TOXIC SALTS ACCUMULATION IN LANDSCAPES RESULTING FROM WATER MANAGEMENT AND AMELIORATION

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Abstract
Large-scale water management and amelioration (irrigation and drainage) have caused an accumulation of salts, toxic for plants, in landscapes, investigated in Ukraine (humid zone) and in Kazakhstan (arid zone). In Ukraine the salt accumulation in soils and groundwater occurs in river valleys, where swampy and peat soils are drained, and along the coast of large reservoirs on the Dnipro River. In drained peat soils 0.3-0.4 % of salts have accumulated and the alkaline reaction is formed. Mineralization of surface (river's) water and groundwater here is 0.5-1.2 g/l. Along the coast of reservoirs salt accumulation occurs in waterlogged soils. The salts composition in soils of the northern Kiev reservoir coast is sodium sulphate, and in soils of more southern Kremenchuk reservoirs – sodium hydrocarbonate with presence of soda and pH up to 8-10. Much stronger processes of salt accumulation we investigated in Kazakhstan and Central Asia at the coast of irrigation and hydropower reservoirs, on periphery of foothills, in deltas of Syrdarya and Ily Rivers, and also along the coasts and drying up bottom of Aral Sea and Lake Balkhash. At the coasts of reservoirs in a strip of 3-5 km width up to 400-500 t/ha of salts (sodium chlorides and sulphates) is accumulated in soils, and groundwater mineralization reaches 30-70 g/l. Salt affected soils of cones of debris are fringe with almost all foothill plains. Soil salination in deltas is combined with powerful desertification because of rivers runoff regulation. Salt accumulation at the bottom of Aral Sea (4 million hectare) is important as a source of toxic salts carry out by a wind on adjacent territories on the distance up to 300-500 km.

Introduction
The processes of salt accumulation in soils, surface and ground waters, and also in an atmosphere become one of major sources of environment pollution in XXI century. Thus to the already traditional phenomena of soil and water salination in arid regions and on irrigated lands new or insufficiently investigated processes are added. They are caused by river runoff regulation for economic activity, and also by some amelioration measures. Already in 70-80s we revealed a landscapes desertification and salination processes strengthening in deltas of the rivers in Kazakhstan and Central Asia (1-3). At the same time an acceleration of river water mineralization increase was found (4, 5). Large attention was given to investigation of a soil salination scope at the coast of water reservoirs (6). It became clear, that salt accumulation processes cover new territories in different natural zones.

Methods
Salt content in soils, surface and ground waters and ionic composition were investigated on the different sites during 30-40 years. Sampling of soils was carried out from entire soil profile (from surface to groundwater table) at the time of survey and mapping of "key plots" and vast territories in river deltas, at the reservoirs coast on the drying-up bottom of Aral Sea, etc. Perennial research on the key plots makes the results reliable and trustworthy positive. We also used a statistical analysis of river water mineralization data, collected by hydrometeorological organizations. In all samples of soil and water we analyzed a total soluble salts content and ionic composition (HCO_3^-, CO_3^{--}, Cl^-, SO_4^{--}, Ca^{++}, Mg^{++}, $Na^+ + K^+$).

Results and discussion

On Ukraine the new regions of salt accumulation on ameliorated (drained) swampy and meadow soils, and also on waterlogged coast even of the most northern reservoirs of Dnipro river cascade (fig. 1) are found out.

Figure 1: Location of sites for salt accumulation research in Ukraine (1- Kyiv reservoir coast, 2- Trubizh river valley, 3- Kremenchuk reservoir coast)

In XIX and XX centuries in Forest and Forest-Steppe zones of Ukraine 3 million hectares of swampy soils was drained for their use in agriculture. Among negative ecological consequences of large-scale amelioration (overdrying of peat horizons, accelerated mineralization of organic matter, wind erosion, the pollution of groundwater and surface waters with biogenic elements) unique place occupy processes of meliorated soils salination. These processes occur in hydromorphic soils (organic and mineral) in basins of such left-bank tributaries of the Dnipro river, as the rivers Trubizh, Nedra, Sula (figure 1, site 2). The geological structure of this region is characterized by presence of salt domes, formed as a result of ancient tectonic processes, which cause an increase of groundwater and surface waters mineralization with calcium and sodium hydrocarbonate accumulation. And a long interaction of salted waters with soils (both organic, and mineral) has resulted in formation here slight salt affected, often alkaline and even solodized soils. Naturally water mode of wetlands promoted a periodic removal of salts from soils during high waters. Now accumulation of salts gradually amplifies (table 1, P-1, v. Zavorychi), the amount of salts in a soil profile reaches 0,3-0,4 %, hydrocarbonate and chloride in composition of anions are prevailed. Soil reaction is poorly alkaline. Slightly drained mineral hydromorphic and semi-hydromorphic soils are less salted (P-8, v. Kuchakovo). And alkaline soils, on which the drainage and chemical amendments was applied, have more than 0,2 % salts in their profile. There are normal soda and alkaline reaction in those soils. It essentially reduces their fertility and amelioration efficiency.

Table 1: Salt content in reclaimed hydromorphic soils (site 2), %

Depth of samples, cm	pH	Anions				Cations			Sum of salts, %
		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	
Peat soil (P-1, v. Zavorychi)									
0-10	7.6	-	0.230	0.041	0.024	0.070	0.019	0.012	0.387
10-30	7.8	-	0.224	0.043	0.029	0.073	0.019	0.007	0.393
30-50	7.7	-	0.227	0.041	0.025	0.086	0.010	0.008	0.394
50-70	7.8	-	0.194	0.042	0.043	0.087	0.008	0.008	0.378
70-100	7.8	-	0.187	0.041	0.043	0.063	0.021	0.007	0.360
Soddy-gley soil (alkaline-saline). P-8, v. Kuchakovo									
0-29	7.7	-	0.060	0.012	0.025	0.016	0.002	0.019	0.134
29-45	7.8	-	0.050	0.012	0.025	0.010	0.004	0.019	0.120
45-72	7.9	-	0.050	0.012	0.025	0.010	0.002	0.021	0.120
72-100	8.0	-	0.030	0.010	0.025	0.008	0.002	0.015	0.090
Meadow-chernozemic soil (alkaline), P-1, v. Lyubartsy									
0-10	7.9	-	0.139	0.018	0.015	0.031	0.017	0.003	0.224
10-30	8.0	-	0.143	0.016	0.002	0.027	0.016	0.004	0.209
30-50	8.2	0.006	0.147	0.010	0.003	0.022	0.020	0.005	0.213
50-70	8.3	0.007	0.131	0.006	0.002	0.025	0.013	0.007	0.192
70-100	8.5	0.008	0.139	0.020	0.006	0.021	0.009	0.034	0.237
100-125	8.5	0.010	0.142	0.017	0.007	0.028	0.004	0.037	0.244

Soil salination on the coast of reservoirs has huge scales in the world. Usually salt accumulation on the reservoirs' coast is characteristic for arid regions. Therefore special attention attracts this process at the coast of Kiev (forest zone) and Kremenchuk (forest-steppe zone) reservoirs in Ukraine. On the Kiev reservoir weak salination (0.1-0.4%) has taken place at waterlogged soils, which contained soluble salts in deep horizons of parent rocks. On the Kremenchuk reservoir a strong waterlogging by salted alkaline waters has resulted to strong salination (amount of salts 0.6-1.8 % in upper horizon) and alkalization (pH 9-10) of soils in all profile. And at weak waterlogging salts are accumulated in a small amount on depth of 1-5 m. In the long term they can rise to a surface and reduce soil fertility.

Immeasurably more strongly soil salination occurs at the coast of reservoirs in Central Asia. We investigated in details this process on irrigation Bugun and hydropower Kapchagay reservoirs (6, 9). The areas of waterlogged strongly salt affected soils here can reach tens thousand hectares, and amount of salts in two-meter layer is more than 500 t/ha.

The intensive regulation of a rivers runoff in Central Asia (Syrdarya, Amudarya, Ily, Chu and others) for the purposes of water-power engineering and irrigation stipulated for deep changes of hydrological and hydrochemical regimes of rivers, and also has called powerful processes of desertification and salination of landscapes. For example, at the downstream of Syrdarya River desertification and salt accumulation have got character of ecological accident of global importance.

The areas of irrigation in Syrdarya River basin have increased with 1 million ha in the beginning of XX century up to 3 million ha in 80 years. The runoff regulation of Syrdarya River is carried out with the help 6 large and numerous average and fine reservoirs, and also 5 largest dams and large number canals for irrigation. The runoff of the river in delta already in 70-80s years sharply has decreased and made only 10-30 % of norm (4, 5, 9), and in 1976-1978 with shortage of water the runoff in the Aral sea in general was absent. Only in 90 years the water flow has increased (up to 3-8 км3) because of an economic crisis and reduction of water use for irrigation. Water mineralization in the downstream has increased by 1990 up to 1,6-1,9 g/l, separate figures reached 3 g/l (5), and only last decade of XX century it temporarily has decreased up to 1,2-1,6 g/l. Ionic runoff of the river into the sea has decreased on the average with 12 up to 5 million t per year, that is annually about 7 million t of salts in addition are accumulated in landscapes of ancient and modern deltas. In turn, the deterioration of supplying in water of delta Syrdarya region has resulted in processes of landscapes desertification and salt accumulation in soils in connection with evaporation of salted groundwater. In modern delta the area of solonchaks is promptly increased and by 2010 will reach (under the forecast) 250 thousand ha. And if to take into account, that practically all drying and desertified hydromorphic soils also basically are salted, the general area of salt affected soils in modern (Kazalinsk) delta makes about 380 thousand ha. The very intensive processes of soil salination occur also in ancient delta of Syrdarya River (near city of Kzylorda). Here 0,5 million ha of hydromorphic soils has dried and partially desertified, 100 thousand ha of them became solonchaks.

The processes of salts accumulation in deposits and formed here soils on drying up bottom of the Aral Sea have exclusive ecological importance. into The level of sea for the period from 1960 till 2002 has decreased on 18 m, the square of water area has decreased on 4 million ha, and volume of water - on 830 km^3 because of water flow reduction in the rivers Syrdarya and Amudarya. As a result, on the area of the former sea bottom the salt and sandy deserts are formed. The parity between them changes both in time, and in space. In northern and east parts of the sea more heavy deposits (loams) are mainly distributed, and in a southern and southeast part - easy deposits (sandy and loam-sandy) are prevailing. Besides, for the first decades of the sea level fall easier deposits went on the surface, and last years - heavier deposits were exposed. Accordingly and the processes of salt accumulation occur in loamy and clay deposits and soils more intensively, and less intensively - in easy deposits and soils (sandy and loamy-sandy). The features of salt accumulation in this region at 60-90 years were investigated by scientists of Kazakhstan, Uzbekistan, of former Soviet Union. The brief analysis of these researches is given in (7, 8). Actively participated in this job and authors of this message which has published earlier the results of researches on experimental plot Kaskakulan at the east coast of the sea (7). Let's show schematically the regularities of salt accumulation on the drying up bottom. At a new coastal line in a strip of 2-4 km marsh solonchaks are formed within 1-2 years. Their surface is covered with a thick pudgy layer of salts and is the basic source of transfer of salts in an atmosphere. On the territory which has dried already 3-5 years, marsh solonchaks are replaced with the seaside solonchaks. They have a salt crust on a surface and richly grow with one-year saltwarts that promotes a reduction of blowing of salts by a wind from the former sea bottom. Through 5-7 years processes of accumulation of salts and desertification of landscapes already essentially differ depending on a texture of soils. Loamy soils are most strongly salt affected and poorly grow with perennial saltwarts. But they have rather strong salt crust on a surface interfering to aeolian destruction. Loamy-sandy surfaces are less salted and more strongly grow with vegetation. And only sandy surfaces in this period are subject to strong deflation with barkhans formation. In 10-15 years on former bottom of the sea deserted landscapes with takyr-like soils and solonchaks, and also with sites of sandy barkhans already are generated (7, 8).

Table 2: .Salt content and ionic composition in groundwater and surface water (g-l/mg-ekv).
Aral Sea, Line Karateren'.

№ of soil profile	Distance from the Sea, m	GWT, m	Ionic composition						Sum of salts, g/l
			HCO_3	Cl	SO_4	Ca	Mg	Na	
P-101C	25	0.70	0.517 8.47	7.916 223.01	13.373 278.61	0.720 36.00	1.320 108.54	8.508 365.55	31.774
P-102C	325	0.70	0.483 7.92	8.165 230.01	9.327 194.32	0.800 40.00	1.220 100.32	6.814 291.93	26.809
P-103C	1075	0.78	0.639 10.47	7.739 218.01	7.792 162.33	0.640 32.00	1.240 101.96	6.000 256.85	24.050
P-104C	1585	1.24	0.566 9.28	8.804 248.01	7.723 161.93	0.660 33.00	1.320 108.54	6.480 277.68	25.553
P-105C	3585	2.40	0.312 5.11	14.200 400.01	12.293 256.11	0.760 38.00	2.340 192.42	10.042 430.81	39.947
P-106C	5585	3.09	0.303 4.96	21.300 600.02	16.129 336.02	0.800 40.00	3.600 296.03	14.064 604.97	56.196
Water of sea			0.317 5.20	18.602 524.02	19.531 406.90	0.800 40.00	3.760 309.18	13.776 586.94	56.786

Let's consider briefly features of soil salination on the territory adjoining to the Syrdarya channel (line Karateren). This territory differed long time by a weaker salination because of rather low mineralization of sea water. But after separating of the Small Sea from the Large Sea in 1987 the mineralization of the sea water near the coast has increased till 50-60 g/l (though average mineralization of water in the sea is estimated in 45 g/l). And mineralization of groundwater has reached 24-40, on occasion 56 g/l (table 2). Nevertheless, the contents of salts in superficial horizon here makes 2-6 %, and in the low horizons 0.5-1.5 % (table 3), that is much less, than as a whole at the east coast of the sea (7). Accordingly the amount of salts in soils are less here in 2-3 times - 21-115 t/ha in a layer 0-30 cm and 94-216 t/ha in a layer 0-100 cm.

Table 3: Salt content in soils of drying up bottom of the Aral Sea on the north-east coast
(line Karateren' near Syrdarya mouth), %%

№ of profile and its location	Depth of samples, cm	Salt content	Including	
			Cl'	SO_4''
P-101C, 25 m from sea	0-15	3.439	1.049	1.259
	15-60	1.240	0.445	0.338
	60-70	0.718	0.272	0.177
P-102C, 325 m from sea	0-15	3.278	1.043	1.131
	15-56	1.417	0.535	0.353
	56-76	0.567	0.225	0.118
P-103C, 1075 m from sea	0-15	3.810	1.355	1.188
	15-50	1.762	0.626	0.503
	50-78	1.004	0.431	0.182
P-104C, 1585 m from sea	0-3	6.579	2.502	1.917
	3-25	2.358	0.869	0.674
	25-43	1.864	0.589	0.626
	43-94	0.917	0.431	0.126
P-105C, 3585 m from sea	0-10	2.652	0.771	1.011
	10-30	1.679	0.570	0.543
	30-50	1.107	0.473	0.233
	50-70	0.840	0.306	0.219
	70-100	0.786	0.292	0.191
P-106C, 5585 m from sea	0-9	2.506	0.737	0.939
	9-25	1.636	0.417	0.654
	25-53	0.989	0.354	0.270
	53-74	0.572	0.210	0.140

	74-91	0.634	0.243	0.132
P-107C, 6585 m from sea	0-10	2.439	0.765	0.840
	10-30	0.984	0.368	0.260
	30-50	1.052	0.452	0.218
	50-70	1.315	0.514	0.335
	70-100	1.205	0.507	0.256
P-108C, 8585 m from sea	0-10	2.055	0.966	0.094
	10-30	1.477	0.563	0.383
	30-50	0.775	0.257	0.237
	50-70	1.618	0.577	0.474
	70-100	0.681	0.215	0.032
P-110C, 10685 m from sea (120 m from a shore)	0-10	1.731	0.848	0.070
	10-30	1.272	0.431	0.398
	30-50	0.844	0.313	0.228
	50-70	0.524	0.209	0.115
	70-100	0.239	0.070	0.065

The large interest is caused by a problem of the further changes of salination of this territory as source of transfer of salts by a wind on adjacent with the Aral Sea territories (10). Since 70s the dried bottom began to be exposed to strong deflation processes. Thus huge amount (from 7,3 million t - according to the Kazakhstan experts till 15-75 million t per one year - according to the Uzbek and Russian scientists) dust-salt aerosol is transferred by a wind on the territory of Kazakhstan, Uzbekistan and Turkmenistan. Its large part drops out on a ground on the distance of 30-50 km from the sea, much less - on 150-200 km, and few - on the distance of 300-500 km. And the thinnest salt particles are involved in the global migration in stratosphere.

Conclusions

Peculiarities of salt accumulation in soils and water, caused by water management, were revealed in tradition regions (arid and sub-arid), and in new (humid) ones as well. The most intensive soil salination (up to 500 t/ha in 2 m layer) takes place on the coast of large reservoirs in Central Asia, on the low part of foothills in arid zone, in the Syrdarya delta and on the drying-up bottom of the Aral Sea. Very strong desertification processes in those regions manifested themselves on the square more 4 million hectares. In Ukraine weak processes of salt accumulation are revealed in the reclaimed swampy soils, and in waterlogged soils on the Kremenchuk and Kiev reservoirs coast.

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