluvial-meadow soils of the Mughan Plain.

Sections	Depth (cm)	CO_2		HCO_3		SO_4		Cl		Dry residue (%)
		mg,eq	%	mg.eq	%	mg.eq	%	mg.eq	%	
1	0-15	yox	yox	1.41	0.086	2.37	0.112	1.01	0.036	0.310
	15-29	yox	yox	1.05	0.064	3.44	0.163	1.43	0.050	0.305
	29-63	yox	yox	1.47	0.089	3.18	0.152	0.79	0.025	0.309
	63-92	yox	yox	1.10	0.067	2.43	0.115	0.82	0.028	0.315
	92-122	yox	yox	1.15	0.070	2.12	0.100	0.81	0.026	0.316
3	0-16	yox	yox	0.67	0.042	2.09	0.102	0.26	0.009	0.264
	16-31	yox	yox	1.12	0.069	1.03	0.049	0.51	0.019	0.226
	31-57	yox	yox	0.63	0.042	1.36	0.065	0.39	0.015	0.281
	57-90	yox	yox	0.74	0.047	0.97	0.048	0.52	0.016	0.196
	90-104	yox	yox	1.21	0.071	1.12	0.055	0.36	0.014	0.248
	104-115	yox	yox	0.62	0.039	1.58	0.079	0.51	0.017	0.239
4	0-17	yox	yox	0.26	0.017	16.49	0.795	1.94	0.068	1.254
	17-28	yox	yox	0.28	0.019	15.76	0.758	1.18	0.043	1.128
	28-53	yox	yox	0.29	0.019	17.13	0.861	4.55	0.164	1.506
	53-79	yox	yox	0.21	0.013	16.55	0.796	3.02	0.109	1.435
	79-101	yox	yox	0.20	0.012	9.18	0.445	0.72	0.028	0.681
	101-117	yox	yox	0.17	0.011	15.24	0.710	2.35	0.086	1.462
8	0-23	yox	yox	0.50	0.030	0.81	0.042	3.61	0.126	0.356
	22-60	yox	yox	0.94	0.056	1.06	0.054	0.47	0.019	0.251
	60-85	yox	yox	1.13	0.068	0.65	0.032	0.28	0.012	0.187
	85-115	yox	yox	2.01	0.120	1.82	0.085	0.42	0.018	0.363
9	0-29	yox	yox	0.51	0.032	2.25	0.109	0.57	0.021	0.202
	29-51	yox	yox	0.46	0.027	2.15	0.103	0.46	0.017	0.201
	51-64	yox	yox	0.61	0.036	3.41	0.167	0.43	0.016	0.285
	64-97	yox	yox	0.58	0.035	2.74	0.130	0.85	0.030	0.421
	97-112	yox	yox	0.57	0.034	3.51	0.164	0.64	0.021	0.220
10	0-27	yox	yox	0.37	0.022	3.97	0.192	6.39	0.228	0.651
	27-53	yox	yox	0.38	0.024	5.53	0.267	7.01	0.250	0.774
	53-78	yox	yox	0.34	0.021	2.09	0.103	6.05	0.215	0.453
	78-94	yox	yox	0.42	0.028	2.51	0.122	7.52	0.269	0.621
	94-116	yox	yox	0.56	0.034	1.94	0.095	4.51	0.162	0.365
	116-123	yox	yox	0.40	0.023	2.17	0.108	6.03	0.215	0.472

these ions also increase, which in turn causes a 1,000 to 1,500 kg/ha decrease in the productivity of crops cultivated in these soils (Azizov, 2006; Huseynova, 2012, 2016a, 2016b, 2016c; Mustafayev, 2014a, 2014b, 2020).

Salinization was notable in some parts of the territory where the salts varied between 0.108% and 0.250%. In the studied areas, the dry residue content in soils with the highest crop yield was 0.16%–0.25%; in well-fertile soils, it was 0.26%–0.46%; in medium-fertile soils, it was 0.50%–0.85%); in low-fertile soils, it was 0.85%–1.25%; and in the areas devoid of vegetation and with very sparse vegetation, it ranged from 1.35% to 1.86%) (Huseynova, 2016a, b, c; Mustafayev, 2020). Factually, the groundwater depth and mineralization indicators are exceptionally important in soils with a high risk of salinization. According to the results, shown in Table 3, in the non-saline meadow-gray soils of the Mughan Plain, the salts in the area with a groundwater depth of three meters were the lowest (0.128%), and the minerality of groundwater was 1.2 g/l. In these soils, a rise in the groundwater level by half a meter led to an increase in the salt content by two times, and in minerality, by 2.3 times. With a 40-cm rise in groundwater in weakly salined soils, the salts reached 0.464%, and the minerality of groundwater increased by 1.6 times. In

Table 3. The salt content, depth, and minerality of groundwater in the meadow-gray soils of the Mughan Plain.

Soils	Salts content (%)	Groundwater depth (m)	Groundwater minerality (g/l)
Unsalted	0.128	3.00	1.2
	0.164	2.90	1.5
	0.210	2.78	1.7
	0.219	2.63	2.6
	0.225	2.57	2.7
	0.249	2.54	2.8
Weakly salted	0.267	2.60	2.8
	0.359	2.55	3.1
	0.411	2.45	3.6
	0.445	2.28	4.4
	0.464	2.20	4.6
Medium salted	0.531	2.45	2.6
	0.678	2.42	3.4
	0.761	2.40	3.8
	0.886	2.33	4.7
	0.948	2.25	5.1
Severely salted	1.330	2.20	4.4
	1.512	2.13	4.8
	1.635	2.10	5.1
	1.651	1.95	7.8
	1.816	1.75	8.4
	1.837	1.70	8.5

moderately saline soils, a 20-cm rise in groundwater boosted the salt content from 0.531% to 0.948% and increased the minerality of groundwater by two times. In highly salined soils, the groundwater appeared very close to the surface, and in the area where the groundwater depth was 1.7 meters, the salt content was 1.837%, and the groundwater's mineral content has almost doubled.

According to the recent research, the 33,002 ha (52.71%) of irrigated soils in the Sabirabad Region were not saline, 36.43% were weakly saline, 8.54% (5,348 ha) were moderately saline, and 1,445 ha (4.38%) were highly saline (Table 4, Figure 1) (Huseynova, 2016a, b, c; Mustafayev, 2014a, b, 2020). These indicators vary in District Saatly as follows: 30.51% of the 47,529 ha of irrigated land was not saline, while slightly saline soils account for more than half of the area (55.05%). The 13.16% of the area was moderately saline, 602 ha (1.27%) were severely and extremely severely saline, becoming completely unusable. The study determined 60% of the irrigated arable lands in the District Salyan were not saline, with 40% exposed to varying degrees of salinization. Of these, 17.59% were weakly saline, and 13.58% were medium saline. Severely and very severely saline lands constitute about 4,000 ha (8.9%) of the area. According to the indicators reflected in Table 4, for District Lmishli, 41.1% of the irrigated lands were not saline in the said area, 22.16% were weakly saline, and 12.38% were medium saline. The area rendered unusable due to severe and highly severe salinization was massive and amounted to 10,605 ha (24.35%). Only 9,741 ha (25.03%) of the 38,909 ha of irrigated lands of District Bilasuvar were nonsaline. In the studied area, the most widespread were the weakly saline soils (43.81%). Medium saline soils constitute 25.37%, while severely and very severely saline soils were the least widespread, covering around 2,250 ha (5.78%) (Figure 2) (Mustafayev, 2006, 2020).

Table 4. Salinity levels of Mugan Plain soils.

Soils (ha) / Districts	İrrigated	Unsalted	Weakly salted	Medium salted	Severely and very severely salted
Sabirabad	62604	33002	22809	5348	1445
Saatly	47529	14504	26167	6256	602
Salyan	44905	26905	7900	6100	4000
Lmishli	43551	17906	9650	5390	10605
Bilasuvar	38909	9741	17045	9873	2250

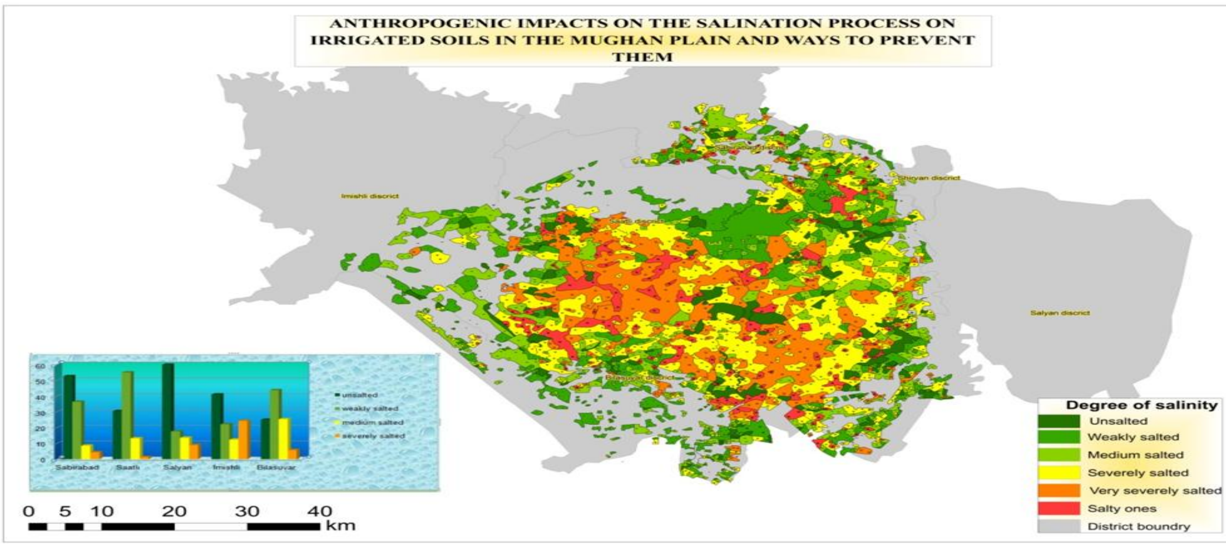

Figure 2. Anthropogenic impact on the salination process in the irrigated soils of the Mughan Plain and measures to prevent them.

By comparing the different regions, the most satisfactory situation for the saline soils was outstanding in the Sabirabad District (52.71%), while the weakly saline soils were the most widespread in the Saatly District (26,167 ha). Medium saline soils were the most common in the District of Bilasuvar (9,873 ha) (Table 4), and the soils exposed to severe and very severe salinization becoming unusable were most common in the District of Lmishli (24.35%) (Figure 1). The research conducted in the Mugan-Salyan massif had appropriate areas determined by regions, considering the depth of groundwater (Mustafayev, 2014a, b). According to the results, as provided in Table 5, lands with favorable land reclamation (groundwater depth of 3.0–5.0 m) were the most widespread in the territory of the Lmishli District (34,000 ha), followed by lands of the District of Sabirabad (6,261 ha), and these types of lands were not evident in the Districts of Salyan and Bilasuvar. Lands with groundwater depth of 2.0–3.0 m were the most typical in the Bilasuvar District (17,835 ha), and lands with groundwater depth of 1.5–2.0 m were the most usual in the District of Sabirabad.

The most unfavorable land reclamation conditions (groundwater less than 1.0 m) resulted in the territories of the Districts of Sabirabad and Salyan (14,896 and 10,200 ha, respectively) (Figure 2). In Sabirabad District, 10% of the lands have favorable conditions for reclamation (groundwater = 3.0–5.0 m), in 23.79% of the groundwater was close to the surface, and soils predominate (66.2%) with groundwater (1.0–3.0 m). For the District of Saatly, soils with deep groundwater make up

Table 5. Distribution of Mughan Plain soils by groundwater depth.

Soils (ha) / Districts	Groundwater depth (m)				
	<1.0 m	1.0–1.5 m	1.5–2.0 m	2.0–3.0 m	3.0–5.0 m
Sabirabad	14896	41447			6261
Saatly	582	9860	26887	9162	1038
Salyan	10200	28950			-
Lmishli	1035		16000	14900	34000
Bilasuvar	1271	4710	12715	17835	-

only 2% of the territory, soils with groundwater close to the surface comprise 1.22%, and the soils with groundwater at the depth of 1.5–2.0 m predominate (56.57%). In the District of Salyan, in the main part of the lands (73.94% and 28,950 ha), the groundwater depth was within 1–3 m. In the territory, the 10,200 ha of cultivated land was in a very unfavorable melioration state, with a high risk of salinization. More than half of the lands (51.57%) of Lmishli District have a satisfactory melioration state (groundwater = 3.0–5.0 m), and the lands in a crisis state account for 1.57% of the territory. In the District of Bilasuvar, lands with a groundwater depth of 2.0–3.0 m were widespread (48.82%), and lands with a groundwater depth of less than 1.0 m account for 3.48% (1,271 ha) of the territory.

During the research, an investigation on the issue of conducting ecological monitoring of the Mughan Plain soils also succeeded. This purpose followed the methodology of Mammadov (2007). Furthermore, the research studied the variations in the main fertility indicators of meadow-gray and alluvial-meadow soils in the Mughan Plain. Monitoring of meadow-gray and alluvial-meadow soils in the Mughan Plain covered a 40-year period, which was divided into the following historical stages:

Stage I—1980: data of the steppe-soil survey of the Cadastre and Land Structure Project Research Center Limited Liability Company covering the years 1960–1980 (Babaev, 1984); Stage II—2010: the results of personal research and the data of the steppe-soil survey of the Land Structure Project Research Center Limited Liability Company covering the years 2005–2010; and Stage III—2020: results of personal research and research materials of studies carried out by Mustafayev (2014a, b; 2020). The monitoring results of meadow-gray and alluvial-meadow soils in the Mughan Plain follow herein. The first monitoring covered a period of 30 years, while the second monitoring covered the last 10 years. The monitoring of meadow-gray and alluvial-meadow soils proceeded on the main fertility indicators: humus, nitrogen, phosphorus content (%), total absorbed bases (mg-eq), pH indicator, mechanical composition (%), $CaCO_3$ content (%), and salt content (%).

Moreover, the collection and analysis of materials on the soil salinization and reclamation status of the research area transpired. In the meadow-gray soils, the humus content increased during 1980–2010 (+0.08% in the upper layer of the profile and +0.17% in the one-meter layer), and a corresponding enhancement (+0.01%) was noteworthy in the total nitrogen and phosphorus contents (Table 6). In the last decade, a decrease was evident in the humus content (-0.03% in the 0–20 cm layer and 0.06% in the 0–50 cm layer). Similarly, a decrease in the total nitrogen content (-0.01%) materialized, while the total phosphorus content remained unchanged. A gradual increase in the absorbed bases was noticeable over a period of 40 years, i.e., +3.33 mg-eq in the 0–20 cm layer and +2.76 mg-eq in the 0–50 cm soil layer. An increase in the carbonates also existed, i.e., +1.63% over 30 years and +1.33% over the last 10 years.

In alluvial-meadow soils, based on all the indicators, the negative processes have been apparent in these soils for the period of 40 years. Thus, the humus content has decreased by -0.12% in the 0–20 cm layer, -

Table 6. Ecological monitoring of Mughan plain soil.

Fertility indicators	Meadow-grey			Alluvial-meadow		
	1980	2010	2020	1980	2010	2020
<0,01 mm, % 0-100 cm	54,30	56,45	61,20	48,30	51,75	53,81
<0,001 mm, % 0-100 cm	22,94	24,50	25,36	17,04	21,50	22,18
Humus, %						
0-20 cm	2,07	2,15	2,12	2,52	2,43	2,40
0-50 cm	1,58	1,71	1,65	2,04	1,90	1,72
0-100 cm	1,33	1,50	1,43	1,77	1,65	1,51
Common nitrogen, % 0-20 cm	0,14	0,15	0,14	0,19	0,17	0,17
0-50 cm	0,13	0,13	0,13	0,17	0,15	0,16
Common phosphorus, %	0,18	0,19	0,19	0,25	0,24	0,23
0-20 cm 0-50 cm	0,17	0,17	0,18	0,23	0,20	0,22
SAB, mg-eq/100g						
0-20 cm	25,42	27,94	28,75	31,10	33,40	34,75
0-50 cm	25,80	27,50	28,56	32,07	33,15	35,03
$CaCO_3$, %, 0-100 cm	9,88	11,51	12,84	9,72	11,45	11,96
pH, 0-100 cm	7,9	8,2	8,3	7,7	8,0	8,1
Dry residue, % 0-100 cm	0,39	0,56	0,68	0,26	0,45	0,51

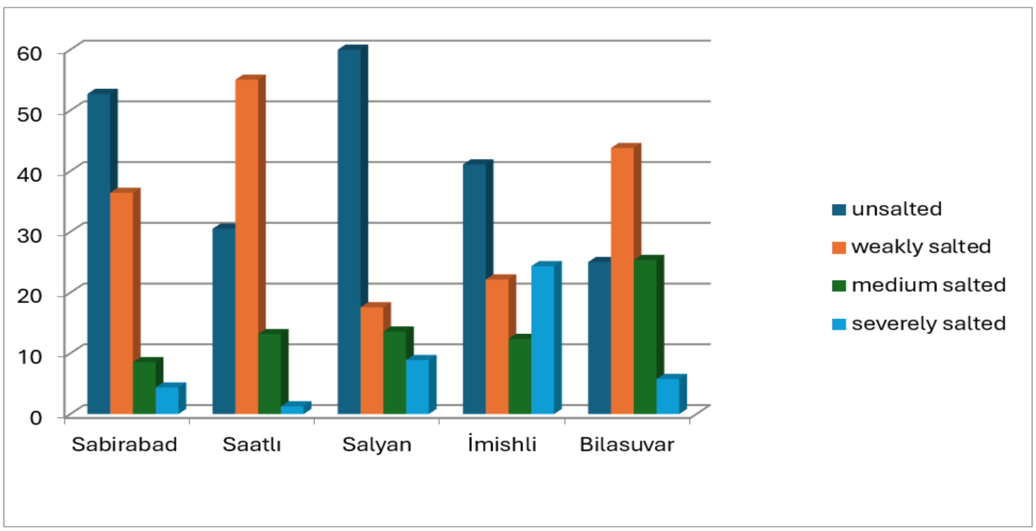

Figure 3. Saline soils in the Mughan Plain**.**

0.32% in the 0–50 cm layer, and -0.26% in the 0–100 cm soil layer. A decline of -0.01%–0.02% is also evident in the common nitrogen and phosphorus contents. However, in the absorption capacity of alluvial-meadow soils, an increase of +3.65 mg-eq resulted in the 0–20 cm layer and +2.96 mg-eq in the 0–50 cm soil layer. The carbonation of these soils increased by +2.24%, and the enhancement in the easily soluble salts in water by +0.25% indicated the salinization process has intensified in these soils. This, in turn, raised the alkalinity of the soil condition (pH +0.4).

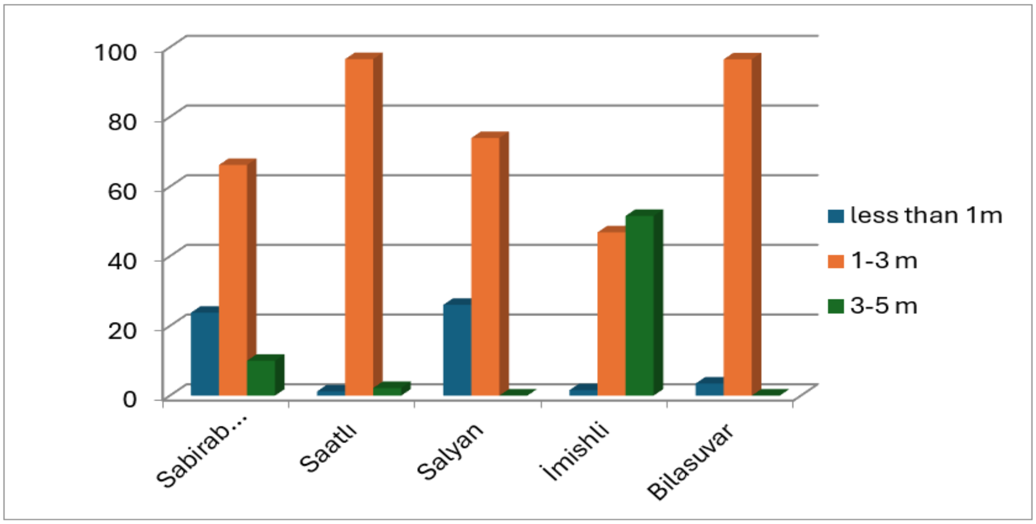

Figure 4. Groundwater depth in the soils of the Mughan Plain.

Salinization has led to an aggravation of the mechanical composition of these soils, and over 40 years, the medium loamy soils have turned into clay soils (<0.002 mm, +5.51%). The monitoring analysis of the meadow-gray and alluvial-meadow soils of the Mughan Plain provides the causes in the research area. With the improper observance of agrotechnical and melioration measures, non-application of crop rotation, non-compliance with regular use of organic and mineral fertilizers, improper irrigation, and poor control over collector-drain systems, the soils have been sustaining varying levels of salinization, which led to a decrease in the soil fertility, their degradation, and a considerable decline in crops' productivity.

CONCLUSIONS

The soil monitoring analysis in irrigated lands of the Mughan Plain revealed weak salinization was prominent in alluvial-meadow soils (+0.19%), medium and severe salinization in gray-brown soils (+0.29%), and very severe salinization in meadow-gray (+0.67%) and gray-meadow soils (+0.44%). The study also determined that 33.9% of the research area was not saline, and 66.1% was saline to varying degrees. Thus, 10.58% of these soils were weakly saline, 15.64% were medium saline, and 39.88% were severely and very severely saline.

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