Factors that intensify soil degradation in the Kazakhstan part of the Golodnostepsky irrigation massif

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Abstract. As a result of the studies made it was established that the intensity of degradation processes in the roots soil strata increased in the Kazakhstan part of the Golodnostepsky irrigation massif. The main factors in intensifying degradation processes are low technical level of irrigation systems, considerable losses (up to 60-70% of the intake) of irrigation water, rising level of mineralized ground water, degradation in quality of irrigation water, and salinity and alkalinity of soil.

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Introduction

In the conditions of the southern Kazakhstan where irrigated land is located in trans-boundary river basins, water availability in existing irrigation systems is between 75 and 95%, and in dry years, it drops to 50-60 %. At the same time, huge amounts of collector-waste and waste water that form on the river basins (up to 30-50% of the water supply) is flushed outside them, pollute water sources and compromise the environment in surrounding areas. A similar picture is observed in the irrigation systems of the Kazakhstan part of the Golodnostepsky massif, which requires detection of the main factors that intensify the processes of irrigated soils degradation.

Materials and methods of research

In the Golodnostepsky massif, the source of irrigation is the Dostyk Arterial Channel (AC) with water intake in the Syr-Darya River. His head intake is 230 - 260 m³/sec. Overall length is 113 km, including the territory of Kazakhstan, 40 km with normal flow 125 m³/sec. The channel runs in an earthen bed [1]. In this massif, water is supplied to irrigated land through the 1st order distribution channels that take water directly from the Dostyk arterial channel. About 95.6 % of interfarm and 79.2 % of in-house channels are made in cut-and-fill of earthen bed. Therefore, only 40-45 % of water taken from the irrigation systems is used for crops, and the remaining water was used for filtering, evaporation, and discharge [2]. Significant amounts of water technological losses in the irrigation network and in irrigation fields inevitably lead to salinization and alkalinization of irrigated land and to contamination of water sources [3, 4, 5, 6].

This requires examining the factors that have influence on the intensity of the degradation processes in the root layer in the Kazakhstan part of the Golodnostepsky massif. The factors were established by organizing 6 pilot plots located in the northern, central, and southern part of the irrigation massif. In these plots, limits of changes in aqua-physical and chemical properties of the root layer of soil were studied. For this purpose, the mechanical (using the method by Kachynski N.A.) composition, density of the solid phase (using pycnometry), density (cylinder), porosity (calculated), the maximum field water capacity (sites flooding), water permeability (sites flooding and lysimetric) were determined layer by layer every 20 cm [7, 8, 9].

Out of soil chemical properties we determined humus (method of I.V. Tyurin); gross forms of nitrogen (method of Kjeldahl) and phosphorus (calorimetric method); mobile forms of nitrogen (calorimetric method), phosphorus (method of Machigin) and potassium (method of Oniani); cationic composition of soil-absorbing complex (sodium - method of Schmuck); pH and water extract (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+) [10].

During chemical analysis of water we determined: total content of salts, anions and cations, nitrates, phosphorus, humus and pH [10]. Qualitative composition of the irrigation, drainage and ground water was assessed by ion composition of water; by "residual sodium carbonate" (RSC); by content of magnesium (Mg) cations; by irrigation coefficient (using method of I.N. Antipov-Karataev and G.M. Kader); by sodium adsorption ratio (SAR and SAR USA). The result of research made it possible to determine the dynamics of soil moisture, the cationic composition of soil-absorbing complex and the ion-salt soil composition.

Research results and discussion

For the Golodnaya Steppe, typical and light gray soils have been chosen as zonal automorphic soils. Gray soils get formed on loesses, which are yellow-brown loam with particles of physical clay (mostly 35-40 %). By mechanical composition, soils of the massif examined are mainly loamy.

Analysis of soils mechanical composition shows that the arable layer is followed by subsoil, where content of physical clay sharply increases. Comparative analysis of the averaged parameters of physical clay shows that, if compared to 1985, in 2009 their values in the top 0-40 cm layer increased by 23%, and in the 0-100 cm layer increased by 15% (Table 1). This indicates that in the period between 1985 and 2009, thickening occurred in the upper horizons of the subsoil horizon.

Table 1.Results of comparing averaged content of physical clay in horizons

Horizons, cm	1985, %	2009	
		%	% from 1985
0-40	42.80	52.87	123
0-100	41.56	47.93	115

Comparative analysis of the physical properties of soil shows that, as compared to the 80s of the last century, there was an increase in the volumetric weight of soil in the upper root layer. A particularly sharp increase of soil density occurred in the 20-40 cm subsoil layer. Density increase in top layers predetermined decrease in soil porosity in these horizons (Table 2).

Table 2. Time variation limits for the average values of soil density and porosity

Indicators	Horizons, cm	1985	2009	
				in % from 1985
Density, g/cm³	0-40	1.30	1.37	105.4
	0-100	1.36	1.42	104.4
Porosity, %	0-40	50.4	47.7	94.6
	0-100	48.1	46.0	95.6

Increase in soil density and reduction of its porosity in the top layers slows down the water absorption by soil and the rate of air exchange between the top and underlying layers of the root layer [11].

Important factors that increase the intensity of degradation processes in the root layer is increasing scarcity of water resources and increasing level of mineralized groundwater above the critical depth. The reason for increase in these factors is water loss during transportation from the irrigation source to the field irrigated.

It has been established that in conditions of the Golodnostepsky massif, during crops watering, water loss during discharge, evaporation and infiltration reaches 30% of the water supply to the field. Consequently, the effectiveness of elements of watering technique is 0.7. Using the results of the research, we calculated the effectiveness of the irrigation system in the Kazakhstan part of Golodnostepsky massif (Table 3).

Table 3. Efficiency of the irrigation system in the Golodnostepsky irrigation massif

No.	Irrigation systems	Performance factor (PF)		
		of the irrigation network	of elements of irrigation technique	of the irrigation system
1	Makhtaaral	0.57	0.7	0.40
2	Asyk-Ata	0.47	0.7	0.33
3	Zhetysai	0.58	0.7	0.41
For the array		0.54	0.7	0.38

Until the mid-90-s of the twentieth century, the groundwater level was maintained below the critical depth and prevented from mineralization of irrigated soils in the Kazakhstan part of the Golodnostepsky massif using horizontal (CDW) and vertical drainage wells (VDW) [10]. Failure of the VDW and deteriorating of CDW technical state reduced drainage conditions of the irrigated land.

In these conditions, the main factor that influences ecological and ameliorative state of the irrigated land is the level and mineralization of groundwater [11, 12, 13]. Shallow mineralized groundwater inevitably causes accumulation of salts in the root layer. On top of it, in case of low mineralization of groundwater, its income to the root layer reduces the value of irrigation norms.

Synthesis of the available material showed that termination of drainage wells operation and deterioration of the technical state of open collectors predetermined intense rise of ground water. For example, in 1994, the area of irrigated land with groundwater depth up to 1 m was 105 hectares; in 2013 it was 2,562 hectares (Table 4).

Table 4. Distribution of irrigated land by the depth of groundwater

Years	Total area, hectares	Groundwater depth, m				
		0-1	1-2	2-3	3-5	over 5
1994	125715	105	7792	72084	43441	2293
		0.1	6.2	57.3	34.6	1.8
2009	138767	1417	71476	44273	19926	1675
		1.0	51.5	31.9	14.4	1.2
2013	144039	2562	37348	34512	48245	1372
		2	26.0	38.0	33.0	1

Note: the numerator is the area in hectares; the denominator is the area in % of the total area

Comparative analysis of the data shows that with decrease in drainage condition of the territory there is a decrease in the area of irrigated land with groundwater level over 2 m. In 1994, when VDWs were operating, the share of the irrigated area with ground water 2 m deep was 93.7 %, and at present it is 47.5 %.

During the period when VDW and CDW were operating full-scale, the area of the irrigated land with fresh ground water (up to 3 g/l) was 54.9 % of the total irrigated area (Table5). Later, the area of the irrigated land with fresh ground water decreased.

Table 5. Distribution of irrigated land by groundwater mineralization

Years	Total irrigated land, hectares	Unit of measurement	Mineralization, g/l			
			<1	1-3	3-5	>5
1994	125,715	hectares	2718	66,270	37491	19,236
		% of the total area	2.2	52.7	29.8	15.3
2009	138,767	hectares	40	34,914	50849	52,964
		% of the total area	0,03	25.2	36.6	38.2
2013	144,039	hectares	189	62,879	41964	39,007
		% of the total area	0.1	43.7	29.1	27.1

From the materials presented one can see that in 1994 the area of the irrigated land with mineralization of about 3-5 g/l and over was 56,727 hectares, or 45.1%, while in 2013 it was 81,971 hectares, or 57 %.

Thus, changes in the levels and salinity of groundwater show that in the Kazakhstan part of the Golodnostepsky massif the following occurred due to decrease in the drainage condition of the irrigated land: groundwater rise; increase in irrigated area with shallow ground water; increase in mineralization and growth of areas with high groundwater mineralization; increase in soil salinity and salinized areas of irrigated lands; and alkalinity and alkalization of soils.

With reduction in drainage state of the irrigated land, salts are accumulated in the root layer. This is confirmed by the data of soil chemical analysis on samples from the Makhtaaral, Zhetysai and Asyk-Ata irrigation systems. Research results have shown that the increase in toxic salts content in the top 0-40 cm layer on the Golodnostepsky massif is only 1.9 t/hectare. However, in the lower horizons, the rate of toxic salts accumulation in the 0-100 cm layer increased by 22.7%, or 11.0 t/hectare (Table 6).

Table 6. Change of salt content in the root layer (0-100 cm)

Years	Salt reserve					
	total		toxic		chlorine	
	%	t/ha	%	t/ha	%	t/ha
2009	0.562	79.8	0.313	45.7	0.038	5.4
1985	0.410	55.8	0.255	34.7	0.021	2.9
Difference	0.152	24.0	0.050	11.0	0.017	2.5

The reason for rapid accumulation of toxic chlorides is proximity of groundwater, their high solubility and low sorption capacity. As a result, their migration from groundwater into the top layers of soil increases. The cumulative nature of salts in the root layer predetermined growth of the areas of salinified irrigated land (Table 7).

Table 7. Dynamics of soil salinity in the 0-100 cm layer

Years of observation	Irrigation area, thousand ha	Including by salinity			
		non-saline and slightly salinified.		moderately and strongly salinified	
		hectares	%	hectares	%
1995	125.4	93.6	74.6	31.8	25.4
2005	138.8	92.2	66.4	46.6	33.6
2013	144.039	87.9	61.0	56.1	39.0

Thus, results of the analysis of ameliorative condition of the irrigated lands in the Golodnostepsky massif showed the following: deterioration of soils physical state; reduction of the drainage condition of the irrigated land; rising of groundwater level above critical depth; soil salinization; soil alkalinization; and the possibility to use collector-wastewater for irrigation and washing.

Conclusions

In the current situation in the Kazakhstan part of the Golodnostepsky massif, the problem of stable development of irrigated agriculture can be solved by: technical upgrade of irrigation network and structures; improving physical and chemical properties of soils; desalinization and dealkalinization of salinified and alkaline soils; upgrade and implementation of water-saving irrigation technologies; increasing drainage condition of irrigated land; and utilization of groundwater and drainage waters by using it for irrigation and sub-irrigation.

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