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Research article

MONITORING IRRIGATION WATER QUALITY FROM THE FIRST AQUIFER IN VOJVODINA, SERBIA

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ABSTRACT

The quality of groundwater from the first aquifer in Vojvodina is primarily influenced by the geology of the Pannonian Plain, and it is mineralized to a certain extent. If used for irrigation, such mineralized water can cause soil degradation and yield reduction. This research aimed to assess the quality of groundwater by collecting water samples at locations with installed irrigation systems. The soils at the investigated sites, located in southwestern Bačka, Serbia, are classified as chernozem and meadow soils. The paper presents baseline data on groundwater quality, as well as monitoring data obtained during the irrigation system operation on two occasions. Based on the analyses performed, water quality was assessed using the American Salinity Laboratory classification and the FAO classification.

The data on the electrical conductivity and quantitative analysis of ionized components indicate that the quality of groundwater was predominantly in C3S1 class according to the US Salinity Laboratory classification. Based on FAO classification, the restrictions on use based on salinity were slight to moderate. However, deviations were recorded at certain localities, e.g. higher pH values, total dissolved solids, and electrical conductivity, indicating that irrigation management must be adapted for each locality or system. Residual sodium carbonate values suggest that sodium-related problems are not expected at certain locations, while other locations require periodical monitoring of infiltration and soil pH in order to amend the soil with acid or gypsum.

The determined chemical composition of groundwater indicates a potential risk of soil salinization, though not alkalization. Therefore, continuous monitoring is required to determine timely measures aimed at reducing the risk of salinization.

Key words:
water quality, groundwater, monitoring, salinization

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INTRODUCTION

According to the European Environmental Agency, groundwater is the source of 65% of drinking water and 25% of irrigation water. In the European Union, 24% of groundwater is classified as having poor chemical quality, with increasing pressures from agriculture and industry, which are further exacerbated by climate change (European Environment Agency, 2022). In Serbia, about 80% of the water supply relies on groundwater, whose quality is assessed for the territory of Vojvodina.

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Groundwater quality is influenced by both natural processes and anthropogenic activities. It primarily depends on the lithology and the quality of recharge water. Variations in groundwater mineral content related to secondary salinization can be caused by anthropogenic actions such as irrigation and drainage, land use, and pollution (Helena et al., 2000; Nyika et al., 2024). Therefore, the quality of irrigation water varies in different regions and locations. Reliance on groundwater for irrigation in areas and years with scarce rainfall can lead to increased salinity, which may reduce the yields of cultivated crops. Therefore, determining the concentration and composition of soluble salts is essential for evaluating water quality (Zaman et al., 2018). High content of salts is frequently attributed to slow movement of water within the first aquifer, so changes in both quantity and quality of groundwater are often slow. One of the causes of groundwater salinity is irrigation-induced salinity which, in conditions of intensive irrigation, can negatively affect both the level and quality of groundwater. Although irrigation increases soil productivity and the effectiveness of applied agronomic measures, it can lead to soil degradation and reduced yields in case the soil and irrigation water quality are not compatible.

In addition to pedogenetic factors of climate, relief, parent substrate, and organic matter, groundwater and surface waters are of great importance for land formation in Vojvodina. Their level and quality can influence the direction and intensity of pedogenetic processes. The groundwater regime of the first aquifer in Vojvodina is formed by complex interactions of climatic, topographic, and hydrological factors of the Pannonian Plain, and it has a predominantly local character. The groundwater of this aquifer in Vojvodina is mineralized, with varying concentrations of dissolved solids, most commonly calcium and/or magnesium bicarbonate type.

Groundwater monitoring is a systematic and continuous examination of its quantity and quality, including data collection, processing, analysis, and use. Its purpose is to monitor the changes in groundwater status and enable informed decision-making. Monitoring is the first step in the water management process and the preservation and protection of water as a strategic natural resource in each country. It also shows how much a country prioritizes its natural waters as a prerequisite for survival and sustainable development (Ristić-Vakanjac et al., 2018).

Groundwater management relies on baseline data and time-variant data (monitoring). Groundwater monitoring involves the collection, analysis, and storage of collected data for each specific case. The type and volume of collected data depend on the groundwater issue to be solved, but also on available financial resources. Although groundwater monitoring is often considered expensive (due to installation, sampling and analytical costs), it is a prerequisite for adequate assessment of water status, changes in trends, and corrective action requirements (Albert et al., 2006).

The aim of the paper is to evaluate the quality of groundwater baseline data and monitoring data. A further objective is to point out the importance of water quality monitoring in agricultural production and the impact of poor-quality water on crops.

MATERIAL AND METHODS

Research on the monitoring of the first aquifer was conducted in the northern Serbia, within the southwestern Bačka region (Figure 1). The baseline data were collected in June, for the purpose of designing and building irrigation systems, while monitoring was carried out the following year, in June (monitoring 1) and December (monitoring 2). Detailed sampling locations are given in Table 1.

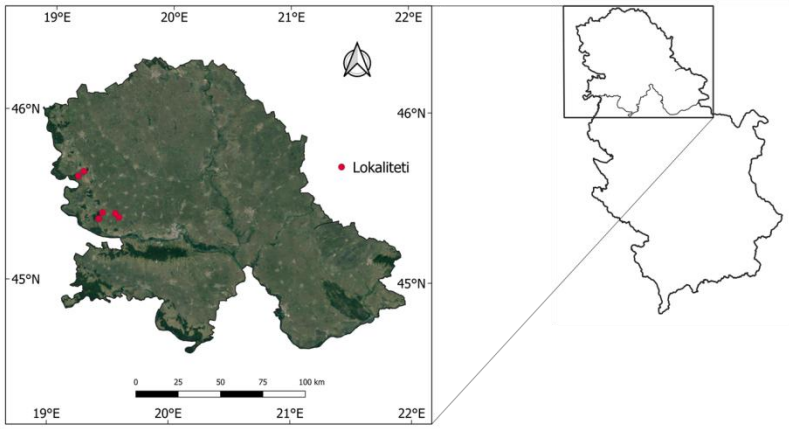

Figure 1. Studied site locations

Study area

The research site is located in Vojvodina, which occupies the southern part of the Pannonian Basin and the northern part of Serbia (Figure 1). According to the Köppen classification, the climate in the investigated area is classified as "Cfwbx″. The mean annual precipitation in the research area is 640 mm, while the mean annual temperature is 11.7°C (Lalić et al., 2014). However, the region is characterized by high variability in precipitation, especially pronounced during the vegetation period. Water deficits occur in the summer months of July and August. The land is predominantly agricultural, mostly cropland. The soil at the studied site includes chernozem, characterized by good water and air regimes, and meadow soil at the SN location. The region has abundant hydrological resources with the Danube, Tisa, Sava, as well as several lower-capacity watercourses.

Table 1. Locations of water sampling

Locality, municipality	Latitude (N)	Longitude (E)	Altitude (m)	Abbreviation
Bačka Palanka	45°20'22.3"	19°24'26.6"	78	JD
Bačka Palanka	45°21'28.8"	19°23'42.8"	80	KD
Bač	45°20'23.5"	19°15'43.0"	81	AB1
Bač	45°19'49.7"	19°15'22.8"	82	AB2
Sonta	45°33'15.9"	19°05'37.4"	78	SN1
Sonta	45°33'49.0"	19°06'37.1"	78	SN2

Sampling and analysis

During the field survey, specific sites were selected where soil pits were dug and water samples were collected. Six piezometers were installed for observation, monitoring, and data collection on groundwater status and regime over a long-term period. Four piezometers were installed on chernozem soils and two on meadow soils. Groundwater samples were taken from all six piezometers for laboratory tests (Table 1). The collected samples were analyzed using standard methods for this type of research.

For evaluating water quality, the following basic parameters were assessed: pH and total dissolved solids (TDS, mg/l) of the water samples; salinity hazard, determined from water salinity measured by the electrical conductivity of water (ECw 25°C); sodium hazard, assessed by calculating sodium adsorption ratio (SAR), residual sodium carbonates (RSC) and ion quantitative content of cations (calcium, magnesium, sodium, and potassium), as well as anions (hydrocarbons, carbons, chloride and sulfate ion).

The pH was determined by potentiometric analysis, while electrical conductivity of water was measured using conductance analysis. Total dissolved solids were determined by evaporation of water at 105°C. The content of anions was determined by the titrimetric method using a solution of sulfuric acid in the presence of 1% methyl orange solution (hydrocarbons) and phenolphthalein (carbons), and chloride using silver nitrate solution in the presence of 5% potassium chromate solution. Sulfates were determined by gravimetric deposition with barium chloride. The contents of calcium and magnesium were determined by atomic absorption spectrophotometry, while the content of sodium and potassium were measured using a flame photometer.

Water quality was assessed according to the American Salinity Laboratory classification (Richards et al., 1954) and the FAO classification (Ayers and Westcot, 1985).

RESULTS AND DISCUSSION

In addition to the geological composition, spatial positioning is of primary importance for water quality. In the study area, the proximity to the terrain surface facilitates intensive infiltration of precipitation, while in the zones adjacent to river flows, e.g. in the proximity to the Danube River, the composition is greatly influenced by the surface waters which recharge them. Equally important is the anthropogenic impact, which is increasingly affecting the quality of groundwater.

Water samples from six locations within the study area were analyzed for 11 chemical parameters (Tables 2 and 3). Based on the obtained data, groundwater from the examined localities was classified for baseline data and monitoring data (Tables 4, 5, and 6).

Groundwater chemical composition

Hydrochemistry

The variations in water pH reflect lithological variations, as soil pH generally correlates with regional bedrock chemical properties (Chadwick and Chorover, 2001). The pH of the water samples ranged from 7.57 to 8.90. Most of the samples were classified as moderately alkaline and were within the usual range for irrigation water (pH 6.0-8.5). An exception was observed in the baseline data at the JD location, where pH exceeded 8.5. Higher pH values are often caused by increased concentrations of bicarbonate and carbonate ions, which can intensify sodic soil conditions (Fipps, 2003). High pH values may indicate a potential problem for localized irrigation, requiring moderate (pH 7.0-8.0) to severe (pH >8.0) usage restrictions (Ayers and Westcot, 1985).

Most water quality guidelines rely on indirect measurement of the amount of dissolved ions by measuring electrical conductivity (EC). Water with high salinity poses a salinity hazard to plants, as higher EC values of irrigation water increase the severity of physiological drought. The monitoring data showed that, according to permissible limits for irrigation water classes (Fipps, 2003), the water at the investigated sites belonged to class 3 in most cases. Water in this class can be used for irrigation but requires leaching. The baseline data belonged to class 2 (good irrigation water) and class 3 (permissible). An exception was the KD location, where both baseline and monitoring data belonged to class 4 (doubtful). If used for irrigation, water from this site requires good drainage. At this site, irrigation water could cause 25% reduction in maize grain yield and up to 50% in onions and beans (Fipps, 2003). Generally, cultivation of sensitive and moderately sensitive crops should be avoided at the KD location. At other locations, achieving a full yield potential is possible, provided that sensitive crops are carefully managed to maintain soil salinity within tolerable levels. The majority of vegetable crops are classified as sensitive or moderately sensitive to saline irrigation water, although salt sensitivity varies depending on plant growth stages (Machado and Serralheiro, 2017; Zörb et al., 2019).

The content of total dissolved solids (TDS) has historically been the primary parameter for irrigation water classification, with EC values corresponding to TDS levels. The baseline data vary from low, medium to medium-high salinity hazards, while monitoring data range from medium to medium-high salinity hazards (Hopkins et al., 2007). Both baseline and monitoring data are site-specific. At most locations, TDS values ranged between 480 and 1.280 mg/l, indicating that salinity may adversely affect plants. In such cases, production management requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching. Special care should be taken at the KD location, where TDS values exceeded 1280 mg/l. At this site, groundwater use requires careful management to cultivate most crops (Hopkins et al., 2007). No significant restrictions are necessary at any location, as no values exceeded 1920 mg/l.

Table 2. Water salinity

Locality	Term	Depth (m)	pH	EC_w dS/m	TDS mg/l
JD	Start	4,4	8.90	0.36	169
	1st		7.59	0.85	493
	2nd		8.12	0.85	436
AB1	Start	5,9	8.00	0.64	585
	1st		7.80	1.20	899
	2nd		7.79	1.18	1550
AB2	Start	5,15	8.40	0.86	657
	1st		7.58	1.22	891
	2nd		7.99	1.22	770
KD	Start	4,4	8.05	2.59	1792
	1st		7.57	2.18	1886
	2nd		7.90	2.35	1673
SN1	Start	1,8	8.35	1.13	586
	1st		7.90	0.98	665
	2nd		8.00	0.97	453
SN2	Start	1,2	8.46	1.11	583
	1st		8.03	1.12	759
	2nd		8.07	1.05	552
Usual range in irrigation water			6.0-8.5	0-3	0-2000

The presence of anions, carbonates, and bicarbonates was analyzed in the irrigation water. If their content in the irrigation water is high, they can cause precipitation of calcium and magnesium in the soil solution, increasing the concentration of exchangeable sodium and negatively affecting the SAR value. Among the water-soluble salts, bicarbonates of calcium and magnesium are predominant, which can cause salinization (but not alkalization) in poorly drained soils. In the tested samples, the bicarbonate content was mostly above the usual content values (Table 3). According to Ayers and Westcot (1985), using such water for sprinkler irrigation has severe restrictions on use. High levels of bicarbonates cause soil alkalinity, which can lead to reduced accessibility of some nutrients, e.g. high bicarbonate induced by high soil water content can lead to iron deficiency (Zuo and Zhang, 2011).

Chloride toxicity is the most common form of crop toxicity caused by irrigation. Chloride is highly soluble in water and barely adsorbed to soil particles. High mobility through soil solution enables its uptake by plant roots. If water income exceeds the crop water needs, chloride anion can be leached through saturated pores. However, in case of excess concentration in the soil, chloride concentrations in plants can reach toxic levels, reducing both yield and quality (Cole, 1985). In the examined water samples, chloride concentrations were below the safety threshold of 3 meq/l, indicating no restriction on use according to Ayers and Westcot (1985). The exception was the KD location, where a slightly higher chloride concentration indicated a slight to moderate restriction on use. Special care should be taken with sprinkler irrigation in high evaporative conditions since leaf burns could appear even at lower concentrations. The impact of chloride toxicity on physiological dysfunctions and yield quality depends on the crop (e.g. low starch content in potato, decreases in fruit yield and quality in grape and citrus). When crops are cultivated on soils that are moderately salinized by chloride, providing e.g. mineral nitrate fertilization can be a strategy to suppress chloride uptake because of antagonistic anion-anion uptake competition (Geilfus, 2019).

The content of sulfate was within the usual range for irrigation water. The average value for all localities and sampling terms was 2.36 meq/l, while the maximum content was 6.28 meq/l. Although sulfate does not contribute to toxicity, high concentrations can increase soil salinity, limit plant water uptake and productivity of irrigated cropland, and cause material damage and pipe clogging (Scanlon et al., 2009). In sensitive plants, sulfate can also cause calcium imbalance and increase the adsorption of sodium and potassium (Fipps, 2003).

Table 3. Content of anions and cations in water

Locality	Term	Anions (meq/l)				Cations (meq/l)			
		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+
JD	Start	0.84	0	1.05	0.23	0.67	0.01	0.60	2.00
	1st	0	11.60	1.30	0.50	4.89	3.87	0.07	1.36
	2nd	0	8.27	0.98	0.09	4.78	4.07	0.04	1.72
AB1	Start	0	9.84	0.15	1.58	4.37	4.55	1.00	0.80
	1st	0	13.52	2.50	4.46	5.57	9.95	0.10	0.44
	2nd	0	14.66	1.78	0.03	5.58	5.66	0.40	0.67
AB2	Start	0.84	9.00	0.19	3.16	3.39	7.53	0.60	0.45
	1st	0	13.61	1.92	4.21	5.49	10.20	0.08	0.40
	2nd	0	11.02	1.70	3.21	4.78	10.00	0.01	0.45
KD	Start	0	9.41	6.79	4.08	7.18	14.60	1.55	1.00
	1st	0	13.63	7.44	4.01	15.70	13.40	0.25	1.08
	2nd	0	9.67	6.10	3.33	12.80	14.56	0.09	0.85
SN1	Start	0	4.01	4.65	4.91	6.31	0.20	0.10	2.00
	1st	0	10.08	2.19	1.16	6.43	2.77	0.02	2.00
	2nd	0	8.76	1.77	0.27	6.38	2.87	0.01	1.97
SN2	Start	1.14	11.12	1.37	6.28	3.33	0.70	0.09	1.00
	1st	0.40	13.11	3.16	0.86	5.55	7.07	0.07	1.50
	2nd	0	10.62	1.76	0.17	4.78	5.48	0.05	3.23
Usual range in irrigation water		0-0.1	0-10	0-30	0-20	0-20	0-5	0-2	0-40

The content of calcium and magnesium was within the usual range for irrigation water. The average value for all localities and sampling terms was 6.00 meq/l for calcium and 6.53 meq/l for magnesium, with the maximum content at the KD location of 15.70 meq/l and 14.56 meq/l, respectively. The readily exchangeable calcium and magnesium are the dominant cations in the soil solution. High Ca concentrations in irrigation water do not cause toxicity, but deposits can reduce the marketability of fruit and cause clogging problems in irrigation systems, while high content

of exchangeable magnesium can cause lower infiltration. On the other hand, the positive effect of Mg on soil (e.g. hydraulic conductivity) is weaker compared to Ca (Smith et al., 2015). In the examined water samples, the Ca/Mg ratio was above 1, except in baseline data at AB2 and KD and monitoring data at AB2, while the Ca to total cation ratio at these locations was above 0.15, indicating no risk for plant nutrition.
The values of potassium were below 2 meq/l, with a maximum of 1.55 meq/l at KD. The proportion of potassium in total salt content in irrigation water is generally small (Fipps, 2003). Higher potassium concentrations originate from agricultural fertilizers or rock material. Compared to sodium, high potassium levels have a less deleterious effect on soil hydraulic properties (Smith et al., 2015). Sodium concentrations at the studied locations were low, ranging from 0.40 to 3.23 meq/l, with an average value of 1.27 meq/l. High amounts of sodium in irrigation water pose a hazard, which can lead to serious soil degradation. Continuous use of such water leads to a breakdown in soil structure and dispersion of clay, making dry soil compact, hard and impervious to water infiltration when wet (Zaman et al., 2018).

Groundwater classification

US Salinity Laboratory classification
The US Salinity Laboratory classification is based on assessing the risk of salinization and alkalization. The risk of salinization is determined through the EC of water, which reflects the total salt concentration in the water. The alkalization risk is assessed using the SAR value as an indicator of the relative activity of sodium in exchangeable reactions within the soil adsorptive complex. All analyzed water samples belonged to low-sodium water, S1 class (Table 4), which is water with a small sodium concentration. It can be used for irrigation on almost all soils with a small risk of alkalization. However, sodium-sensitive crops (e.g. stone-fruit trees) under intensive irrigation can accumulate harmful sodium levels. Based on conductivity, baseline data varied from low-salinity (C2) to very high-salinity water (C4), while monitoring data belonged to high-salinity water (C3), except at KD. Monitoring indicated deterioration of water quality at two locations (JD and AB1), ranging from medium-salinity (C2) to high-salinity water (C3). At these locations, water can be used for irrigation with adequate drainage and adequate selection of salt-tolerant plants. At other locations, no deterioration of water quality was detected, with monitoring data classified as C3. At KD, very high salinity water was recorded, unsuitable for irrigation under ordinary conditions. This water can be used occasionally for irrigation on permeable soil with adequate drainage and leaching, and with selection of salt-tolerant crops. The obtained results are consistent with the findings by Pivić et al. (2022), who tested surface and groundwater samples for irrigation in the area of the three Morava rivers in central Serbia. Their research shows that, according to the USSL diagram, 82% of the samples belonged to very good or good irrigation water. Most samples (62.79%) were medium salinity water with EC between 250 and 750 µS $cm^{-1,}$ which corresponds to C2, while 36.74% were high-salinity waters between 750 and 2250 µS cm^{-1}, corresponding to C3, and with SAR below 10. Nemčić-Jurec et al. (2019) reported that the groundwater of northern Croatia and the Allahabad district in India fell in the category C2S1 and C3S1. They also determined that local environmental factors and regional distribution have greater impact on water quality than the geographical distribution.

Table 4. US Salinity Laboratory classification for groundwater samples

Locality	Baseline data	Monitoring 1	Monitoring 2
JD	C2S1	C3S1	C3S1
AB1	C2S1	C3S1	C3S1
AB2	C3S1	C3S1	C3S1
KD	C4S1	C3S1	C4S1
SN1	C3S1	C3S1	C3S1
SN2	C3S1	C3S1	C3S1

FAO classification
The FAO classification system addresses quality-related water problems in irrigated agriculture. Restrictions on use refer to salinity, infiltration, specific ion toxicity, and miscellaneous effects. Irrigation water is categorized depending on the degree of restriction imposed, including none, slight, moderate, and severe.
Salinity is estimated based on electrical conductivity and the total amount of salt. Most of the analyzed samples had slight to moderate restrictions, except for the JD location, which had no restriction on use (Table 5). However, EC values are not sufficient to determine water quality, considering that soluble ions have different effects on soil and crops, especially because of the crucial role of certain ions in soil dispersion and destruction. Therefore, sodium levels, indicated by SAR values, require particular attention. Infiltration problems are assessed based on electrical

conductivity and SAR values, since the infiltration rates are inversely proportional to the degree of its salinity and alkalization. According to SAR and EC values, the risk of water infiltration problems was generally low, and the water could be used without any restrictions. This classification also considers the toxicity of certain ions that can accumulate in sensitive plant species, especially in orchards. The risk of chloride ion toxicity was low, indicating that, in most cases, water could be used for irrigation without restrictions. An exception was the KD location, with slight to moderate restrictions when surface or sprinkler irrigation methods are used. Similar values for the region of northern Serbia were recorded by Mačkić (2016), Pekeč et al. (2021), and Vranešević et al. (2023).

Table 5. Restrictions on use based on salinity according to FAO classification for groundwater samples

Locality	Baseline data	Monitoring 1	Monitoring 2
JD	none	none	none
AB1	none	slight to moderate	slight to moderate
AB2	slight to moderate	slight to moderate	slight to moderate
KD	slight to moderate	slight to moderate	slight to moderate
SN1	slight to moderate	slight to moderate	slight to moderate
SN2	slight to moderate	slight to moderate	slight to moderate

The FAO guidelines are based on the assumption of arid to semi-arid climate and low rainfall. In Serbia, however, the average annual precipitation is 640 mm, which could be effective in meeting all of the leaching requirements. According to Nemčić-Jurec et al. (2022), chloride and EC values are variable and influenced by rainfall dilution, changes in land use and anthropogenic activities.

Based on irrigation water samples from locations within 6 areas in central Serbia, Grujić et al. (2021) reported that the water belonged to S1, with most samples classified as C3 and C4. They concluded that preference should be given to the FAO classification rather than Neugebauer's classification, owing to its local character, as well as to USSL classification for the territory of Serbia.

Residual Sodium Carbonate

Bicarbonate hazard is commonly expressed as RSC (Residual sodium carbonate). If the content of carbonates and bicarbonates in irrigation water is high, they can cause precipitation of Ca and Mg in the soil solution, increasing the concentration of exchangeable sodium. When RSC is below zero, no RSC-associated problems occur, and when the value is above zero, calcium is lost from the soil solution, increasing the risk of sodium hazard to soil structure. As RSC rises, close monitoring of soil pH and water infiltration becomes necessary, as well as potential use of amendments to reduce RSC (Hopkins et al., 2007).

Most water samples in the investigated area were safe for use since their RSC values were below zero, so using this water indicates no sodium-related problems (Table 6). At some locations, RSC values were occasionally between 0-1, representing medium values that may require periodic monitoring of infiltration and soil pH. Very high RSC values (above 2.5) appeared sporadically, in which case monitoring infiltration and soil pH as well as amendments with acid or gypsum are necessary. Variability in RSC values was particularly prominent at the JD location, where the risk of sodium hazard ranged from low to very high. At this location, continuous monitoring of water quality is of particular importance. Generally, according to RSC, the water quality in the region is suitable for irrigation, with only a small portion being unusable (Mrazovac Kurilić et al., 2019; Nemčić-Jurec et al., 2019; Pivić et al., 2022).

Table 6. Classification of groundwater samples based on Residual sodium carbonates (RSC)

Locality	Baseline data	Monitoring 1	Monitoring 2
JD	medium	very high	low
AB1	medium	low	very high
AB2	low	low	low
KD	low	low	low
SN1	low	medium	low
SN2	very high	medium	medium

CONCLUSION

This paper aimed to highlight the importance of irrigation water monitoring. The presented data should provide a basis for adapting management practices when using poor-quality water and a prerequisite for preventing soil deterioration and ensuring successful crop production.

The investigated water samples revealed no risk of alkalization, although most of the data indicated the risk of salinization. Considering the climatic and soil conditions, this water can be used for irrigation with certain precautions. Well-permeable soil and sufficient amounts of non-vegetation precipitation enable the leaching of salts from the active rhizosphere zone. However, it is necessary to continue monitoring of irrigation water quality and adjusting crop management. In addition, periodic assessments of soil salinity status and pH levels, as well as soil infiltration, are recommended. Management strategies should be specifically tailored to each location based on water quality analysis and crop production.

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