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Environmental effects of using large rivers for irrigation in the Kazakhstan – Syr Darya case study

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Abstract

The issues discussed in the paper concern the assessment of changes in quantitative and qualitative indicators of water resources in the climatic conditions of the southern part of Kazakhstan. For this purpose, many years of systematic field observations and other continuous data obtained from the functioning measurement and observation stations operating within the Aral-Syrdarya Basin Inspection were used. On the basis of the obtained data, indicators were determined that characterize the quantity and quality of water supplied to the soil in the irrigation process, as well as the quantity and quality of water flowing out of the drainage systems, together with an evaluation of the effectiveness of irrigation and drainage systems. Soil salinity was assessed in five irrigated massifs with a total area of 332.55 thous. ha. For the same irrigated massifs, the annual amounts of water taken for irrigation, the amount of outflowing water and the assessment of the mineralization level were determined. Based on the developed results of field observations characterizing the hydrological and environmental situation of the lower section of the Syr Darya River in 1960–2015, the negative reaction coefficients were calculated for the local population, soil and vegetation for five of the irrigated massifs of the Kyzylorda region. The ecological situation of the habitat of soil and plants in the lower reaches of the Syr Darya River in all irrigation areas deteriorates on a time scale, since as a result of the reclamation of agricultural lands, intensive secondary soil salinization occurs and the formation of infiltration runoff with high mineralization, contributing to the violation of the harmonization of the relationship between nature and man.

Key words: *diversity index, irrigation, soil degradation, Syr Darya River, the environmental risk indicator*

INTRODUCTION

The issues discussed in the paper concern the assessment of changes in quantitative and qualitative indicators of water resources in the climatic conditions of the southern part of Kazakhstan. For this purpose, many years of systematic field observations and other continuous observational data obtained from the functioning measurement and observation stations operating within the Aral-Syr Darya Basin Inspection were used. On the basis of the obtained data, indicators were determined to characterize the quantity and quality of water supplied to the soil in the irrigation process, as well as the quantity and quality of water flowing out of drainage systems. On this basis, the effectiveness of both irrigation and drainage systems was assessed. The salinity level of soils was assessed in 5 irrigated massifs with a total area of 332. 55 thous. ha. For the same irrigated massifs, the annual amounts of water taken for irrigation, the amount of run-off water and the level of mineralization of water used for irrigation and run-off water were determined with drainage systems.

Reclaimed land areas, in particular irrigated land, comprises about 10–15% of the ploughed areas of the world, but they are responsible for about 30% of the production (in money terms). Hence, in order to supply the growing population with food, a constant input of new reclaimed land is required, in addition to intensification of agriculture on existing reclaimed land. According to UN experts, to resolve the global food problem, the irrigated area should be increased by 0.5% annually [MINAYEV, MASLOV 2002; NIKOLSKIJ 1996, RYDÉN *et al*. (eds.) 2017].

At the same time, to ensure stable agriculture, the distribution of irrigated lands, in terms of natural-climatic zones should be in excess of 20–25% in the arid zone, 10–20% in dry steppe, 5–10% in steppe, and 1–5% in forest-steppe [MASLOV 2000]. Modern reclamation systems do not always possess such properties, because basically only the regulation of water flow is controlled. Using ecological principles, it is possible to believe that creating more sophisticated reclamation systems will permit significant increases in crop production (not less than 30–50%) on existing reclaimed lands, and this can reduce the gap between population growth and creation of new areas of reclaimed land. Today, the concept of complex reclamation regulation is sufficiently developed. The systems have been proved, and in future, their area and importance can only increase [RYDÉN *et al*. (eds.) 2017].

Hence, in order to supply the growing population with food, a constant input of new reclaimed land is required, in addition to intensification of agriculture on existing reclaimed land. According to UN experts, to resolve the global food problem, the irrigated area should be increased by 0.5% annually. At the same time, to ensure stable agriculture, the distribution of irrigated lands, in terms of natural-climatic zones should be in excess of 20–25% in the arid zone, 10–20% in dry steppe, 5–10 % in steppe, and 1–5% in forest-steppe [AIDAROV, PESTOV 2000; MASLOV 2000].

The Syr Darya River is a very important part of Aral Sea Basin, and also it is important because the Central Asian Republics depend on it for drinking water, irrigation, and hydroelectric power. In the upstream countries of the Basin, Kyrgyzstan and Tajikistan, the river is used for hydroelectric power, especially during winter months, while downstream, in Turkmenistan, Kazakhstan and Uzbekistan it is used for agricultural purposes in the summer time. The post-independence upstream shift in water use away from irrigation has created disputes between the upstream and downstream countries over how the region's transboundary waters should be managed. Agriculture is the largest water consumer in the region and a major employer of the region's workforce, producing a large percentage of each country's gross domestic product (GDP). Water diversions for irrigation have resulted in severe problems associated with lack of water in the downstream areas of the Syr Darya Basin near the Aral Sea [KOZYKEYEVA *et al*. 2020; TALTAKOV 2015]. Improving water quality and increasing water quantity to meet basic human needs in these environmentally damaged and economically depressed areas is an urgent need. Large irrigation projects are theoretically beneficial. However, there are examples of outstanding failures that partly led to environmental disasters. We believe that irrigation in itself does not necessarily lead to land degradation. Even in the famous case of the Mesopotamian plains, the idea that ancient Sumerian irrigation has resulted in irreversible salinity is far less obvious than often assumed in public discussion [NIKOLSKIJ 1996; RYDÉN *et al*. (eds.) 2017]. The current ecological situation in the nature management system on a global scale is characterized by certain features that significantly affect the state of the environment, i.e. the quantitative and large-scale expansion of energy exchange between society and nature, which contributes to the continuous increase of negative anthropogenic pressures on the natural system [ADILBEKTEGI 2019a].

Modern methods of managing natural resources should strive for their sustainable use. However, examples of resource use in many places around the globe show that in many cases we are dealing with irrationality and inefficiency – both from an economic and environmental point of view. This is evidenced by the fact that in all regions of the world the relatively ecologically favourable territory is rapidly decreasing, which contributes to the emergence of both socio-ecological and economic problems [JURIK *et al*. 2018; YUNUSOVA, MOSIEJ 2016]. Thus, the interaction between society and nature follows the principle of feedback, i.e. changes in the components of the natural system lead to significant changes in the environment, which requires an assessment of the level of impact of anthropotechnical loads on determine their environmental sustainability. At the same time, learning about social and environmental phenomena occurring in the human environment in anthropotechnical activities requires proper research and assessment of the features and activities of the environmental factor, which has become the subject of research in the lower area of the Syr Darya River, which is a zone of the ecological crisis [NIKOLSKI *et al*. 2010; SHABANOV 2000].

Conducting an analysis of the environmental situation assessment in the lower section of the Syr Darya River along with an assessment of the threat to the health and life of the local population. The practical goal was to isolate the areas at risk and friendly to the local population from the point of view of environmental well-being. An important goal is also to assess the natural conditions and factors creating a specific ecological environment in the area of varying welfare and environmental risks, taking into account the health of the local population [ADILBEKTEGI 2019b; MUSTAFAYEV, KOZYKEEVA 1997; MUSTAFAYEV, KOZYKEEVA 2009].

MATERIALS AND METHODS

The results presented in the study concern a 55-years observation period and cover the years 1960–2015, results concerning the regulation of the use and protection of water resources characterizing changes in the environmental elements in the lower reaches of the Syr Darya River in the context of the irrigated massifs. The environmental situation was assessed in the context of irrigated massifs as human habitat. Based on the results of field observations characterizing the hydrological and environmental situation of the lower section of the Syr Darya River in 1960–2015, negative response coefficients were calculated for the population, soil and vegetation for the Kyzylorda region for five sections. Habitat trophism was determined using the Shannon diversity method and classified together with the state of agricultural land. Based on the calculations, a functional relationship was also developed between the Shanon index and the environmental risk index, which can be used to predict changes in the natural environment under similar conditions, such as the downstream Syr Darya River.

To assess the ecological situation of natural systems in the lower reaches of the Syr Darya River, multi-year information and analytical materials of the South Kazakhstan hydro-geological and land reclamation (drainage and irrigation) expeditions and the Aral-Syr Darya Basin Inspection for regulating the use and protection of water resources were used (Tabs. 1, 2, Fig. 1) [ALMOV 1990; MUSTAFAYEV, KOZYKEEVA 2012].

Methodological support for the assessment of the environmental situation of the natural system in anthropogenic activities is based on an assessment of the environmental situation in the justification of the reconstruction projects of KHACHATURIAN [1990a, b], KHACHATURIAN and AYDAROV [1990; 1991], MUSTAFAEV and KOZYKEEVA [2009] as well as MUSTAFAEV *et al.* [2019] which follows from the fundamental natural laws and, above all, the laws of conservation of matter and energy, the change of which is caused by anthropogenic factors. At the same time, natural and man-made systems should take into account that the

Table 1. State of irrigation areas in the lower reaches of the Syr Darya River (Kyzylorda region, Republic of Kazakhstan)

Irrigation massif	Years	State of irrigation areas							
		non-saline		slightly saline		medium saline		strongly saline	
		ha	%	ha	%	ha	%	ha	%
1. Kazalin (59 450 ha)	1960	22 450	37.8	8 100	13.6	3 000	5.0	25 900	43.6
	1970	20 160	33.9	8 700	14.6	5 460	9.2	25 130	42.3
	1980	14 700	24.7	9 260	15.6	7 210	12.1	28 280	47.6
	1990	6 850	11.5	10 128	17.0	14 260	24.0	28 212	47.5
	2000	4 200	7.0	13 267	22.3	15 180	25.5	26 803	45.2
	2010	3 586	6.0	12 640	21.3	17 520	29.4	27 430	43.3
	2015	3 013	5.0	14 120	23.7	14 887	25.0	27 430	46.3
2. Kuan-Zhana-dar'ya (67 100 ha)	1960	1 000	1.5	28 700	42.8	6 300	9.4	31 100	46.3
	1970	1 000	1.5	28 100	41.8	7 400	11.0	30 600	45.7
	1980	950	1.4	28 500	42.4	7 950	11.8	29 700	44.4
	1990	950	1.4	29 100	43.3	8 150	12.1	28 900	43.2
	2000	940	1.4	29 600	44.1	8 260	12.3	28 300	42.2
	2010	920	1.4	28 200	42.0	9 450	14.0	28 530	42.6
	2015	900	1.3	27 282	40.6	10 918	16.3	30 000	41.8
3. Kyzylorda (128 900 ha)	1960	32 200	25.0	30 500	23.7	12 500	9.7	53 700	41.6
	1970	30 100	23.3	28 500	22.1	13 600	10.6	56 700	44.0
	1980	29 500	22.9	27 630	21.4	14 200	11.0	57 570	44.7
	1990	29 150	22.6	26 500	20.6	15 000	11.6	58 250	45.2
	2000	28 100	21.8	26 150	20.3	16 500	12.8	58 150	45.1
	2010	26 100	20.2	25 400	19.7	17 450	13.5	59 950	46.6
	2015	25 450	19.7	24 600	19.1	18 500	14.3	60 350	46.9
4. Shiely--Zhanakorgan (45 600 ha)	1960	10 700	23.5	5 800	12.7	8 000	17.5	21 100	46.3
	1970	9 200	20.1	6 820	15.0	16 150	35.4	13 430	29.5
	1980	7 150	15.7	10 520	23.0	14 500	31.9	13 430	29.4
	1990	5 420	11.9	15 200	33.3	11 000	24.2	13 980	30.6
	2000	3 327	7.3	17 771	39.0	15 730	34.5	8 772	19.2
	2010	3 059	6.7	23 000	50.4	10 153	22.4	9 388	20.5
	2015	2 980	6.5	23 500	51.5	11 420	25.1	7 700	16.9
5. Togusken (31 500 ha)	1960	14 100	44.8	6 500	20.6	5 000	15.9	5 900	18.7
	1970	13 100	41.6	7 100	22.5	6 180	19.6	5 120	16.3
	1980	12 200	38.7	6 800	21.5	8 000	25.3	4 500	14.5
	1990	11 000	34.9	5 000	15.9	12 000	38.0	3 500	17.6
	2000	10 000	31.7	3 000	9.5	14 500	46.0	4 000	12.8
	2010	9 640	30.6	2 980	9.4	15 080	47.8	3 800	12.2
	2015	8 500	27.0	2 850	9.3	16 950	53.8	3 200	9.9
Kyzylorda region Total area of 5 massifs (332 550 ha)	1960	80 450	24.2	79 600	23.9	34 800	10.5	137 700	41.4
	1970	73 560	22.1	79 220	23.8	83 590	25.1	131 480	30.0
	1980	64 500	19.4	80 710	24.3	51 860	15.6	133 480	40.7
	1990	53 370	16.0	85 328	25.6	60 410	18.2	132 842	40.2
	2000	46 567	14.0	89 788	27.0	70 170	21.1	126 025	37.9
	2010	43 305	13.0	92 220	27.7	69 653	20.9	129 098	38.4
	2015	40 843	12.3	92 352	27.8	72 675	21.8	128 680	38.1

Source: own elaboration.

Table 2. Dynamics of water intake and collector-drainage water in irrigated areas in the lower reaches of the Syr Darya River (Kyzylorda region, Republic of Kazakhstan)

Indicator	Value in years						
	1960	1970	1980	1990	2000	2010	2015
The Kazalin massif (59 450 ha)							
Specific water intake (thous. $m^3 \cdot ha^{-1}$)	21.1	23.4	24.1	26.1	24.6	20.1	22.9
System efficiency	0.69	0.67	0.65	0.63	0.60	0.60	0.60
Share of drainage water	0.43	0.49	0.50	0.54	0.47	0.40	0.32
Mineralization of river water ($g \cdot dm^{-3}$)	0.85	1.01	1.72	1.82	2.15	1.85	1.50
Mineralization of drainage water ($g \cdot dm^{-3}$)	1.8	2.9	3.8	4.5	5.3	5.2	5.2
The Kuan-Zhana-dar'ya massif (67 100 ha)							
Specific water intake (thous. $m^3 \cdot ha^{-1}$)	21.1	22.8	24.1	26.1	23.8	20.6	31.5
System efficiency	0.69	0.67	0.65	0.63	0.60	0.60	0.60
Share of drainage water	0.43	0.47	0.50	0.54	0.42	0.37	0.42
Mineralization of river water ($g \cdot dm^{-3}$)	0.70	0.98	1.74	1.71	1.48	1.52	1.30
Mineralization of drainage water $g \cdot dm^{-3}$)	1.5	2.7	3.2	3.7	4.1	4.2	4.3
The Kyzylorda massif (128 900 ha)							
Specific water intake (thous. $m^3 \cdot ha^{-1}$	21.1	23.2	24.1	26.1	23.0	26.0	30.5
System efficiency	0.69	0.67	0.65	0.63	0.60	0.60	0.60
Share of drainage water	0.43	0.48	0.50	0.57	0.41	0.54	0.45
Mineralization of river water ($g \cdot dm^{-3}$)	0.70	0.98	1.74	1.71	1.48	1.52	1.30
Mineralization of drainage water $g \cdot dm^{-3}$)	1.3	2.5	2.9	3.7	4.4	4.2	4.2
The Shiely-Zhanakorgan massif (45 600 ha)							
Specific water intake (thous. $m^3 \cdot ha^{-1}$)	23.2	23.6	24.1	24.3	16.7	17.8	17.9
System efficiency	0.68	0.65	0.63	0.60	0.60	0.60	0.60
Share of drainage water	0.48	0.49	0.50	0.51	0.40	0.41	0.40
Mineralization of river water ($g \cdot dm^{-3}$)	0.74	0.94	1.74	1.40	1.30	1.35	1.30
Mineralization of drainage water $g \cdot dm^{-3}$)	1.2	2.1	2.6	2.8	3.3	3.2	3.2
The Togusken massif (31 500 ha)							
Specific water intake, thousand ($m^3 \cdot ha^{-1}$)	24.7	24.1	24.8	26.1	17.3	25.0	15.2
System efficiency	0.68	0.65	0.63	0.60	0.60	0.60	0.60
Share of drainage water	0.51	0.50	0.52	0.54	0.31	0.53	0.40
Mineralization of river water ($g \cdot dm^{-3}$)	0.74	0.94	1.74	1.40	1.30	1.35	1.30
Mineralization of drainage water ($g \cdot dm^{-3}$)	1.2	2.3	2.8	2.9	3.3	3.2	3.2

Source: own elaboration.

Fig. 1. Administrative map of Kyzylorda region of the Republic of Kazakhstan; source: own elaboration

causes of the negative ecological situation are not only the subsequent use of natural resources with the deployment of various productive forces, as in activities that transform the agricultural landscape system.

Quantitative assessment of the ecological situation of agro landscapes can be made as follows, first to consider the natural environment at the regional or local level, zoning by type of activity that does not vary significantly in the space-time scale $t_i \rightarrow t_o$ (where t_i = past period; t_o = present period). Activity parameters $\overline{D}_i$ are expressed in fractions of the total volume of the natural resource that were under the influence of various factors (Φ_i). Within each anthropogenic activity, the reduced negative reaction coefficients for human – $\overline{NR} = NR_i/NR_{\max}$ and for its habitat – $\overline{nr} = nr_i/nr_{\max}$ [KHACHATURYAN 1990a, b; MUSTAFAYEV, KOZYKEEVA 2012].

The values $\overline{NR}$ and $\overline{nr}$ varies from 0 to 1, with an increase in the coefficients of an assessment of the deterioration of the situation.

Approximate dependencies for assessing the impact of anthropogenic activities have the form [DMITRIEV 1995]:

– for human/man $\overline{NR} = \left(\sum_1^i \overline{D}_i q_x\right) \sum_1^i \varepsilon_i(k)$ (1)

– for its habitat $\overline{nr} = \left(\frac{\overline{D}_{iw}}{\overline{D}_{rw}} + q_x\right) \sum_1^i \beta \varepsilon_i(k)$

Where: $\overline{D}_i$ – the degree of contamination of pesticides with drinking water to supply the population; $\overline{D}_{iw}$ – level of use of river waters for irrigation (iw); $\overline{D}_{rw}$ – level of use of return water (rw) for irrigation; ε_i = particular parameters of the deterioration of the properties of the components of the natural system (for humans this is the dynamics of diseases associated with the consumption of contaminated water and air pollution), $\varepsilon_i(r)$ = for soil, plants and crops, $\varepsilon_i(k)$ = the content of toxic salts in the soil, for groundwater an increase in their mineralization and level); β = correction factor (for soils and groundwater, for crops $\beta > 1$); q_x = the intensity of the flow of pesticides and nitrates into soils and groundwater.

Intensity of intake of pesticides and nitrates in groundwater q_x^{gw} and in the soil (q_x^n) are estimated by empirical relationships [KHACHATURYAN 1990a, b; MUSTAFAYEV, KOZYKEEVA 2012]

$$q_x^{gw} = 1 - q_x^n \quad (2)$$

$$q_x^n = \exp[-(\alpha\, q_w + 1/R_\Phi)]$$

Where: α = constant, depending on the type of pesticides and equal to 2.0; q_w = intensity of infiltration nutrition (in fractions of the norm); R_Φ = infiltration resistance, which is determined by the formula: $R_\Phi = 1/f_m$, where f_m = relative area occupied by land with low fertility due to thin surface layer of the soils.

RESULTS

On the basis of the information and analytical materials of the South Kazakhstan hydro-geological and land reclamation (drainage and irrigation) expeditions and the Aral-Syr Darya Basin Inspection for regulating the use and protection of water resources (Tabs. 1 and 2), as well as methods for assessing the environmental situation of natural systems for assessing the impact of anthropogenic activities of its habitat and the main parameters of the impact of anthropotechnogenic activity were determined (Tab. 3).

As can be seen from Table 3, the intensity of the intake of pesticides and nitrates in soils (q_x^n) and in plants (q_x^n) have feedback, that is, if the intensity of the intake of pesticides and nitrates decreases in soils, then the intensity of the intake of pesticides and nitrates in plants increases or vice versa.

In the forecast calculation, the specific parameters of degradation of the properties of the components of the natural system were determined depending on the level of the tasks being solved, that is:

Table 3. Assessment of the parameters of the impact of anthropotechnogenic activity of its habitat (soil and plants) in the context of irrigated areas in Kyzylorda region

Irrigation massif	Years	Hydroecological indicators			
		intensity of infiltration nutrition (q_w, in fractions of the norm)	intensity movement of pesticides and nitrates in the soil (q_x^n)	intensity movement of pesticides and nitrates in groundwater (q_x^g)	ratio of the use of return waters to the use of river water $\overline{D}_{iw}/\overline{D}_{rw}$
1	2	3	4	5	6
Kazalin (59 450 ha) $R_\Phi = 1/f_m = 1/0.25 = 4.00$	1960	0.43	0.3295	0.6705	0.15
	1970	0.49	0.2923	0.7077	0.20
	1980	0.50	0.2865	0.7135	0.40
	1990	0.54	0.2644	0.7356	0.45
	2000	0.47	0.3042	0.6958	0.51
	2010	0.40	0.3166	0.6834	0.53
	2015	0.32	0.4106	0.5894	0.32
Kuan-Zhana-dar'ya (67 100 ha) $R_\Phi = 1/f_m = 1/0.35 = 2.36$	1960	0.43	0.2982	0.7018	0.13
	1970	0.47	0.2753	0.7247	0.16
	1980	0.50	0.2592	0.7408	0.32
	1990	0.54	0.2393	0.7607	0.38
	2000	0.42	0.3042	0.6958	0.42
	2010	0.37	0.3362	0.6638	0.47
	2015	0.42	0.3042	0.6958	0.42

cont. Tab. 3

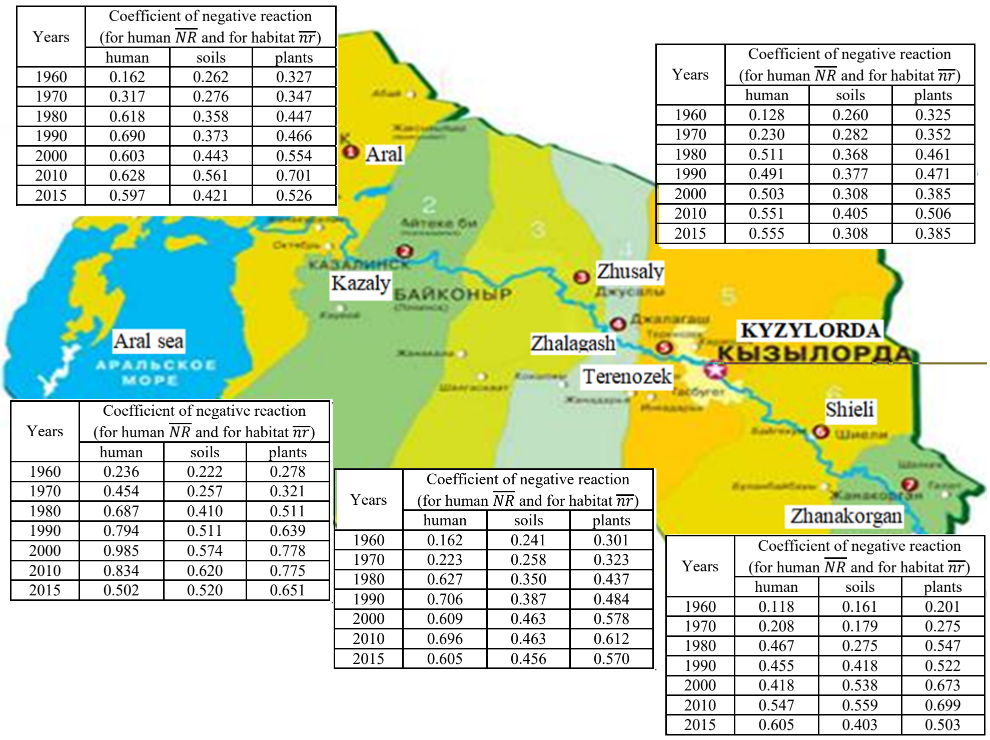
1	2	3	4	5	6
Kyzylorda (128 900 ha) $R_Ф = 1/f_m = 1/0.32 = 3.13$	1960	0.43	0.3073	0.6927	0.13
	1970	0.48	0.2780	0.7220	0.16
	1980	0.50	0.2671	0.7329	0.32
	1990	0.57	0.2322	0.7678	0.38
	2000	0.41	0.3198	0.6802	0.42
	2010	0.54	0.2466	0.7534	0.47
	2015	0.45	0.2952	0.7048	0.45
Shiely-Zhannakorgan (45 600 ha) $R_Ф = 1/f_m = 1/0.30 = 3.30$	1960	0.48	0.2836	0.7164	0.10
	1970	0.49	0.2780	0.7220	0.13
	1980	0.50	0.2725	0.7275	0.30
	1990	0.51	0.2671	0.7329	0.36
	2000	0.40	0.3329	0.6671	0.40
	2010	0.41	0.3263	0.6737	0.42
	2015	0.40	0.3329	0.6671	0.40
Togusken (31 500 ha) $R_Ф = 1/f_m = 1/0.50 = 2.00$	1960	0.51	0.2187	0.7813	0.10
	1970	0.50	0.2231	0.7769	0.13
	1980	0.52	0.2144	0.7856	0.30
	1990	0.54	0.2060	0.7940	0.36
	2000	0.31	0.3263	0.6737	0.40
	2010	0.53	0.2101	0.7899	0.42
	2015	0.40	0.2725	0.7275	0.40

Source: own study.

– when assessing the impact of anthropogenic activities on humans ($\overline{NR}$) the particular parameters of the degradation of the properties of the components of the natural system were taken from the parameters of deterioration of the river water properties, which are defined as the ratio of the salinity of the river waters considered in the calculation range (C_{oi}) to the maximum permissible salinity of river water for drinking water supply (C_o = 1.0 g·dm^{-3}), that is $\varepsilon_{p\text{в}i} = C_{oi}/C_o$;

– when assessing the impact of anthropogenic activities for soil, the degree of soil salinity, that is, the ratio of saline land area ($F_{\text{з}i}$) to the total area of the irrigated massif (F_o) for the period t_i and t_o:$\varepsilon_i(\text{з}k) = F_{\text{з}i}/F_o$.

The result of the predictive calculation of the anthropotechnical activity of its habitat, that is a negative reaction for a person in the context of irrigated massifs in the Kyzylorda region in a time scale, is shown in Figure 2 and Table 4.



Years	Coefficient of negative reaction (for human $\overline{NR}$ and for habitat $\overline{nr}$)		
	human	soils	plants
1960	0.162	0.262	0.327
1970	0.317	0.276	0.347
1980	0.618	0.358	0.447
1990	0.690	0.373	0.466
2000	0.603	0.443	0.554
2010	0.628	0.561	0.701
2015	0.597	0.421	0.526

Years	Coefficient of negative reaction (for human $\overline{NR}$ and for habitat $\overline{nr}$)		
	human	soils	plants
1960	0.128	0.260	0.325
1970	0.230	0.282	0.352
1980	0.511	0.368	0.461
1990	0.491	0.377	0.471
2000	0.503	0.308	0.385
2010	0.551	0.405	0.506
2015	0.555	0.308	0.385

Years	Coefficient of negative reaction (for human $\overline{NR}$ and for habitat $\overline{nr}$)		
	human	soils	plants
1960	0.236	0.222	0.278
1970	0.454	0.257	0.321
1980	0.687	0.410	0.511
1990	0.794	0.511	0.639
2000	0.985	0.574	0.778
2010	0.834	0.620	0.775
2015	0.502	0.520	0.651

Years	Coefficient of negative reaction (for human $\overline{NR}$ and for habitat $\overline{nr}$)		
	human	soils	plants
1960	0.162	0.241	0.301
1970	0.223	0.258	0.323
1980	0.627	0.350	0.437
1990	0.706	0.387	0.484
2000	0.609	0.463	0.578
2010	0.696	0.463	0.612
2015	0.605	0.456	0.570

Years	Coefficient of negative reaction (for human $\overline{NR}$ and for habitat $\overline{nr}$)		
	human	soils	plants
1960	0.118	0.161	0.201
1970	0.208	0.179	0.275
1980	0.467	0.275	0.547
1990	0.455	0.418	0.522
2000	0.418	0.538	0.673
2010	0.547	0.559	0.699
2015	0.605	0.403	0.503

Fig. 2. Hydro-ecological situation in the lower reaches of the Syr Darya (Kyzylorda region of the Republic of Kazakhstan); source: own study

Table 4. Assessment of anthropo-technogenic activity on human habitat of the natural system of the Kyzylorda region in the context of irrigated massifs on a time scale

Irrigation massif	Years	Parameters of the ecological situation of the natural system			
		parameters of deterioration of properties of river water ($\varepsilon_{r\beta_i}$)	the degree of contamination with potable water ($\overline{D}_i$)	intensity of intake of pesticides and nitrates in groundwater (q_x^g)	negative reaction coefficient for humans ($\overline{NR}$)
Kazalin (59 450 ha)	1960	0.850	0.40	0.6705	0.2355
	1970	1.010	0.52	0.7077	0.4543
	1980	1.720	0.56	0.7135	0.6874
	1990	1.820	0.60	0.7356	0.7936
	2000	2.150	0.65	0.6958	0.9849
	2010	1.850	0.66	0.6834	0.8344
	2015	1.500	0.67	0.5894	0.5923
Kuan-Zhana-dar'ya (67 100 ha)	1960	0.700	0.35	0.7018	0.1617
	1970	0.980	0.48	0.7247	0.3169
	1980	1.740	0.52	0.7408	0.6183
	1990	1.710	0.58	0.7607	0.6901
	2000	1.480	0.62	0.6958	0.6028
	2010	1.520	0.65	0.6638	0.6282
	2015	1.300	0.66	0.6958	0.5969
Kyzylorda (128 900 ha)	1960	0.700	0.35	0.6927	0.1618
	1970	0.980	0.48	0.7220	0.3229
	1980	1.740	0.52	0.7329	0.6266
	1990	1.710	0.58	0.7678	0.7057
	2000	1.480	0.62	0.6802	0.6091
	2010	1.520	0.65	0.7534	0.6963
	2015	1.300	0.66	0.7048	0.6047
Shiely-Zhanakorgan (45 600 ha)	1960	0.740	0.25	0.7164	0.1281
	1970	0.940	0.35	0.7220	0.2299
	1980	1.740	0.42	0.7275	0.5106
	1990	1.400	0.50	0.7329	0.4913
	2000	1.300	0.58	0.6671	0.5030
	2010	1.350	0.63	0.6737	0.5106
	2015	1.300	0.64	0.6671	0.5550
Togusken (31 500 ha)	1960	0.740	0.25	0.7813	0.1176
	1970	0.940	0.35	0.7769	0.2080
	1980	1.740	0.42	0.7856	0.4673
	1990	1.400	0.50	0.7940	0.4546
	2000	1.300	0.58	0.6737	0.4185
	2010	1.350	0.63	0.7899	0.5469
	2015	1.300	0.64	0.7275	0.6053

Source: own study.

As can be seen from Table 4, the negative human reaction of anthropo-technogenic activity in the lower reaches of the Syr Darya River in the context of irrigated massifs on a time scale shows that their amplification is observed along river basins and the duration of exposure to natural and man-caused loads, that is, on a spatial and temporal scale, favourable conditions are observed in the area of location of the Togusken irrigation massif in comparison with the Kazalinsky massif, since the former is located relatively higher along the river.

Assessment of the ecological situation of the natural system in the lower reaches of the Syr Darya River as a habitat for soil and plants in the context of irrigated massifs in the Kyzylorda region on a time scale is shown in Table 5.

The assessment of the environmental situation in 1960–2015, both in natural areas (not transformed by economic activity) as well as agricultural areas in the lower reaches of the Syr Darya River, was carried out on the basis of many years of research and field observation results. Research and systematic measurements as well as field observations were carried out by field expeditions, both hydrogeological and ameliorative (drainage and irrigation). The purpose of field measurements and observations obtained by expeditions in South Kazakhstan and the Aral-Syr Darya Basin Inspection was to assess the use and protection of water resources (Tabs. 1 and 2, Fig. 1) [ALIMOV 1990; MUSTAFAYEV, KOZYKEEVA 2012]. Methodological support for the assessment of the environmental situation and, above all, the assessment of the environmental effects resulting from anthropogenic activity is based on the assessment of the condition of the natural environment. However, the basis for justifying the implementation of drainage projects is compliance with the basic laws of nature, and above all with the laws of conservation and the circulation of matter and energy, the change of which is caused by anthropogenic factors included in the works of KHACHATURIAN [1990a, b], KHACHATURIAN and AIDAROV [1990; 1991], as well as MUSTAFAYEV and KOZYKEEVA [2009].

Table 5. Assessment of anthropo-technogenic activity on soils and plants of the natural system of the Kyzylorda region in the context of irrigated massifs on a time scale

Irrigation massiv	Years	Parameters of the ecological situation of the natural system				
		relative area of saline lands ($\varepsilon_i(sk)$)	intensity of intake of pesticides and nitrates in soils (q_x^n)	ratio of utilization rate of returnable waters to use river water $\overline{D}_{iw}/\overline{D}_{rw}$	coefficients of negative reaction ($\overline{nr}$)	
					soil	plant
Kazalin (59 450 ha)	1960	0.486	0.3295	0.150	0.2223	0.2779
	1970	0.515	0.2923	0.200	0.2567	0.3209
	1980	0.597	0.2865	0.400	0.4097	0.5112
	1990	0.707	0.2644	0.450	0.5114	0.6393
	2000	0.713	0.3042	0.510	0.5741	0.7176
	2010	0.732	0.3166	0.530	0.6197	0.7746
	2015	0.713	0.4106	0.320	0.5209	0.6511
Kuan-Zhana-dar'ya (67 100 ha)	1960	0.557	0.2982	0.130	0.2616	0.3270
	1970	0.567	0.2753	0.160	0.2757	0.3446
	1980	0.562	0.2592	0.320	0.3578	0.4472
	1990	0.545	0.2393	0.380	0.3729	0.4661
	2000	0.581	0.3042	0.420	0.4433	0.5541
	2010	0.672	0.3362	0.470	0.5606	0.7008
	2015	0.581	0.3042	0.420	0.4207	0.5260
Kyzylorda (128 900 ha)	1960	0.513	0.3073	0.130	0.2409	0.3011
	1970	0.546	0.2780	0.160	0.2585	0.3231
	1980	0.557	0.2671	0.320	0.3495	0.4369
	1990	0.579	0.2322	0.380	0.3871	0.4839
	2000	0.612	0.3198	0.420	0.4628	0.5785
	2010	0.640	0.2466	0.470	0.4897	0.6121
	2015	0.612	0.2952	0.450	0.4560	0.5700
Shiely-Zhanakorgan (45 600 ha)	1960	0.638	0.2836	0.100	0.2600	0.3250
	1970	0.649	0.2780	0.130	0.2818	0.3523
	1980	0.613	0.2725	0.300	0.3685	0.4606
	1990	0.537	0.2671	0.360	0.3771	0.4714
	2000	0.420	0.3329	0.400	0.3078	0.3848
	2010	0.494	0.3263	0.420	0.4049	0.5061
	2015	0.420	0.3329	0.400	0.3078	0.3847
Togusken (31 500 ha)	1960	0.346	0.2187	0.100	0.1606	0.2008
	1970	0.359	0.2231	0.130	0.1787	0.2234
	1980	0.398	0.2144	0.300	0.2749	0.3436
	1990	0.588	0.2060	0.360	0.4178	0.5223
	2000	0.637	0.3263	0.400	0.5382	0.6728
	2010	0.720	0.2101	0.420	0.5594	0.6993
	2015	0.599	0.2725	0.400	0.4028	0.5035

Source: own study.

When assessing the ecological situation of the soil and plant environment, however, a factor is adopted to correct soil tolerance to pollution, because soils are more resistant to anthropogenic effects compared to vegetation. This means that depending on the state of the soil habitat, there are changes in the plant cover that adapts to the surrounding environment. Therefore, taking into account the current state of the plant cover in the lower course of the Syr Darya River, it is assumed that the quantitative value of the correction factor for plants is β = 1.25.

As can be seen from Table 5 and Figure 2, the condition of the soil and plant environment in the lower reaches of the Syr Darya River in all irrigated areas deteriorates on a time scale as a result of intensive irrigation of agricultural areas, (intensive) secondary soil salinity occurs but also the generation of infiltration outflow with high mineralization, harmonization of relations between nature and different activity of society).

In addition, there is a need for a comprehensive assessment of the needs of appropriate technical and organizational measures in the lower reaches of the Syr Darya River. The aim of these activities should be to restore environmental sustainability and sustainable development through technical and organizational measures aimed at renewing the natural environment, both as a place of residence for the local population and economic activities (including agricultural activities). To assess biodiversity, qualitative methods were often used to assess the environmental situation in the lower reaches of the Syr Darya River. However, quantitative methods are much more appropriate. The most commonly used quantitative measure of biodiversity is the Shannon index. Its value determines the probability that two individuals selected from the sample will belong to different species [ESPOSITO, FLOUDAS] [2001].

At the same time, the quality of the community's habitat, that is, man, soil and plants, is a very effective indicator of the trophic state of agrolandscapes. Almost any limnological survey of agrolandscapes begins with determining the level of soil salinity, plant productivity and quality, that is, the latter is one of the main indicators of the quality of human life. Therefore, when developing the classification of the trophic state of agrolandscapes, the index of the integral danger of the ecological situation on human health [KHACHATURYAN, AIDAROV 1990] and the assessment of the trophic status of the water body according to the Shannon index (*H*) [MUSTAFAYEV 1997; 2004 – Table 6.

Table 6. Evaluation of trophic status of agrolandscapes

The Shannon diversity index (*H*)	Index of ecological situation (E_s)	Status		
		human	soil	plants
Ultra-oligotrophic agrolandscape				
3.06–2.30	0.16	not dangerous	very high	the cleanest
Oligotrophic agrolandscape				
2.30–1.89	0.16–0.32	conditionally dangerous	high	very clean
Mesotrophic agrolandscape				
1.89–1.70	0.32–0.48	little dangerous	moderately high	clean
Mesoeutrophic agrolandscape				
1.70–1.52	0.48–0.64	differently-dangerous	average	moderately contaminated
Eutrophic agrolandscape				
1.52–1.25	0.64–0.80	very dangerous	low	contaminated
Hypereutrophic agrolandscape				
1.25–1.11	1	excessively dangerous	very low	very contaminated

Source: own elaboration.

To determine the level of interconnection of the Shannon diversity index (*H*) and index of integral danger of ecological situation on human health E_s) methods of math-statistics were used, which showed the presence of high correlation (Fig. 3).

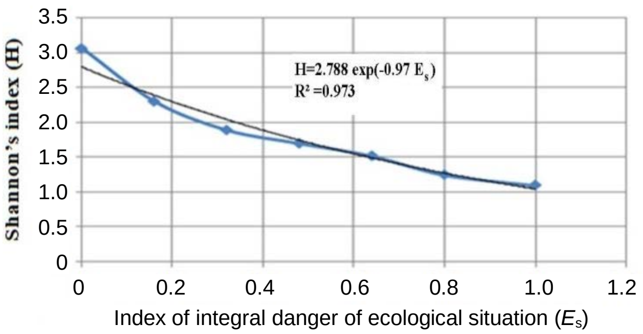


Fig. 3. Dependence of the Shannon diversity index (*H*) of the integral hazard index of the environmental situation (E_s); source: own study

The Shannon diversity index (*H*) is determined on the basis of the index of the integral danger of the ecological situation on human health (E_s) by the following formula: $H = 2.788 \exp(-0.97 E_s)$.

CONCLUSIONS

1. The results presented in the paper concern annual salinity indices in the years 1960–2015 for five irrigated complexes with a total area of 332.55 thous. ha. Such a long period of investigation allows for the formulation of objective conclusions concerning the dynamics of changes in salinity in the irrigated areas. In general, it can be concluded that the share of unsalted and poorly saline land is decreasing in favour of saline and highly saline areas.

2. At the same time, it should be noted that the results of the assessment of the ecological situation of the natural system in the lower reaches of the Syr Darya River allow for the development of the right decisions, guaranteeing, first of all, the preservation of natural features of nature as far as possible. This may allow rational decisions to be made to restore the natural productivity of landscape systems and, above all, to minimize the salinity of soils and water resources.

3. Based on the results of field observations characterizing the hydrological and environmental situation of the lower section of the Syr Darya River in the years 1960–2015, negative response coefficients for the population, soil and plants for the area of the Kyzylorda Region were calculated for fiver sections.

4. Using the Shannon diversity index, habitat trophism was determined and classified along with the status of agricultural areas. Based on the calculations, a functional relationship has also been developed between the Shannon diversity index and the environmental risk indicator, which can be used to predict changes in the natural environment under similar conditions, such as the lower course of the Syr Darya River.

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