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IRRIGATIVE ASSESSMENT OF SASYK WATER QUALITY

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Abstract. The article is dedicated to the problem of artificial Lake Sasyk which was transformed from a salty water estuary into a freshwater reservoir at the expense of the Danube waters.
In the first decades, the irrigative water conditions were not achieved due to the arrival of salts from the bottom sediments. Currently, the water quality formation process in Lake Sasyk has stabilized, but the problem of land irrigation remains urgent.
The article gives an irrigation assessment of the quality of the Sasyk reservoir according to various methods considering observations in the HPS-2 region from 2007 to 2017. A detailed typification of irrigation waters based on Alekin O. A. water typing is proposed.
It was found that mineralization and the content of sodium and magnesium ions in the Sasyk waters promote salinization and alkalinization of soils. For the safe use of this water for irrigation, both chemical reclamation and dilution with water are necessary.

Key words: irrigative assessment, water quality, salinization, alkalinization.

1. Introduction

To irrigate the lands of the Tatarbunarsky and Saratsky regions the salt-water estuary Sasyk was transformed into a fresh-water reservoir: in 1978, it was separated from the sea by a dam and connected to the Danube by a canal. In the first decades of the existence of the Sasyk reservoir, the design water conditions were not achieved primarily because the mineralization of the Danube water in the reservoir increased due to the flow of salts accumulated in the sediments of the salt-water estuary during its existence.

The process of water quality formation in Sasyk has now stabilized (after forty years of its existence as a reservoir). But today the problem of irrigation of the Tatarbunarsky and Saratsky regions remains relevant because of the unsatisfactory quality of the irrigation water.

Many scientific and popular science works are devoted to the ecological problems of Sasyk (Lazovitskii, 2003; Kulibabin et al., 1997; Vasenko, 2004; Tymchenko, Ivanova, 2012; Ivanova, 2010). In these works, the irrigation properties of water are evaluated by the average and maximum values of indicators. But during some periods of the year, the properties of water can differ significantly from each other and not meet the averaged characteristics. During the year, water can belong to different irrigation categories (classes).

The aim of the work is to assess the irrigation properties of Sasyk waters and their variability during the warm period according to hydro-chemical observations in the area of the village of Trapivka, GNS-2 from 2007 to 2017 (according to the Odessa Regional Department of Water Resources).

The object of research is the Sasyk Reservoir.

The subject of the study is the assessment of the variability of the irrigation properties of Sasyk waters.

2. Basic principles of irrigation water quality assessment

The irrigation water quality assessment is carried out according to four criteria:

– the concentration of salts;

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– the ratio of ions (mainly sodium cations with magnesium and calcium);

– the concentration of toxic elements that can negatively affect agricultural plants and the environment in general;

– the concentration of nutrients.

Concentration of salts. The main ions that determine the mineralization of water are cations – potassium (K^+), sodium (Na^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}); anions – chlorides ($Cl^–$), sulfates ($SO_4^{2–}$), carbonates ($CO_3^{2–}$) and hydrocarbons ($HCO_3^–$). Potassium is often considered with sodium, and carbonates with hydrocarbons.

Using water with high mineralization can lead to soil salinization. The salinization of soils is called an excessive accumulation of electrolyte (dissolved or absorbed) salts Na_2CO_3, $NaHCO_3$, NaCl, $CaCl_2$, Na_2SO_4, $MgCl_2$, $MgSO_4$ in the root containing layer which oppress or destroy agricultural plants, reduce the yield and its quality. Salinity can be neutral (chlorides and sulfates of sodium and magnesium) and alkaline (carbonates and bicarbonates of sodium and magnesium) (Slyusarev et al., 2014).

According to Kostyakov A., the danger of soil salinization based on the total mineralization of the irrigation water is estimated as follows:

– up to 1.0 g/dm^3–is suitable for irrigation; from 1.0 to 1.5 g/dm^3 – cautious irrigation; from 1.5 to 3.0 g/dm^3–it is necessary to analyse the chemical composition of salts, over 3 g/dm^3–is not suitable for irrigation (Kostyakov, 1960).

– up to 0.4 g/dm^3 – the water is suitable for irrigation; from 0.4 to 1.0 g/dm^3 – limited using; from 1.0 to 3.0 g/dm^3 – an increased risk for plants; over 3 g/dm^3 – the secondary salinity (Zanosova, Molchanova, 2017).

In the USA the following irrigation water salinity classification (MG, g/dm^3) is used:

– MG≤0.20 – low salinity water suitable for irrigation of most crops on the most soils;

– 0.20 <MG≤0.50 – medium salinity water used in the conditions of moderate leaching, medium salt tolerance crops can be grown without using anti-salinity agents;

– 0.50 <MG≤1.00 – high salinity water, even with good drainage, measures to control salinity may be necessary; cultures that have a high salt resistance should be selected;

– 1.00 <MG≤3.00 – very high salinity water, unsuitable for irrigation under normal conditions, irrigation is possible under the following conditions: high soil permeability, drainage, salt-resistance of crops.

The level of soil salinity is also characterized by the toxicity index. The toxicity threshold is the boundary value of the salt content in which the inhibition of agricultural crops growth and development is observed.

Table 1 presents the toxicity of the main salts that are found in soil and water.

Table 1

The toxicity of main salts [6, p. 9; 9, p. 84; 10, p. 386]

NaCl	Na_2SO_4	Na_2CO_3	$NaHCO_3$
$MgCl_2$	$MgSO_4$	$MgCO_3$	$Mg(HCO_3)_2$
$CaCl_2$	$CaSO_4$	$CaCO_3$	$Ca(HCO_3)_2$

Salts that are above a strip (Table 1) are harmful to plants. The most toxic ones are soda (Na_2SO_3, $NaHCO_3$), chloride (NaCl) and sulfuric acid (Na_2SO_4) sodium, calcium chloride ($CaCl_2$). Sulfate and magnesium chloride ($MgSO_4$, $MgCl_2$) have less toxicity. The mixtures of salts are always less toxic than their cleaner clusters.

Kovda V. (Arinushkina, 1970) arranges the toxicity of salts in the following order: Na_2CO_3 > >$NaHCO_3$ > NaCl > $CaCl_2$ > Na_2SO_4 > $MgCl_2$ > $MgSO_4$.

Salts dissolved in water are usually represented as ions. However, sometimes the suitability of water for irrigation is determined by the ratio of the content of the certain types of soluble salts in it (Kostyakov, 1960).

The main ions can be toxic and non-toxic. Toxic ions include ions that can form toxic salts. The ions of Cl^- and Na^+ are toxic, other main ions can be both toxic and non-toxic depending on their mutual equilibrium: Mg^{2+} and Ca^{2+} with Cl– are toxic salts, but with $CO_3^{2–}$ and $HCO_3^–$ – nontoxic; $CO_3^{2–}$ and $HCO_3^–$ with Na^+ are the most toxic to plants, but with Mg^{2+} and Ca^{2+} are non-toxic (Zaydel'man et al., 2007). Such an analysis of ions toxicity is presented in the work (Zaydel'man et al., 2007). Isolation of toxic ions can be conveniently performed if the mineralization of water is presented as a sum of hypothetical salts.

Presentation of the mineral composition of water as a set of hypothetical salts is not used in practice, since in water the ions are in a bound state, and in the chemical analysis, the content of ions is determined, but these salts are rather often mentioned in the literature (Kostyakov, 1960; Zaydel'man et al., 2007; Astapov, 1958; Maksimov, 1979; Alekin, 1970).

For example, the founder of the Soviet period melioration Kostyakov A. points out the need to analyze the chemical composition of salts for the waters with the mineralization of 1.5–3.0 mg/dm^3 (Kostyakov, 1960). According to Alekin O. one can get an approximate idea of the nature of the salts that will come to the ground from this water, if we conditionally assume that when the water evaporates, salts will fall out when the ions are combined in the following sequence: cations – Ca^{2+}, Mg^{2+}, Na^{+}; anions – HCO_3^{-}, SO_4^{2-}, Cl^{-} (Alekin, 1970).

In the Hydrogeologist Reference Guide (Maksimov, 1979) the sequence of combining the ions is reversed: anions – Cl^{-}; SO_4^{2-}; (CO_3^{2-}+HCO_3^{-}); cations – (K^{+}+Na^{+}); Mg^{2+}; Ca^{2+}. However, the result of the salts analysis in a direct sequence or in reverse one will be the same.

The authors of the article offer the types of natural waters (I, II, III) (Alekin, 1970) for irrigation purposes, divide into subtypes (I, IIa, IIb, IIIa, IIIb, IIIc), which have different irrigation properties. Type IV is not considered since it includes waters (Alekin, 1970) which are not suitable for irrigation.

For waters of types I and II (fig. 1) the ratio of ions $rNa^{+}>rCl^{-}$ is characteristic, for type III – $rNa^{+}\le rCl^{-}$, further:

I – $rNa^{+}>rCl^{-}+rSO_4^{2-}$;
IIa – $rNa^{+}>rCl^{-}$ and $rNa^{+}\le rCl^{-}+rSO_4^{2-}$ and $rCa^{2+}\le rHCO_3^{-}$;
IIb – $rNa^{+}>rCl^{-}$ and $rNa^{+}\le rCl^{-}+rSO_4^{2-}$ and $rCa^{2+}>rHCO_3^{-}$;
IIIa – $rNa^{+}\le rCl^{-}$ and $rNa^{+}+rMg^{2+}>rCl^{-}$ and $rCa^{2+}\le rHCO_3^{-}$;
IIIb – $rNa^{+}\le rCl^{-}$ and $rNa^{+}+rMg^{2+}>rCl^{-}$ and $rCa^{2+}>rHCO_3^{-}$;
IIIc – $rNa^{+}+rMg^{2+}\le rCl^{-}$.

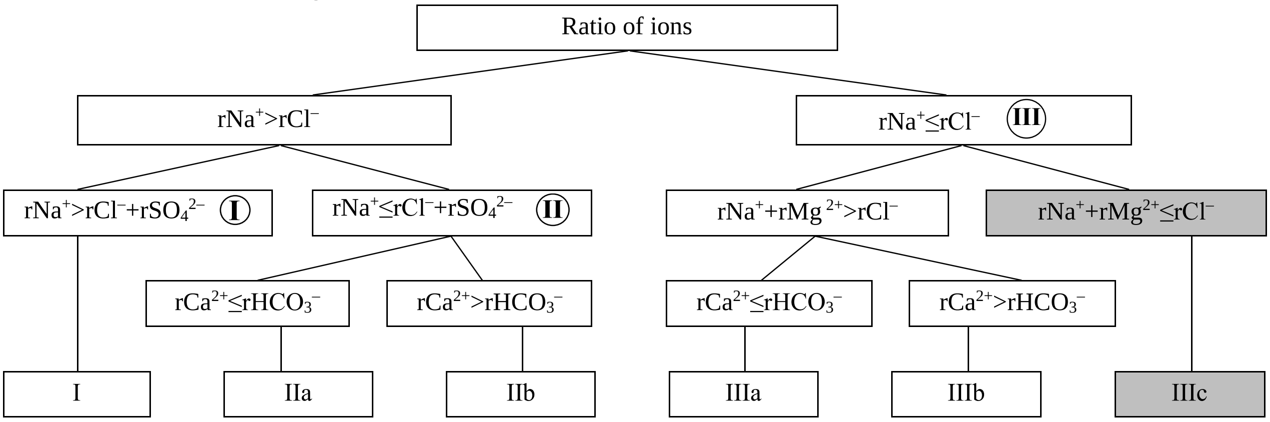

Fig. 1. The scheme of the irrigation water detailed typification

By the mutual balancing of the main ions in the sequence described above, it is possible to compose sets of hypothetical salts for water subtypes (that is, to estimate toxic ions in water):

I	– **$NaCl$**,	**Na_2SO_4**,	**$NaHCO_3$**,	$Mg(HCO_3)_2$,	$Ca(HCO_3)_2$;
IIa	– **$NaCl$**,	**Na_2SO_4**,	**$MgSO_4$**,	$Mg(HCO_3)_2$,	$Ca(HCO_3)_2$;
IIb	– **$NaCl$**,	**Na_2SO_4**,	**$MgSO_4$**,	$CaSO_4$,	$Ca(HCO_3)_2$;
IIIa	– **$NaCl$**,	**$MgCl_2$**,	**$MgSO_4$**,	$Mg(HCO_3)_2$,	$Ca(HCO_3)_2$;
IIIb	– **$NaCl$**,	**$MgCl_2$**,	**$MgSO_4$**,	$CaSO_4$,	$Ca(HCO_3)_2$;
IIIc	– **$NaCl$**,	**$MgCl_2$**,	**$CaCl_2$**,	$CaSO_4$,	$Ca(HCO_3)_2$.

For all considered water subtypes, the possibility of forming sodium chloride ($NaCl$) and calcium bicarbonate ($Ca(HCO_3)_2$) in the soil is common, therefore, in the analysis, let us focus only on the characteristic differences.

By the set of toxic salts the water of type I can be the most unfavourable for irrigation since besides sodium sulfate (Na_2SO_4) they can form sodium bicarbonate ($NaHCO_3$) in the soil, and in the presence of carbonate ions (CO_3^{2-}) – common soda (Na_2CO_3), of all salts formed by the main ions, is the most toxic to plants. These salts cause an alkaline reaction of the soil.

– Water of type II differs from water of type I because magnesium sulfate (MgSO4) which is in the last place in a number of salts toxicity (according to V. Kovda) may be added to the soil instead of carbonate and sodium hydrogen carbonate (Na_2CO_3 and $NaHCO_3$).

– The difference between subtypes IIa and IIb is as follows:

– from waters of subtype IIa besides $MgSO_4$, magnesium hydrocarbonate ($Mg(HCO_3)_2$) may also come into the soil. It is a non-toxic salt to plants, but it can cause alkaline soil reactions;

– water of subtype IIb contributes to forming another non-toxic salt – gypsum ($CaSO_4\times 2H_2O$), instead of magnesium hydrocarbon, – in the soil. Gypsum is a meliorant of alkaline soils.

Subtype IIIa in comparison with subtype IIa is more favourable, since when the water of this subtype evaporates less toxic magnesium chloride ($MgCl_2$), instead of sodium sulfate (Na_2SO_4), may come into the soil. However, in the waters of this subtype, there is a large number of magnesium ions and their excessive content in water contributes to the alkalinization of the soil.

Subtypes IIIa and IIIb differ from each other in the same way as subtypes IIa and IIb: IIIa promotes the formation of magnesium bicarbonate in the soil ($Mg(HCO_3)_2$), and IIIb promotes the formation of calcium sulphate ($CaSO_4$).

In waters of subtype IIIв in contrast to subtype IIb there is more toxic plant salt – calcium chloride ($CaCl_2$) – instead of magnesium sulfate ($MgSO_4$). According to the degree of favorableness for irrigation, the qualitative composition of toxic salts of this water subtype should be in the second place after the water of type I.

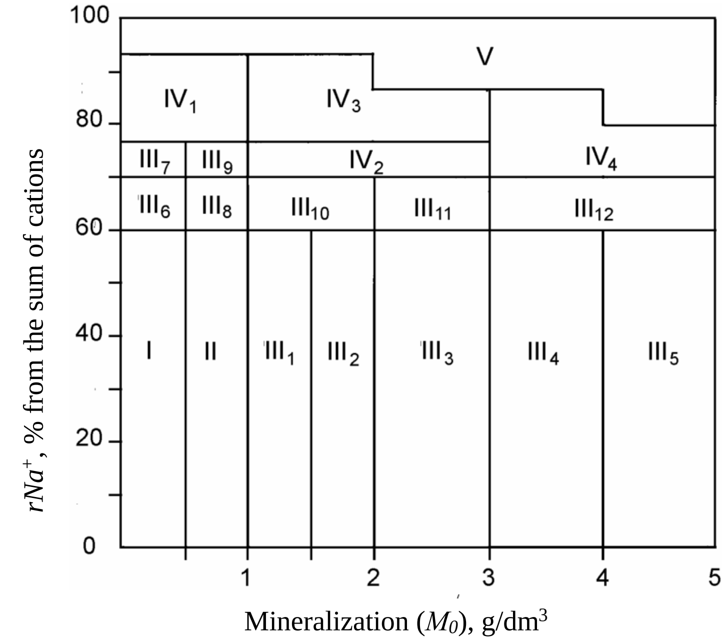

Fig. 2. Classification of mineralized waters by the degree of their suitability for irrigation (Bezdnina S.):
I – water is completely suitable for irrigation of all types of soils;
II – water is suitable for irrigation of most types of soils;
III – water is partially suitable (III1-5 – requires to be improved by dilution,
III6-7 – requires chemical melioration, III8-12 – requires dilution and chemical melioration);
IV – conditionally suitable water (IV1 – requires chemical melioration,
IV2-4 – requires dilution and chemical melioration);
V – water is not suitable for irrigation

The concentration of toxic ions (mg-eq/dm^3) in different water subtypes is as follows:

– type I – rCl^-; rNa^+; rSO_4^{2-} and a portion of hydrocarbonate ions, which is balanced by a portion of sodium ions $(rHCO_3^-)_{Na}=(rHCO_3^- – rCa^{2+} – rMg^{2+})$;

– subtype IIa – rCl^-; rNa^+; rSO_4^{2-} and a portion of magnesium ions which is balanced by a portion of sulfate ions $(rMg^{2+})_S=(rCl^- + rSO_4^{2-} – rNa^+)$;

– subtype IIb – rCl^-; rNa^+; rMg^{2+} and a portion of sulfate ions which is balanced by a portion of sodium and magnesium ions $(rSO_4^{2-})_{Na,Mg}=(rNa^+ – rCl^- + rMg^{2+})$;

– subtype IIIa – rCl^-; rNa^+; rSO_4^{2-} and a portion of magnesium ions which is balanced by a portion of chloride and sulfate ions $(rMg^{2+})_{Cl,S}=(rCl^- – rNa^+ + rSO_4^{2-})$;

– subtype IIIb – rCl^-; rNa^+; rMg^2 and a portion of sulfate ions which is balanced by a portion of magnesium ions $(rSO_4^{2-})_{Mg}=(rNa^+ + rMg^{2+} – rCl^-)$;

– subtype IIIc – rCl^-; rNa^+; rMg^2 and a portion of calcium ions which is balanced by a portion of chloride ions $(rCa^{2+})_{Cl}=(rCl^- – rNa^+ – rMg^{2+})=(rCa^{2+} – rHCO_3^- – rSO_4^{2-})$.

To recalculate the ion concentration from an equivalent form (mg-eq/dm^3) to a weight form (mg/dm^3) it is necessary: to multiply the value of the equivalent concentration of an ion by its ionic weight and to divide by the valence of this ion.

The ratio of ions. The assessment of the irrigation water quality by the ion ratio is the most common.

In Bezdnina S. classification the percentages of sodium (Bezdnina, 2013) ions and the sum of cations are taken into account along with the mineralization of water (Fig. 2).

Stebeler irrigation (alkaline) coefficient is numerically equal to the thickness of the water layer in inches, when this water evaporates the amount of salts harmful for most plants is formed in the soil. This coefficient is calculated by the following formulas depending on the type of water (Slyusarev et al., 2014):

$K_a = 288/(5rCl^-)$, at $rCl^- > rNa^+$ (III),

$K_a = 288/(rNa^+ + 4rCl^-)$, at $rCl^- + rSO_4^{2-} > rNa^+ > rCl^-$ (II),

$K_a = 288/(10rNa^+ - 5rCl^- - 9rSO_4^{2-})$, at $rNa^+ > rCl^- + rSO_4^{2-}$ (I),

where rNa^+, rCl^-, rSO_4^{2-} is a concentration of ions, mg-eq/dm^3.

In this case the suitability of water for irrigation is estimated as follows:

– $K_a \geq 18$ – “good”, unlimitedly suitable for irrigation of all crops;

– $18 > K_a \geq 6$ – “satisfactory”, suitable for irrigation of most cultures depending on the soil-climatic conditions;

– $6 > K_a \geq 1.2$ – “unsatisfactory”, partially suitable for irrigation of salt-resistant crops under good artificial drainage, washing irrigation and reclamation measures (for example, introducing the gypsum emulsion into water);

– $K_a < 1.2$ – “bad”, unsuitable for irrigation.

Antipov-Karatayev I. and Kader G. (Slyusarev et al., 2014; Zanosova, Molchanova, 2017; Zaydel'man, 2003; Arinushkina, 1970) proposed to assess the irrigation water (danger of watering) according to the following ratio:

$$K = (Ca^{2+} + Mg^{2+})/Na^+ \geq 0.23M_O,$$

where: M_0 is a total concentration of soluble salts in water, g/dm^3; Ca^{2+}, Mg^{2+}, Na^+ is a concentration of cations in mmol/dm^3.

Antipov-Karatayev I. and Kader G. believe that the critical ratio of cations $[(Ca^{2+} + Mg^{2+}) / Na^+]_{10}$, at which the amount of absorbed sodium reaches 10 % of the cation exchange capacity (CEC) of the soil, is equal to 0.23 M_O. Therefore, when $K < 0.23\ M_O$ the water is not suitable for irrigation.

Budanov M. states that water with mineralization ≤ 1 g/dm^3 can be used for irrigation when the ratio of sodium to calcium (K_1) is a maximum of 1, and sodium to the sum of calcium and magnesium (K_2) is not more than 0.7. For water with mineralization 1–3 g/dm^3, while preserving the first, an additional condition is introduced: the sum ($r\Sigma\hat{e}$) of the main ions divided by the sum of calcium and magnesium, (K_3) must not exceed: 4 – for medium and highly loamy soils; 5 – for light-loamy soils; 6 – for sub-sandy and sandy soils:

1) $K_1 = rNa^+/rCa^{2+} \leq 1.0$;

2) $K_2 = rNa^+/(rCa^{2+} + rMg^{2+}) \leq 0.70$;

3) $K_3 = r\Sigma\hat{e}/(rCa^{2+} + rMg^{2+}) \leq B$.

Mozheiko A. and Vorotnyk T. believe that waters are suitable for irrigation at the condition:

$$K = (Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+) \leq 0.65,$$

where Na^+, K^+, Ca^{2+} i Mg^{2+} is a concentration of cations in mmol/dm^3.

At $K \leq 0.65$ water is suitable for irrigation, $0.65 < K \leq 0.75$ water is unsuitable, $K > 0.75$ water is very unsuitable, because it causes alkalinization of soil.

Sabolch I. and Dorab K. believe that the amount of rMg^{2+} in irrigation water does not harm the soil if (Zaydel'man, 2003; Arinushkina, 1970; Atdaev, Akmamedov, 2012):

$$rMg^{2+}/(rCa^{2+} + rMg^{2+}) \leq 0.50.$$

The absorption ratio (SAR) is calculated using the Gapon formula (used to estimate water in the United States) [6, p. 16]:

$$SAR = rNa^+/[(rCa^{2+} + rMg^{2+})/2]^{0.5},$$

where rNa^+, rCa^{2+}, $rMg^{2+\ s}$ is a concentration of salt cations, mg-eq/dm^3;

The value of SAR is given for assessing the danger of soil alkalinization: $SAR \leq 10$ – low; $10 < SAR \leq 18$ – average; $18 < SAR \leq 26$ – high; $SAR > 26$ – very high.

Richards L.A. assesses the danger of salinization depending on the total mineralization and the value of SAR (Table 2).

Concentration of toxic ions. For each species of plants, toxic substances may be different, therefore the list of toxic ions depends on the cultivated culture.

In general, when assessing the toxicity of individual ions, the content of boron (B^{3+}), sodium (Na^+), chloride (Cl^-), heavy metals (As^{3+}, Co^{2+}, Cu^{2+}, Pb^{2+}, Ni^+, Zn^{2+}), nitrates (NO_3^-), total alkalinity (HCO_3^-) and pH in water is taken into account. Increased content of toxic ions in irrigation water can lead to their accumulation in the leaves, cause burns of plants (this can occur when sprinkled at the daytime). Table 1.3 shows the characteristics of the irrigation water quality under the different methods of irrigation, depending on the concentration of Na^+, Cl^-, HCO_3^-, B^{3+} i NO_3^-ions.

Table 2

Richards L. [9, p. 87]

M_O, g/dm^3	Danger of soil alkalinization	Danger of alkalinization by the value of *SAR*			
		low	average	high	very high
$M_O \leq 1$	Low	$SAR \leq 10$	$10 < SAR \leq 18$	$18 < SAR \leq 26$	$SAR > 26$
$1 < M_O \leq 2$	Average	$SAR \leq 8$	$8 < SAR \leq 15$	$15 < SAR \leq 22$	$SAR > 22$
$2 < M_O \leq 3$	High	$SAR \leq 6$	$6 < SAR \leq 12$	$12 < SAR \leq 18$	$SAR > 18$
$M_O > 3$	Very high	$SAR \leq 4$	$4 < SAR \leq 9$	$9 < SAR \leq 14$	$SAR > 14$

Table 3

Toxicity of ions for agricultural crops under surface watering and sprinkling

Ion	Watering method	Water quality		
		Good	Average	Bad
Na^+, mol/dm^3	Surface watering	≤3	>3 ÷≤ 9	>9
	Sprinkling	≤3		>3
Cl^-, mol/dm^3	Surface watering	≤4	>4 ÷ ≤10	>10
	Sprinkling	≤3		>3
HCO_3^-, mol/dm^3	Sprinkling	≤1.5	>1.5 ÷ ≤8.5	>8.5
B^{3+}, mg/dm^3	With any watering	≤0.7	>0.7 ÷ ≤2.9	>2.9
NO_3^-, mg/dm^3	With any watering	≤5	>5 ÷ ≤30	>30

3. Assessment of water quality of the Sasyk reservoir and the analysis of the results

In order to assess water quality in the Sasyk water body, the results of the statistical processing of the initial data in the range of the village of Trapivka, HPS-2 locations for the period from 2007 to 2017 (according to the Odessa Regional Department of Water Resources, Table 4) were used.

The assessment of water quality of the Sasyk reservoir for irrigation properties is presented in Table 5.

The mineralization of Sasyk waters during the warm period (WP) is on average 1620 mg/dm^3 in the range of fluctuations from 324 to 3550 mg/dm^3.

By the classification of Alekin O. (Maksimov, 1979) Sasyk waters belong to the chloride class, sodium group within 85–90 % of the WP.

On average, the waters of Sasyk belong to subtype IIb, but the conditions for forming their quality are such that during the WP they may be subtypes: IIa (30 %), Ib (50 %), IIIb (10 %) and IIIc (10 %). If the cold season is included in the review, the distribution of the water subtypes in Sasyk will be as follows: IIa (29 %), Ib (42 %), IIIa (5 %), IIIb (19 %) and IIIc (5 %). That is, all subtypes of water are found except subtype I. Such a variety of water subtypes throughout the year indicates a large number of factors that influence the formation of water quality in Sasyk.

The total concentration of toxic salts (ions) is 1294 mg/dm^3 (range – 96–3273 mg/dm^3). When the waters of Sasyk dry up, NaCl salt can be formed in an average amount of 787 mg/dm^3 (up to 1344 mg/dm^3). This salt, according to a degree of toxicity, corresponds to sodium bicarbonate $NaHCO_3$. In addition, during 80 and 90 % of the WP (respectively) less toxic salts can be formed: Na_2SO_4 in an average of 199 mg/dm^3 (up to 1587 mg/dm^3) and $MgSO_4$ - 358 mg/dm^3 (up to 542 mg/dm^3).

Thus, with the evaporation of a 10 mm water layer on an area of 1 hectare, an average of 130 kg/ha (up to 330 kg/ha) of toxic salts can be formed. They are: 79 kg/ha (up to 130 kg/ha) will be NaCl; 20 kg/ha (up to 160 kg/ha) – Na_2SO_4; 36 kg/ha (up to 54 kg/ha) – $MgSO_4$.

According to Kostyakov's A. A. classification water of Sasyk is classified as "high-risk" water, according to the US classification – water with "very high" salinity. When using Sasyk water for irrigation there is a high risk of salinization of the soil.

According to Bezdnina's S. classification water of Sasyk belongs to category III. The waters of this category can be used for irrigation after chemical melioration and dilution with low mineral water.

Within 90 % of the WP, according to Stegler's X. classification, the water is unsatisfactory. It is limitedly suitable for the irrigation of salt-resistant crops. The danger of salinization according to Antipov-Karatayev I.N. and Kader G.M.–the water is "not suitable" during 70 % of the WP, according to Budanov A.M.–the water is "not suitable" within 90 % of the WP, according to Mozheiko A.M. and Vorotnyk T. K. the water is "very unfavourable" during 65 % of the WP and "unfavourable" during 22 % of the WP. According to the SAR indicator of the United States Department of Agriculture the danger of watering is "low" within 96 % of the WP, this does not coincide with the assessment of other methods.

According to Sobolch G. and Darab K. the amount of magnesium in the water of Sasyk has a detrimental effect on the soils (the danger of magnesium alkanization) during 80 % of the WP. According to Kelly and Libih, using Sasyk water for irrigation is impossible due to the sodium content during 87 % of the WP.

Table 4

The results of monitoring the water quality of the Sasyk reservoir (warm period) (according to the Odessa Regional Department of Water Resources)

No.	Point	Date	pH	mg/dm^3								
				Gen.min.	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
2	lake Sasyk, HPS-2, v.Trapivka	24.04.2007	8.3	2043	12	231.8	553	602.7	115	103.3	424.8	14.7
3		05.07.2007	8.1	324	0	183	39.8	26.6	22	30.4	22.5	2.5
5		14.04.2008	8.4	1552	12	195.2	365.8	478.6	90	60.8	350.1	6
6		21.08.2008	8.3	1662	18	152.5	465.6	496.3	70	85.1	374.9	6
9		28.05.2009	8.3	1197	12	189.1	200.2	407.7	60	48.6	279.9	10
10		26.08.2009	8.4	963	12	140.3	96	390	100	24.3	200.1	7
13		31.05.2010	7.1	1487	0	207.4	416.2	390	90	48.6	335.1	12
14		16.08.2010	7.3	1099	0	158.6	217	372.2	50	51.6	250	14
17		13.05.2011	7.8	1595	0	231.8	403.7	460.9	70	79	349.8	14
18		20.06.2011	7.0	1623	0	219.6	393.6	496.3	60	79	374.9	15
19		12.09.2011	8.2	944	7	139.3	110	355	100	36.3	155.1	6
22		16.05.2012	8.2	1562	18	170.8	396	478.6	60	78.9	359.9	15
23		13.08.2012	7.4	1486	0	170.8	407.1	443.1	40	85.1	339.9	14
26		24.05.2013	7.9	469	0	207.4	88.3	53.2	50	30.4	40	5
27		17.07.2013	8.2	1533	24	115.9	387.8	514	60	91.1	339.9	16
30		26.05.2014	7.2	2094	0	256.2	573.1	593.8	210	60.8	399.9	3
31		02.09.2014	7.1	1955	0	207.4	503	620.4	90	94.2	439.9	16
34		14.05.2015	7.4	2187	0	244	710.4	549.5	90	103.3	489.9	13
35		07.08.2015	8.1	1852	6	170.8	407	655.8	120	66.8	425	16
36		23.10.2015	8.2	3550	12	195.2	1463	726.7	65	103.3	985,1	15
38		16.05.2016	9.2	1782	24	158.6	347.5	673.6	75	103.3	400	15
39		10.08.2016	8.4	2264	24	122	553.9	815.4	80	109.4	559,8	21
42		17.05.2017	7.9	2035	6	250.1	493	638.1	100	97.2	450,1	15
Average value			7.9	1620	14.4	188	417	489	81.2	72.6	363	11.8
MIN			7.0	324	6	116	39.8	26.6	22.0	24.3	22.5	2.5
MAX			9.2	3550	24	256	1463	815	210	109	985	21.0

Table 5

The results of statistical processing of hydrochemical observations in the Sasyk reservoir (HPS-2) (warm period) (the results of statistical processing of the authors of the article)

Value	M_0	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	C_{tox}
aver., mg/dm^3	1620	188	417	489	81.2	72.6	363	11.8	1294
min, mg/dm^3	324	116	39.8	26.6	22.0	24.3	22.5	2.5	96.2
max, mg/dm^3	3550	256	1463	815	210	109	985	21.0	3273

Value	CO_3^{2-}	$MgCO_3$	$CaCO_3$	$Ca(HCO_3)_2$	$NaHCO_3$	$Mg(HCO_3)_2$	$CaSO_4$	Na_2SO_4	$MgSO_4$	$CaCl_2$	NaCl	$MgCl_2$
aver., mg/dm^3	14.4	16.3	21.2	233	0.0	49.4	105	198.9	358	16.1	787.3	78.6
max, mg/dm^3	56.5	17.1	40.0	340	0.0	139	428	1587	542	16.5	1344	142
p%	24.0	13.0	52.2	100	0.0	30.4	60.9	82.6	91.3	8.7	100	17.4

Continuation of Table 5

Value	Class						Group						Type
aver.	carbonate	13	sulfate	34	chloride	53	calcium	16	magnesium	23	sodium	62	IIb
p%	carbonate – 8.7 sulfate – 4.3 chloride – 87.0						calcium – 0.0 magnesium – 8.7 sodium – 91.3						IIa – 30.0 IIb – 50.0 IIIb – 10.0 IIIc – 10.0

Value	Kostyakov A. M.		Bezdnina S. Y.		Mozheiko A. M. Vorotnyk T. K.		Antypov-Karataiev I. N. Kader G. M.			Budanov A. M.			
	M_0	assessment	Na^+	assessment	*K*	assessment	$0.23M_0$	*PKO*	assessm.	K_1	K_2	K_3	assessm.
aver.	1620	incr. dang.	61	III(6, 8, 10–12)	76.2	very unfavor.	0.37	0.32	unsuit.	3.90	1.57	5.18	unsuit.
p%	good – 4.3 caref. appr. – 13.0 incr. dang. – 78.3 subsoil – 4.3		I – 8.7 II –8.7 III(1–5) –17.4 III(6. 8, 10–12) –60.9 IV4 –4.3		favorable – 13.0 unfavorable – 21.7 very unfav. – 65.2		suitable – 30.4 unsuitable – 69.6			suitable – 8.7 unsuitable – 91.3			

Value	The USA Classif.		Stabler X.		The USA Dep. of agricult.		Sabolch G. and Darab K.		Kelly and Libih		
	M_0	salinity	K_H	assessment	SAR	Danger of alkalization	K_{Mg}	Affect on soils	K_{Na}	K_{Mg}	Possibility of using
aver.	1620	very high	4.1	unsatisfactory	7.05	low	60	harmful	1.57	0.60	not possible
p%	average – 8.7 high – 8.7 very high – 78.3		good – 8.7 unsatisfact. – 91.3		low – 95.7 average – 4.3		not harmful – 21.7 harmful – 78.3		possible – 13.0 not possible – 87.0		

4. Conclusions

1. In general, the assessment of the irrigation properties of Sasyk water, according to different methods, is the same: the salinity of the waters is very high and promotes salinization of the soil; the content of sodium and magnesium creates the danger of soil alkalinity.

2. For safe using Sasyk water for irrigation, their chemical melioration and dilution with water with low mineralization are necessary.

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