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Suitability and assessment of surface water in the Bereslav reservoir water-intake zone for irrigation purpose

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Abstract. The aim of the study was to monitor and assess the suitability of surface water in the intake area of the Bereslav Reservoir for irrigation. During the growing season, water mineralization varied from 0.998 to 1.601 g·dm^{-3}. According to A.N. Kostyakov, the water is characterized as slightly mineralized and belongs mainly to group III. According to O.A. Alekin, water at the beginning and end of the growing season is classified as sodium sulfate-chloride class; in July and August, the water chemistry changes to sulfate class of magnesium-sodium group. Observations of seasonal changes in the main components of mineral composition of water relative to their maximum permissible concentrations revealed an excess of sulfate anion in May and August by 7 and 91 mg·dm^{-3}, respectively, and in July — almost 1.5 times. In the cation series, the main pollutants were sodium (in combination with potassium), its highest concentration in May was 299 mg·dm^{-3}, in July it decreased to the maximum permissible value, as well as magnesium, concentration of which in July exceeded the standard by 28 mg·dm^{-3}. In terms of concentration of sodium chlorides and sulfates, the irrigation water is of satisfactory quality. Actual values of mineral composition of the water and calculated values of irrigation coefficients, considering variability of chemical composition of the water over time, indicate its possible negative impact on ionic equilibrium in soil absorption complex. As a result, in order to maintain ameliorative state of the soils, it is necessary to develop and regularly carry out agrotechnical and agroameliorative measures to prevent salinization processes.

Keywords: water quality, ionic composition, mineralization, irrigation assessment, impact on soil, soil salinization

Authors' contribution. All authors planned the experiments, performed the experiments, analysed the data, made an equivalent contribution to the preparation of the manuscript.

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Introduction

Economic activity and environmental factors have a significant impact on ionic composition of watercourses, hydrochemical regime and quality of surface water. The resulting processes of chemical and biological transformation of water bodies determine the type of water use [1, 2].

According to available long-term data, surface waters are regularly polluted with biogenic elements, heavy metals, and other pollutants of anthropogenic origin, the actual concentrations of which exceed the maximum permissible concentrations for open water bodies [3, 4]. Therefore, all natural waters are characterized by a multicomponent composition, which determines their classification according to the set of permissible values of chemical elements, within which the use of a water body is recommended.

One of the important indicators of water quality is its mineral composition, in particular ions of the 1st group (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+), which determine its water-salt balance and mineralization. Seasonal concentration of these ions is subject to change and the indicators of component composition of water vary greatly depending on geological and climatic conditions, which creates problems for interested water users [5].

In this regard, assessing the quality of natural waters used for irrigation is an important task for monitoring meliorative state of soils.

The purpose of the study was to monitor and assess suitability of surface waters in the water intake zone of the Bereslav Reservoir for irrigation.

Materials and methods

The object of the study was the waters of the Bereslav Reservoir. Water samples were collected monthly from May to September 2023 from a depth of 0.30…0.35 m in clean plastic bottles, pre-rinsed in the water. The study of water samples was carried out in the testing laboratory of Russian Research Institute of Irrigated Agriculture using known methods (Table 1).

Table 1

Methods for studying ion-salt composition of water samples

Indicator	Research method
Carbonates CO_3^{2-} and bicarbonates HCO_3^-	Titrimetric[1]
Chloride ion Cl^-	Titrimetric[2]
Sulfate ion SO_4^{2-}	Titrimetric[3]
Calcium Ca^{2+} and magnesium Mg^{2+} in complex	Complexometric titration[4]
Sodium Na^+ and potassium K^+ in the complex	Flame photometric[5]

The water was classified using O.A. Alekin's method[6]: classes by the predominant anion, %-eq: hydrocarbonate (CO_3^{2-} + HCO_3^-), sulfate (SO_4^{2-}) and chloride (Cl–); groups by the predominant cation, %-eq: calcium, magnesium and sodium; types by the ratio between ions, mg-eq/dm³.

The ion-salt composition of water was expressed using M.G. Kurlov's formula in general form[7]:

$$S_p, M \frac{\overrightarrow{\text{anions}}}{\overrightarrow{\text{cations}}} \text{pH}, T, D,$$

where S*p* — microelements (As, Fe, F, etc.) and free gases (CO_2, H_2S, N_2, etc.), mg/dm³; M — total mineralization of water, g/dm³; in the numerator and denominator — respectively, anions and cations in descending order with a content of at least 5%-eq; pH — indicator of hydrogen cation activity, units; T — water temperature, °C;

[1] Interstate Council for Standartization, Metrology and Sertification. GOST 31957—2012. *Voda. Metody opredeleniya shchelochnosti i massovoi kontsentratsii karbonatov i gidrokarbonatov* [Water. Methods for determining alkalinity and mass concentration of carbonates and hydrocarbonates]. Moscow: Standartinform publ.; 2019. (In Russ.).

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[6] Alekin OA. *Osnovy gidrokhimii* [Fundamentals of hydrochemistry]. Leningrad; 1970. (In Russ.).

[7] Reznikov AA, Mulikovskaya EP, Sokolov IY. *Metody analiza prirodnykh vod* [Methods of analysis of natural waters]. Moscow: Nedra publ.; 1970. (In Russ.).

D — water flow rate (consumption), m^3/day. The quality of irrigation water was assessed by its total mineralization (Table 2), as well as the values of irrigation coefficients considering the content of sodium chlorides and sulfates K_i (> 18.0 — good; 18.0…6.0 — satisfactory; 5.9…1.2 — unsatisfactory; < 1.2 — unsuitable for irrigation), the probability of sodium K_{Na} and magnesium K_{Mg} alkalization of the soil (> 1.0 — dangerous, < 1.0 — no danger).

Table 2

Water quality assessment according to A.N. Kostyakov[8]

Group	I	II	III	IV
Mineralization, $g \cdot l^{-1}$	< 0.4	0.4…1.0	1.0…3.0	> 3.0
Water quality	Good	Limited use	Dangerous for plants	Soil salinization

Irrigation coefficients were calculated using formulas [6, 7]:

$$K_i = \frac{288}{(5 \cdot [Cl^-])} \text{ for } [Na^+] < [Cl^-];$$

$$K_i = \frac{288}{(Na^+ + 4 \cdot [Cl^-])} \text{ for } [Cl^-] + [SO_4^{2-}] > [Na^+] > [Cl^-];$$

$$K_i = \frac{288}{\left(10 \cdot [Na^+] - 5 \cdot [Cl^-] - 9 \cdot [SO_4^{2-}]\right)} \text{ for } [Na^+] > [Cl^-] + [SO_4^{2-}];$$

$$K_{Na} = \frac{[Na^+]}{[Ca^{2+}] + [Mg^{2+}]};$$

$$K_{Mg} = \frac{[Mg^{2+}]}{[Ca^{2+}]}.$$

Results and discussion

The results of the conducted studies of ion-salt composition of water samples were presented in the form of graphs (Fig. 1) [8], which illustrate dynamics of anions and cations of mineral composition by months of the growing season.

An increase in sulfate and magnesium ions and a sharp drop in concentration of sodium ions in summer months were noted, which determined the choice of methods for assessing impact of these macrocomponents on quality of water supplied for irrigation. It is worth noting that the growth of Mg^{2+} in natural water is a negative sign, since it is

[8] Kostyakov AN. *Osnovy melioratsii* [Fundamentals of land reclamation]. Moscow: Selkhozizdat publ.; 1960. (In Russ.)

toxic to plants. Moreover, increase in content of magnesium cation leads to increase in hydration of silty part of soil.

During the growing season, mineralization of natural water in the water intake zone varied in the range from 0.998 to 1.601 g/dm^3. The maximum mineralization values were observed in July, this indicator was slightly lower in May. According to A.N. Kostyakov, the water is characterized as weakly mineralized and belongs mainly to group III, posing a danger when used for irrigation of agricultural crops. According to O.A. Alekin, water at the beginning and end of the irrigation season is classified as sodium sulfate-chloride class, in July and August the water chemistry changes to sulfate class of magnesium-sodium group (Table 3).

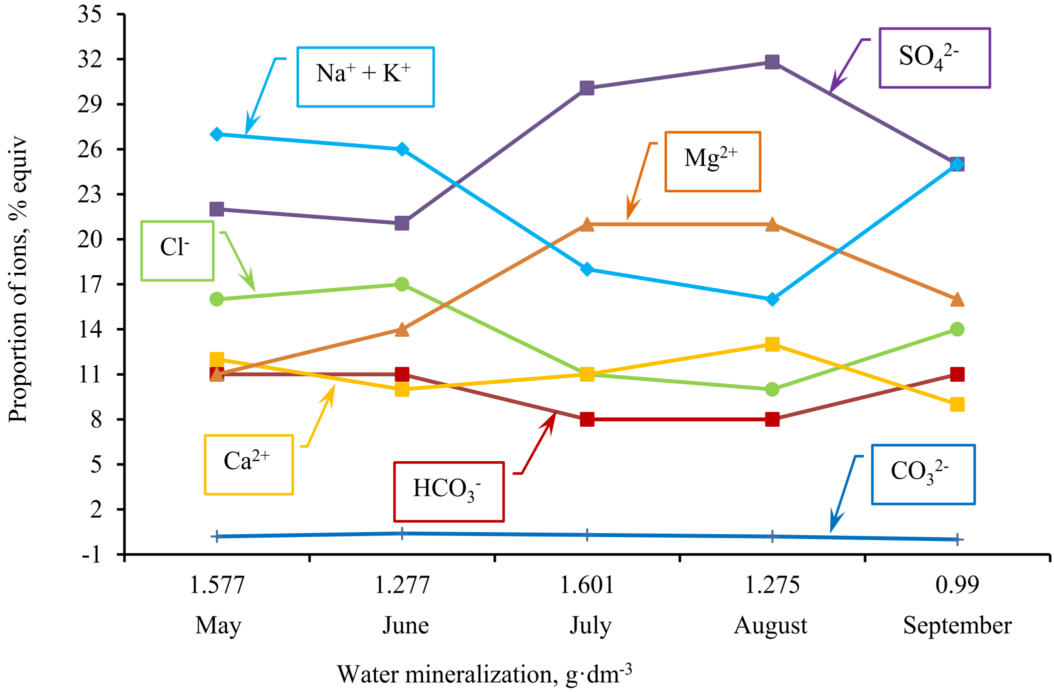

Fig. 1. Dynamics of water-salt composition of water
Sourse: compiled by A.E. Novikov, A.Y. Toropov using MS Excel, MS Word.

Table 3

Characteristics of natural water in the water intake zone by months of vegetation period

Month	Ionic-salt composition of water according to M.G. Kurlov	Water classification	
		A.N. Kostyakov	O.A. Alekin
May	$M1{,}577\frac{SO_4 44 Cl 32 HCO_3 22}{Na 54 Ca 24 Mg 22}T19{,}6 pH 8{,}2$	III	Sulfate-chloride class, sodium group
June	$M1{,}277\frac{SO_4 42 Cl 34 HCO_3 22}{Na 52 Mg 28 Ca 20}T22{,}4 pH 8{,}7$	III	

End tabl. 3

Month	Ionic-salt composition of water according to M.G. Kurlov	Water classification	
		A.N. Kostyakov	O.A. Alekin
July	$M1{,}601\frac{SO_4 60Cl22HCO_3 16}{Mg43Na35Ca22}T25{,}9pH8{,}8$	III	Sulfate class, magnesium-sodium group
August	$M1{,}275\frac{SO_4 64Cl20HCO_3 16}{Mg40Na31Ca29}T23{,}2pH8{,}5$	III	
September	$M0{,}988\frac{SO_4 50Cl28HCO_3 20}{Na50Mg32Ca18}T18{,}7pH8{,}3$	II	Sulfate-chloride class, sodium group

Sourse: compiled by A.E. Novikov, A.Y. Toropov.

In observations of seasonal changes in main components of mineral composition of water (Table 4) relative to their maximum permissible concentrations (for fishery water bodies, MPC$_f$), an excess of sulfate anion by 7 and 91 mg/dm^3, respectively, was noted in May and August, and almost 1.5 times (715 mg/dm^3 against 500 mg/dm^3) — in July.

The main cation pollutants were sodium (in combination with potassium), its highest concentration of 299 mg/dm^3 was noted in May, in July it decreased almost to MPC$_f$ (202 mg/dm^3 against 200 mg/dm^3), as well as magnesium, concentration of which in July exceeded MPC$_f$ by 28 mg/dm^3. The sharp increase in sulfate and magnesium ions in July could have been caused by a decrease in water content of the reservoir intake zone due to changes in hydrological regime, high air temperatures and absence of precipitation. This conclusion is confirmed by earlier research results on water quality in natural water sources in the considered territory of irrigated agriculture [9, 10].

In general, variability of water mineralization, on the one hand, is associated with incoming volumes of Don water pumped by pumping stations to maintain shipping and depends on the intensity of navigation. Another equally important source that increases mineralization in the water intake zone of the Bereslav Reservoir is the Peschany erik with a salt concentration of 3500…4900 mg/dm^3 having joint watershed with it [11, 12].

The calculations of irrigation coefficients (Fig. 2) considering variability of chemical composition of water over time (Table 4) also indicate its possible negative impact on ionic balance in soil absorption complex and meliorative state of soils as a whole [13—15].

Table 4

Chemical composition of natural water in the water intake zone by months of growing season

Ions	Average	Month					MPC$_f$[9], mg/dm^{-3}
		May	June	July	August	September	
CO_3^{2-}	$\frac{3.2}{0.10}$	$\frac{4.0}{0.13}$	$\frac{5.0}{0.16}$	$\frac{5.0}{0.16}$	$\frac{2.0}{0.06}$	–	100
HCO_3^-	$\frac{243.2}{3.98}$	$\frac{320.0}{5.24}$	$\frac{263.0}{4.31}$	$\frac{239.0}{3.91}$	$\frac{193.0}{3.16}$	$\frac{201.0}{3.29}$	1000

[9] Order of the Ministry of Agriculture of Russia dated 13.12.2016 No. 552 «On approval of water quality standards for water bodies of fishery importance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance» (as amended by Orders of the Ministry of Agriculture of Russia dated 12.10.2018 No. 454, dated 10.03.2020 No. 118, dated 22.08.2023 No. 687).

End tabl. 4

Ions	Average	Month					MPC_f9, mg/dm^{-3}
		May	June	July	August	September	
Cl^-	198.6 / 5.60	273.0 / 7.71	231.0 / 6.52	202.0 / 5.70	138.0 / 3.89	149.0 / 4.20	350
SO_4^{2-}	513.4 / 10.67	507.0 / 10.55	401.0 / 8.31	715.0 / 14.88	591.0 / 12.29	353.0 / 7.34	500
Ca^{2+}	96.0 / 4.45	110.0 / 5.48	85.0 / 3.99	110.0 / 5.39	120.0 / 5.88	55.0 / 2.74	200
Mg^{2+}	81.2 / 6.67	64.0 / 5.26	64.0 / 5.26	128.0 / 10.53	92.0 / 7.57	58.0 / 4.77	100
$Na^+ + K^+$	208.0 / 9.04	299.0 / 13.0	228.0 / 9.91	202.0 / 8.78	139.0 / 6.04	172.0 / 7.47	200

Note. Above the line — mg·dm^{-3}, below the line — mg-eq·dm^{-3}.

Source: compiled by A.E. Novikov, A.Y. Toropov.

Irrigation with water having mineral composition formed during the spring flood (May), the beginning of biological summer (June) and the end of crop vegetation (September) contributes to leaching of calcium and magnesium cations from colloidal phase into soil solution and development of sodium alkalinization. In July and August, the risks of magnesium alkalinization of the soil increase, accompanied by deterioration of its water-physical and filtration properties. The type of salinization of natural water (a combination of Mg^{2+} with Na^+) in the water source that developed during the observed period leads to the development of specific alkalinization of soils, which is based on the processes of transformation from a gel to a sol state of soil colloids and lithogenesis of the finely dispersed mineral part during vermiculitization of hydromica material.

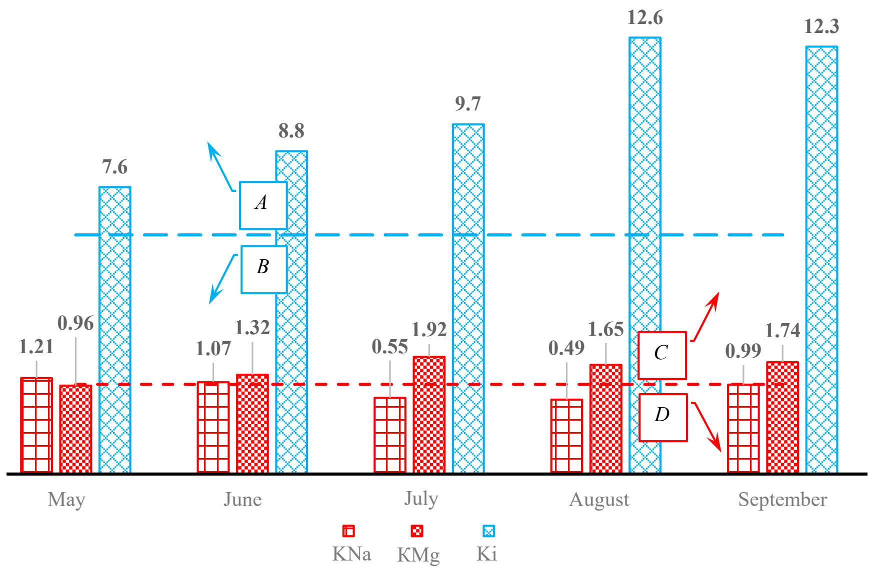

Fig. 2. Assessment of suitability of natural water for irrigation: *A* and *B* — satisfactory and unsatisfactory quality; *C* and *D* — whether or not risk of salinization

Sourse: compiled by A.E. Novikov, A.Y. Toropov using MS Excel, MS Word.

Calculations of the suitability of surface waters in relation to the content of sodium chlorides and sulfates also indicate the possibility of accumulation of harmful salts in soil and its alkalinization. Long-term use of such waters, it requires developing and implementing agrotechnical and agro-ameliorative measures to prevent these negative processes.

Conclusion

The hydrological regime and climatic factors significantly affect the dynamics of water ion-salt composition in the water intake zone of the Bereslav Reservoir. Studies in 2023 showed that during the growing season of agricultural crops from May to September, there remains the possibility of plant suppression and deterioration of melioration state of irrigated lands due to irrigation with mineralized water having a total salt content of 1000 to 2000 mg/dm^3. According to the results of calculations of irrigation coefficients that determine nature of salinization by equivalent ratio of cations, the studied natural waters pose a danger to the established equilibrium in exchange processes of soil, and with a high-quality water composition during the biological summer — risks of soil destructuring. According to the concentration of chlorides and sodium sulfates, the irrigation water is of satisfactory quality, therefore, long-term irrigation requires conducting agrotechnical and agro-ameliorative measures to prevent salinization processes.

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Мелиоративная оценка пригодности поверхностных вод водозаборной зоны Береславского водохранилища для орошения

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Аннотация. Цель исследования — оценить по итогам проводимого мониторинга пригодность поверхностных вод водозаборной зоны Береславского водохранилища для орошения. За период вегетации культур минерализация воды изменялась от 0,998 до 1,601 г/дм^3. По А.Н. Костякову вода характеризуется как слабоминерализованная и относится преимущественно к III группе. По О.А. Алекину вода на начало и конец вегетационного периода классифицируется как натриевая сульфатно-хлоридного класса, в июле и августе химизм воды сменяется на сульфатный класс магниево-натриевой группы. В наблюдениях за сезонными изменениями основных компонентов минерального состава воды относительно их предельно-допустимых концентраций отмечено превышение аниона сульфата в мае и августе соответственно на 7 и 91 мг/дм^3, а в июле — почти в 1,5 раза. В катионном ряду основными загрязнителями были натрий (в комплексе с калием) — его наибольшая концентрация в мае 299 мг/дм^3 снизилась в июле до предельно допустимого значения, а также магний, концентрация которого в июле превысила норматив на 28 мг/дм^3. По концентрации хлоридов и сульфатов натрия поливная вода удовлетворительного качества. Фактические значения показателей минерального состава воды и расчетные значения ирригационных коэффициентов с учетом изменчивости химического состава воды во времени свидетельствуют о ее возможном негативном воздействии на ионное равновесие в почвенном поглощающем комплексе. Сделан вывод о необходимости разработать и регулярно проводить агротехнические и агромелиоративные мероприятия по предупреждению процессов засоления для сохранения мелиоративного состояния почв.

Ключевые слова: качество воды, ионный состав, минерализация, ирригационная оценка, влияние на почву, засоление почв

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