Зборник Матице српске за природне науке / Matica Srpska J. Nat. Sci. № 140, 85—101, 2021

UDC 628.161.1(497.113)
https://doi.org/10.2298/ZMSPN2140085M
ORIGINAL ARTICLE

Stanko B. MILIĆ[1*], *Dušana D. BANjAC*[1], *Jovica R. VASIN*[1], *Jordana M. NINKOV*[1], *Borivoj S. PEJIĆ*[2], *Ivana B. BAJIĆ*[1], *Branka Lj. MIJIĆ*[1]

[1] Institute of Field and Vegetable Crops,
National Institute of the Republic of Serbia,
Maksima Gorkog 30, Novi Sad 21000, Serbia
[2] University of Novi Sad, Faculty of Agriculture,
Trg Dositeja Obradovića 8, Novi Sad 21000, Serbia

ASSESSMENT OF IRRIGATION WATER QUALITY AT THE TERRITORY OF VOJVODINA PROVINCE (SERBIA)

ABSTRACT: Intensive crop cultivation systems require continuous monitoring of irrigation water quality as well as the control of physical and chemical soil properties. In view of the ongoing climate change and a dramatic decrease in soil organic matter content, the use of low quality irrigation water and its adverse effects on soil, cultivated plants and irrigation equipment must not be overlooked. The aim of this paper was to evaluate general quality of irrigation water from the different water intake sources in the Vojvodina Province. The paper presents the results of irrigation water quality, collected during 2018 and 2019. The research included 140 irrigation water samples obtained from three different intake structures which collect water from wells, canals or reservoirs. Water quality was assessed using the following parameters: pH value, electrical conductivity (EC), total dissolved solids (TDS), ionic balance, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) value. Water quality diagram given by the US Salinity Laboratory (USSL) and FAO guidelines for interpretation water quality for irrigation was used. Additionally, the Nejgebauer classification for irrigation water, developed specifically for the area of Vojvodina, was used as a third classification. Based on the results of mineralization of the irrigation water, the following values of the observed parameters were determined: average pH of the analyzed water samples were 7.89, ranged from 7.14 to 9.01, while electrical conductivity values ranged from 0.10 to 3.50 dS/m, with an average of 0.85 dS/m. TDS analysis resulted in a wide range of values, from 112 mg/l to 2,384 mg/l, with an average of 529,22 mg/l. SAR values varied between 0.04–16.52 with a satisfactory average of 1.97. The USSL water classification produced similar results as FAO classification and RSC index <0, indicating that 57% of investigating samples are without concerns for irrigation use, whereas Nejgebauers classification and RSC index 0–1.25 show that over 75% of analyzed samples are suitable and safe for irrigation and soil properties. Since the quality of irrigation water significantly affects plant productivity, as it determines the chemical and physical properties of agricultural land, monitoring of water quality for irrigation is of high importance.

KEYWORDS: irrigation water, irrigation water salinity, water mineralization, SAR, classification of irrigation water

[*] Corresponding author. E-mail: stanko.milic@nsseme.com

INTRODUCTION

The continuous growth of the world's population leads to an increase in the use of drinking and other types of water necessary for undisturbed flow of numerous processes. The fact that this natural resource is endangered by a large number of factors, which accompany modern society, is often forgotten. In agricultural sector, reduction of available water accompanied by its irrational and inadequate use leads to land degradation, deterioration of water quality, as well as its limited use. In addition, crop production in the open field is threatened by global climate change, characterized by increasing air temperatures and decreasing rainfall, i.e. more frequent occurrence of intense drought (Vuković et al., 2018). Higher negative impact of drought can be expected in the near future, while the need for irrigation is expected to increase from 0.7 to 11.6% by the middle of the 21st century in Serbia. In addition, by the end of the 21st century, the water deficit may will have increased by as much as 27 – 35.6% (UNDP, 2019). These reasons impose the need to increase the area under irrigation in our agro-ecological conditions. The Water management master plan – the strategic documents of the Republic of Serbia (*Službeni list RS*, No. 3/2017) stimulate expansion of the irrigation area by 2034 for additional 100,000 to 250,000 hectares. Monitoring water quality is one of the main requirements for stable and sustainable crop production given the fact that water, in addition to soil, is essential for crop growth and development.

Moreover, meeting the needs of cultivated plants as well as expectations of agricultural producers, requires planned irrigation using good quality irrigation water. Defining water quality is a prerequisite for assessing its irrigation suitability. Numerous factors indirectly limit suitability of water for irrigation, ultimately hindering the achievement of high yields and the desired quality of cultivated crops. Generally, mineral composition of water, the crop species and the soil type are the main indicators of suitability of water for irrigation (Čolić et al., 2016).

Soil and climatic conditions in Vojvodina Province can cause salinization of the soil in irrigation systems, especially when irrigation water is mineralized above the permitted level. The accumulation of water-soluble salts in the layer of active rhizosphere of irrigated soils can be expressed to such an extent that it causes serious problems in crop cultivation (Nešić et al., 2003). Research about soil salinization and water quality for irrigation in Vojvodina Province were initiated even before irrigation development in region and continue to be an important issue. With the development of methods and classifications for determining water quality in the world, national experts comparatively worked on this issue (Nejgebauer, 1949; Vučić, 1965; Miljković, 1986a, 1988). The Nejgebauer's water classification was proposed for agro ecological conditions of Vojvodina in 1949 (Vučić, 1976) and provides four main classes. The influence of salts dissolved in water on the infiltration properties of soil, toxicity to plant production as well as the ecological aspect was considered by Miljković (1986b, 1988) with a new classification. Further clarification of the Nejgebauer's classification in order to adapt classes and subclasses to specific conditions was made by Avakumović (1994).

The risk of soil chemical and physical degradation comes from inadequate irrigation and low quality of irrigation water. Vučić (1987) emphasizes that the degradation of soil water status and overall soil physical state can be observed in the surfaces cultivated with vegetable crops for longer periods without crop rotation or use of manure for fertilization. Gajić (1999) states that long-term irrigation of calcareous chernozem and non-calcareous humogley significantly disturb their physical and mechanical properties, compared to the non-irrigated soils, due to a decrease in $CaCO_3$ and humus content. Soil salinization caused by irrigation can occur either directly, by using mineralized water for irrigation, or indirectly, due to a rise in mineralized ground water if the added amount of irrigation water is not controlled (Dragović et al., 1993).

The three-year long research conducted by Dragović et al. (2007) indicated that the use of saline water (class C3-S1) for irrigation causes soil surface salinization, which can limit the yields of crops sensitive to even low soil salinity. Soil salinization particularly occurs in glasshouse or greenhouse vegetable crop production when the quality of irrigation water is not controlled (Hadžić et al., 2004).

Negative effects of mineralized water on soil and plants posed the necessity of determination and evaluation of irrigation water quality (Bošnjak, 1994). The main findings of previous investigations conducted by Belić et al. (2013), concerning the evaluation of quality of irrigation water from several watercourses (for period 1980–2009) in the Vojvodina Province, show a mild decreasing trend in water quality and an increasing mineralization trend in most of the analysed samples of the Danube-Tisza-Danube Hydro System (DTD HS). The waters of the Danube, Tisza and Begej were found suitable for irrigation, except in some cases where it was recommended to monitor the changes in chemical properties due to the potential adverse effects of these waters.

Neutral trend in SAR value on the Bezdan-Danube River profile for 1969–1996 was noticed by Savić et al. (1997). Analyzing water quality for irrigation of Banat watercourses (Karaš, Moravica and Nera) Ilić et al. (2019) concluded that the analyzed watercourses are suitable for irrigation but also require control of the total salt content as well as the SAR ratio of sodium concentration to calcium and magnesium (SAR value), due to the impact on soil and plants. Close control of bicarbonate concentration is required because it has a greater potential to cause various adverse effects. Continuous monitoring of soil and water quality are necessary for proper irrigation management and sustainable agricultural farming. The aim of this study is to estimate and compare overall quality of irrigation water from different water sources in Vojvodina Province in order to provide general insight into the water quality and encourage development of irrigation practice in the region.

MATERIALS AND METHODS

The paper examines the quality of irrigation water on the territory of the Vojvodina Province, obtained from three different sources: wells, canals and

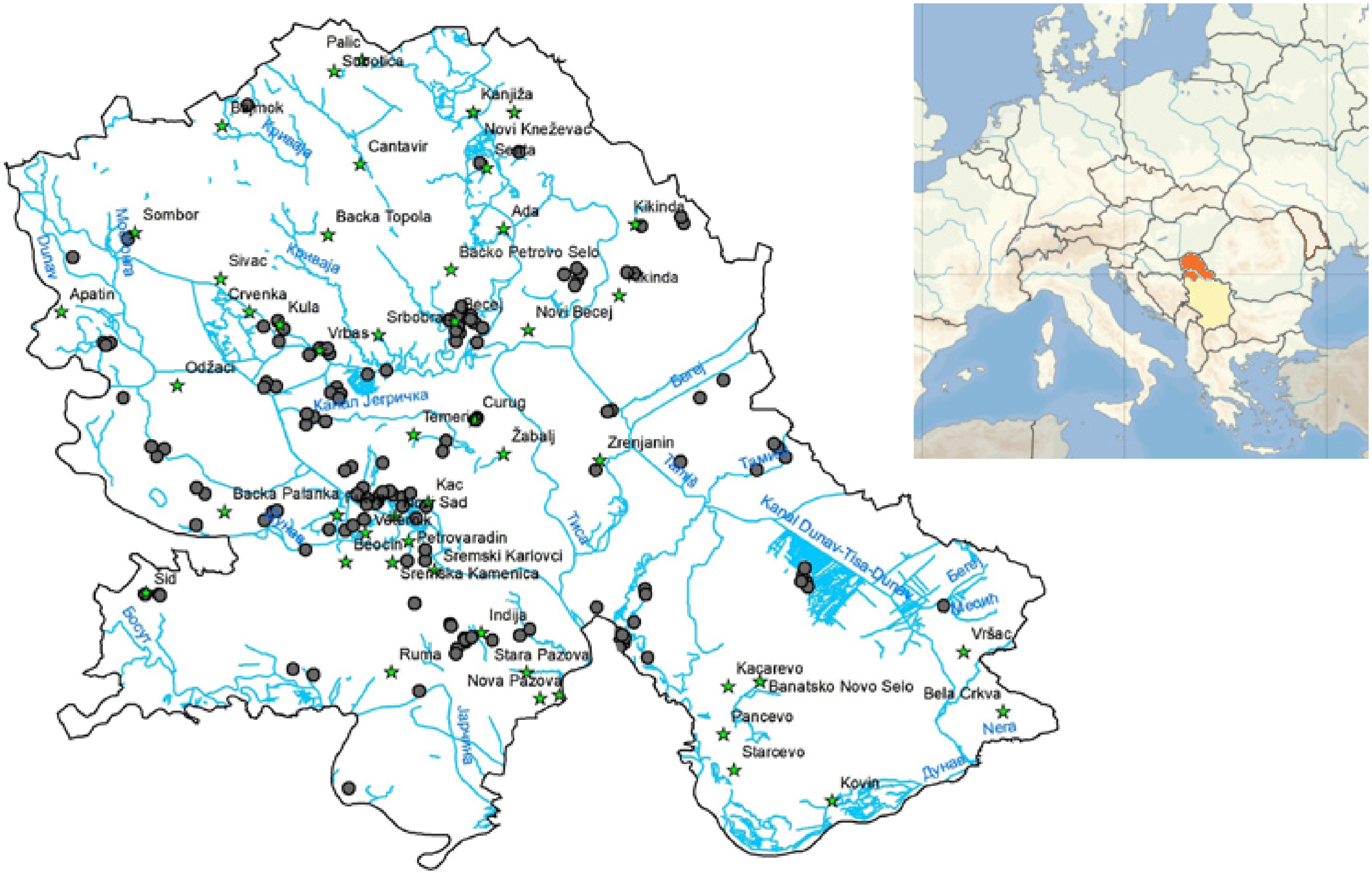


Figure 1. Location of water sampling points in Vojvodina Province

reservoirs. Sampling and laboratory analyses were performed successively during 2018 and 2019. A total of 140 water samples (Figure 1) were analyzed and the following parameters were tested: pH value, electrical conductivity (EC), total dissolved solids (TDS), ionic balance – anions (carbonates, bicarbonates, chlorides, sulfates, nitrates) and cations (calcium, magnesium, potassium and sodium), and sodium adsorption ration (SAR).

Laboratory analyses were conducted at the Institute of Field and Vegetable Crops, The National Institute of the Republic of Serbia – Laboratory for Soil and Agroecology, accredited according to the standard ISO/IEC 17025:2017. The pH value was determined potentiometrically, the electrical conductivity conductometrically at 25 °C, and the TDS by evaporation of water in oven at 105 °C. The content of carbonates, bicarbonates and chlorides according to Mohr was examined by titrimetric methods. Sulfates were determined by gravimetric method with barium chloride, and nitrates by spectrophotometric method. The cation content was determined on a Vista Pro-Varian apparatus, by the induced coupled ICP-OES plasma method. Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were calculated.

An assessment of irrigation water quality is given according to: 1) RSC index classification (RSC), (Richards, 1954); 2) The Nejgebauer classification for irrigation water (Nejgebauer, 1949); 3) Water quality diagram given by the US Salinity Laboratory (USSL), US Salinity Laboratory Staff (1954), and 4) FAO guidelines for interpretation water quality for irrigation (FAO), Ayers and Westcot (1985).

Statistical analysis included a total of 140 samples divided into 3 observation groups – wells (58), canals (72) and reservoirs (10). Descriptive statistics and significance of differences were tested by Fisher's least significant difference test (LSD). Statistica for Windows, version 13 was used for all statistical data processing.

RESULTS AND DISCUSSION

The pH values for the tested irrigation water samples range between 7.14 and 9.01 (Table 1). Most of the tested water samples can be classified as neutral, medium alkaline and strongly alkaline. About 90% of the analyzed waters are within the allowed range according to FAO guidelines (pH 6.5–8.4) (Ayers and Westcot, 1985). In addition, significant differences were found between the three types of water sources, where the observed average values exhibited a decreasing trend: reservoirs> canals> wells.

The electrical conductivity (EC) of the observed water samples varied in the range of 0.10 and 3.50 dS m^{-1} (Table 1). The values were in the same range as shown by the previous investigations (Nešić et al., 2003; Vranešević et al., 2016). Only 9% of observed samples had an EC value greater than 1.5 dS m^{-1}. According to the guidelines for Salinity hazard of irrigation water (Follett and Soltanpour, 2002; Bauder et al., 2011) these samples has moderate hazard, water may have adverse effects on many crops what requires careful management practice. This occurs because the plant roots are not able to take up soil water due to high osmotic potential (Zaman et al., 2018). High EC indicates a high degree of salinity and high index of water solute concentrations (Thompson et al., 2012).

Statistically, the lowest average values of electrical conductivity were determined for water samples from the canal (0.76 dS m^{-1}). Out of the 140 samples observed, only four samples showed significant limitations in terms of their suitability for irrigation, relative to their EC value (>2.25 dS m^{-1}). Assessing the caution of using saline water for irrigation, Hopkins et al. 2007 reported that, at the EC value of 1 dS m^{-1} (salt content about 640 mg/l), over 7.5 t of salt per hectare per year is introduced into the soil at an irrigation rate of 120 l/m^2.

In terms of the content of TDS, the values of the analyzed water samples ranged from 112 to 2,384 mg/l. Statistically, the lowest average value of this parameter (495.68 mg/l) was determined for water samples taken from the canal (Table 2). Salinity is the most important criterion for irrigation water quality evaluation (Ghassemi et al., 1995). High salt concentrations prevent the uptake of water by plants, thus causing crop-yield reductions. This occurs when salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period. The plant symptoms are similar in appearance to those of drought (FAO, 1994). In relation to the total number of samples, 60% of analyzed water samples exhibited the values below 480 mg/l which, according to the classification of total soluble salts in water (Hopkins et al., 2007), has no significant adverse effects on cultivated plants nor causes salt accumulation in soils. According to FAO classification (Ayers and Westcot, 1985), in investigated samples, only one sample (canal) exceeds values shown for severe restrictions (>2,000 mg/l). The majority of analysed samples (53.5%) have no restriction on use regarding concentration of TDS in water. For the achievement of full yield potential, 45.7% of the examined samples require slight to moderate restrictions as well as careful selection of crops and management alternatives. Another crucial issue related to salinity or sodicity management in agriculture is crop selection. Crops vary considerably in their ability to tolerate saline conditions, for example durum wheat, triticale or barley tolerate higher salinity than rice or corn (Mateo-Sagasta and Burke, 2010).

According to the FAO classification of irrigation water (Ayers and Westcot, 1985), chloride content in 85.7% of the tested samples is within the range for safe crop production (<70 ppm or <2 meq/l), while only 7% of water samples can affect hazard in an irrigated farming system, with the possibility of reducing yield of potatoes, alfalfa, wheat, corn, Sudan grass, sorghum, tomatoes squash, etc. Adverse effect of high chlorine concentration is more pronounced with sprinkler irrigation, causing leaf burning (Maral, 2010). Significantly lower values of chloride content in water were found in waters originating from canals (1.26 meq/l) compared to well water and water from reservoirs, where no statistically significant differences were found (Table 2).

The average nitrate content in the analyzed samples was 2.57 mg/l and ranged from 0.01 to 96.76 mg/l (Table 1). The statistically highest average values between the observed water sources were determined in water samples taken from wells (5.92 mg/l), while there was no significant difference between canal waters and reservoirs (0.61 and 0.54 mg/l) (Table 2). Nitrate content was below 10 mg/l in 96.5% of analyzed water samples, which is the usual value of this parameter according to the FAO water quality assessment (Ayers and Westcot, 1994). The highest concentrations of nitrate in irrigation water were observed in four samples taken from a well (36.4–96.7 mg/l). In the Vojvodina Province chemical fertilizers or manure is commonly applied in order to add nutrients to the soil. A major source of nitrates in well water is deep percolation from fertilizer use on cropland. Nitrate from agriculture is the most common chemical contaminant in the world's groundwater aquifers (WWAP, 2013). In addition, in the areas of intensive agricultural production, one of the basic types of groundwater nitrogen contamination is fertilization, i.e. the application of excessive doses of nitrogen (Suthar et al., 2009; Gao et al., 2012). Other important sources of N in wells include leaching from septic peat, animal manure, land application of municipal or industrial sludge, etc. (Ray and Jain, 1998). Waters with high nitrogen content, besides damaging the environment, can compromise crop quality, excess vegetative growth, e.g. impacts maturity, and/or storability which is of high importance for crop such as potato, sugar beet, grass seed apples (Hopkins et al., 2007).

In view of the content of sulphate in water (SO_4), no differences were found between the observed water sources (Table 2). The average content of these ions was 1.03 meq/l ranging from 0.02 to a maximum of 10.15 meq/l (Table 1). In the largest number of the tested samples (96%) the values did not exceed 3 meq/l (144 ppm). The highest content of sulphate in investigation was 10.2 meq/l (489,5 ppm) sourced from a canal. Waters containing more than 1,000 mg/l sulfates are toxic to plant health, growth and development (Ghoraba et al., 2013). Considering the observed low amount of sulfate, current concentrations of these ions pose no significant threats.

Table 1. Descriptive statistics, average values of the analyzed parameters.

Analyzed parameters	Mean	Min	Max	Percentile 25%	Percentile 75%	St. dev.	Coef. var.
pH value	7.89	7.14	9.01	7.59	8.20	0.41	5.16
EC (dS/m)	0.85	0.10	3.50	0.51	0.99	0.52	61.26
TDS (mg/l)	529.22	112.00	2384.00	316.50	588.50	345.44	65.27
CO_3^{2-} (meq/l)	0.24	0.00	2.08	0.00	0.34	0.42	176.99
HCO_3^- (meq/l)	7.06	1.63	35.24	4.03	8.79	4.30	60.93
Cl^- (meq/l)	1.29	0.00	9.69	0.47	1.53	1.63	126.42
SO_4^{2-} (meq/l)	1.03	0.02	10.15	0.25	1.21	1.39	135.99
NO_3-N (mg/l)	2.57	0.01	96.76	0.06	1.04	11.02	428.39
Ca^{2+} (meq/l)	3.31	0.41	13.80	2.25	3.74	1.92	58.01
Mg^{2+} (meq/l)	3.47	0.17	13.58	1.72	4.52	2.33	67.00
K^+ (meq/l)	0.24	0.01	4.60	0.08	0.20	0.50	207.35
Na^+ (meq/l)	3.39	0.08	16.62	1.31	4.35	3.10	91.53
SAR	1.97	0.04	16.52	0.80	2.42	2.10	106.68
RSC	0.51	-12.82	21.58	-1.12	0.94	3.80	739.57

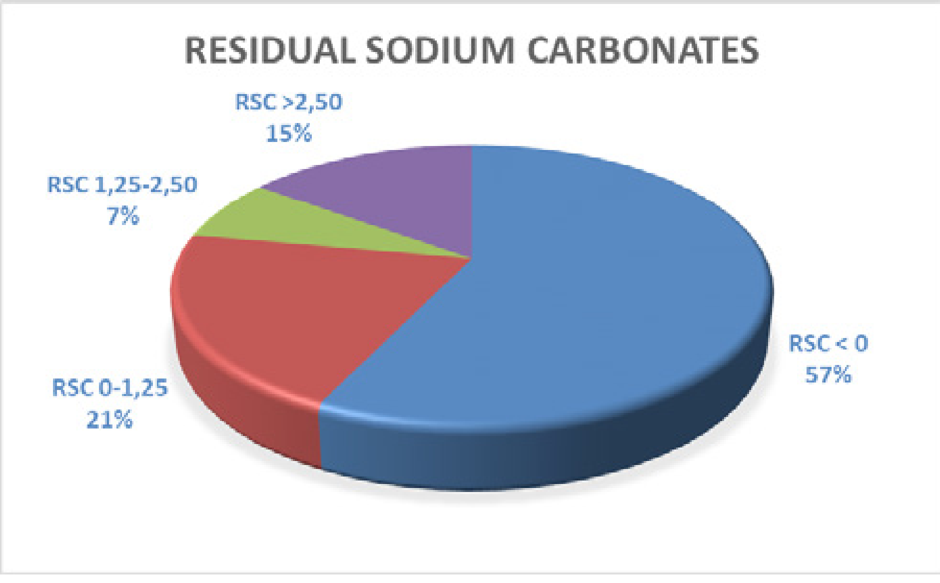
One of the important indicators of irrigation water quality is the content of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^{2-}). The results of the study exhibited the average value of these ions at 0.24 (CO_3^{2-}) and 7.06 meq/l (HCO_3^{2-}), as shown in Tab 1. Significantly lowest bicarbonate content (HCO_3^{2-}) was found in water from the canal, while significantly lowest carbonate content (CO_3^{2-}) was observed in well water (Table 2). Over 83% of the observed samples have a bicarbonate content above 3 meq/l which can have a negative impact on crop production. At values above 3.3 meq/l, correction/treatment of such waters is necessary (Morgan and Graham, 2019) in order to reduce their negative effects. According to FAO (1994), when using overhead sprinklers, there is no restriction on use of waters having HCO_3^- less than 1.5 meq/l, but there is slight to moderate adverse impact on use of waters having HCO_3^- of 1.5-8.5 meq/l, and severe restriction for HCO_3^- greater than 8.5 meq/l (Capar et al., 2016) (Table 1). According to the results of Shahabi et al. (2005) bicarbonate in irrigation water is one of the factors that causes nutritional imbalances in plants disrupting the absorption and translocation of nutrients, particularly Fe and Mn, by the plant roots. When water containing dissolved HCO_3^- is applied to the soil surface in the presence of sufficient Ca^{2+} (and/or Mg^{2+}) ions, it can result in the formation of inorganic carbonates such as calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) (Suarez, 1999; Eshel et al., 2007; Sanderman, 2012).

The process decreases their reactive ability in competition with Na^+ ions towards the exchange complex of clay, leading to sodium permeability hazard. In such circumstances, the concentration of Na^+ ions in the soil solution increases and causes decomposition of structural aggregates, which significantly reduces water permeability of soil, nutrient uptake and root penetration, and intensifies soil degradation (Domenico and Schwartz, 1990; Todd and Mays, 2005). Water infiltration problems caused by excess sodium are easier to prevent than to remedy (Hopkins et al., 2007). Water sodicity can be mitigated through the judicious use of calcium-containing amendments such as gypsum ($CaSO_4.2H_2O$). Relative to other amendments, gypsum is cheap and easy to handle, and by far the most suitable amendment to bring down irrigation water sodicity (the ratio of sodium to calcium + magnesium), as reported by Hopkins et al. (2007) and Zaman et al. (2018).

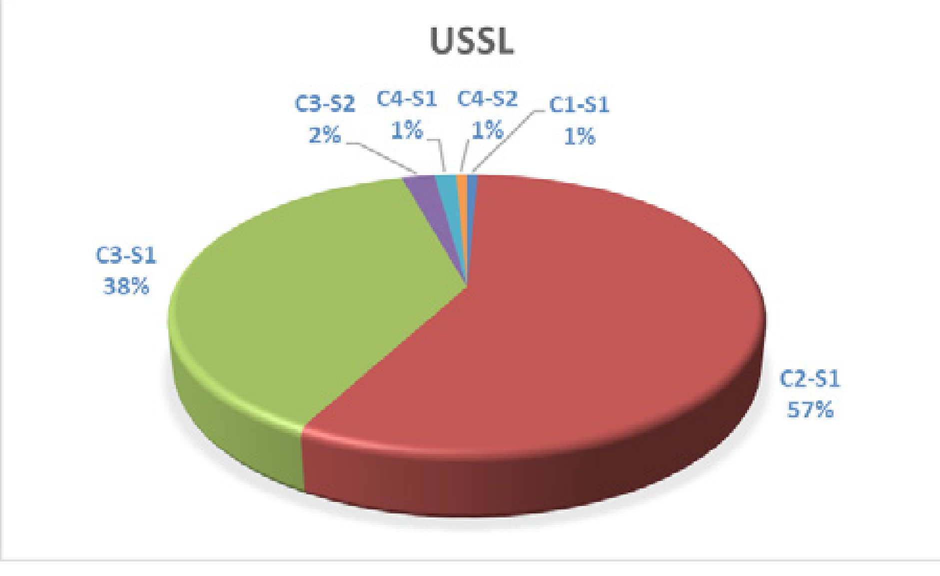
The characteristics of the tested water samples, i.e. the usability of water for irrigation were considered and compared according to the guidelines of the US Salinity Laboratory (Richards, 1954), Figure 2b. This classification considers the risk of salinization and alkalization based on two SAR and EC parameters. The USSL water classification diagram does not present an EC over 2.25 dS m^{-1} therefore, in order to accommodate higher water salinity levels, Shahid and Mahmoudi (2014) have modified the USSL Staff (1954) water classification diagram by extending water salinity up to 30 dS m^{-1}.

In terms of their usability for irrigation, most samples in the study (57%) are moderately saline, classified in class C2-S1, while 38% belong to class C3-S1. Saline (C3) to medium saline (C2) water, with a low content of sodium (S1), can cause salinization, but not alkalization, in poorly drained soils.

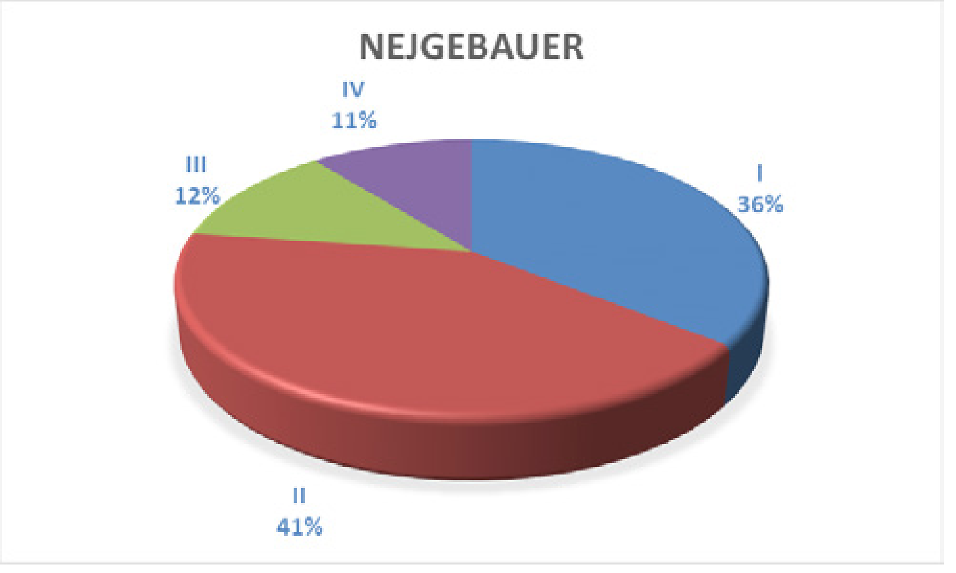
a)


RESIDUAL SODIUM CARBONATES
RSC >2,50
15%
RSC 1,25-2,50
7%
RSC 0-1,25
21%
RSC < 0
57%

b)


USSL
C3-S2
2%
C4-S1
1%
C4-S2
1%
C1-S1
1%
C3-S1
38%
C2-S1
57%

c)



d)

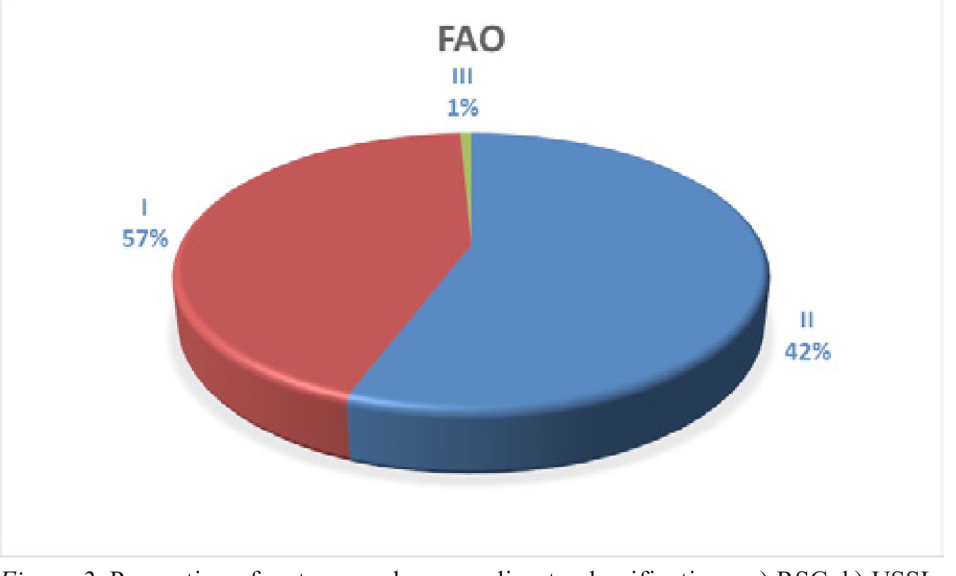


Figure 2. Proportion of water samples according to classifications: a) RSC; b) USSL; c) Nejgebauer; d) FAO

Table 2. Irrigation water quality parameters I and anionic content.

Water Source		pH value	EC (dS/m)	TDS (mg/l)	CO_3^{2-} (meq/l)	HCO_3^- (meq/l)	Cl^- (meq/l)	SO_4^{2-} (meq/l)	NO_3-N (mg/l)
Well	Average	7.71c	0.97ab	625.67ab	0.07c	8.93ab	1.13b	0.90a	5.92a
	Min	7.14	0.10	215.00	0.00	1.95	0.00	0.02	0.01
	Max	8.49	2.55	1699.00	0.90	21.80	6.11	7.82	96.76
	Stdv.	0.33	0.47	331.08	0.19	3.56	1.38	1.42	17.65
Canal	Average	7.95b	0.76c	459.68c	0.28b	5.85c	1.26c	1.11a	0.61b
	Min	7.21	0.26	112.00	0.00	1.63	0.07	0.07	0.01
	Max	8.61	3.50	2384.00	2.08	35.24	8.20	10.15	4.45
	Stdv.	0.38	0.53	340.30	0.44	4.54	1.40	1.42	0.68
Reservoir	Average	8.31a	0.92b	570.10b	0.83a	6.80ab	2.31ab	1.02a	0.54b
	Min	7.21	0.51	269.00	0.00	3.93	0.19	0.08	0.03
	Max	9.01	2.27	1319.00	1.70	11.62	9.69	3.68	1.51
	Stdv.	0.57	0.59	365.42	0.58	2.24	3.46	1.10	0.50

Table 3. Irrigation water quality parameters II and cationic content.

Water Source		Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	K^+ (meq/l)	Na^+ (meq/l)	SAR	RSC
Well	Average	4.50a	4.40b	0.22a	3.60a	1.99a	0.10a
	Min	0.41	0.17	0.01	0.08	0.04	-12.82
	Max	13.80	13.58	4.60	15.98	16.52	14.76
	Stdv.	2.56	2.86	0.71	3.50	2.60	4.13
Canal	Average	2.64bc	2.66c	0.27a	3.25a	1.98a	0.83a
	Min	0.89	0.73	0.03	0.68	0.50	-3.50
	Max	5.00	10.02	1.94	16.62	11.71	21.58
	Stdv.	0.76	1.61	0.35	2.81	1.78	3.75
Reservoir	Average	2.45b	4.98ab	0.14a	3.34a	1.72a	0.20a
	Min	1.05	2.56	0.04	0.81	0.46	-2.80
	Max	5.99	6.65	0.35	9.77	4.82	4.41
	Stdv.	1.48	1.36	0.12	3.28	1.56	2.12

Figure 2. Proportion of water samples according to classifications: a) RSC; b) USSL; c) Nejgebauer d) FAO.

Similar results were reported by Nešić et al. (2003) who pointed out good quality of waters classified as C2-S1 according to the US Salinity Laboratory, while moderate restriction is proposed when using waters classified as C3-S1, due to higher EC and TDS. Only 3% of water samples tested in this study (C3-S2 and C4-S2) belong to high salinity and alkality classes (Figure 2b). Continuous use of such water quality over a long period of time can increase salinity and alkalinity in soils. Läuchli and Epstein (1990) pointed out the effect of salinity on growth and development of plants in different ways, such as osmotic effects, specificion toxicity and/or nutritional disorders.

Although the Nejgebauer classification was created 50 years ago, through the content of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} and the TDS, it simply and easily provides a reliable assessment of the usability of water for irrigation (Belić et al., 2003). According to this classification, the largest number of analyzed samples are placed in I and II class, excellent (36%) and good (41%), 12% are waters which need additional testing (III class), while 11% of tested samples are not suitable for irrigation (Figure 2c). Since Nejgebauer classification gives special emphasis on the ratio (Ca+Mg):Na, for the final evaluation of III class waters (waters that need additional testing) performing supplementary analyses and classification are justified (pH, chloride content, bicarbonates content, EC, sulfates content, FAO classification, RSC index, soil testing, etc.) in order to better understand water quality. In addition to the USSL classification, which is globally accepted, the analysis of water according to Nejgebauer significantly coincides with the classification of samples according to the RSC index. As the parameters of Vojvodina waters are analyzed according the two classifications, they can be, along with EC and SAR, a reliable and fast predictor of irrigation water quality.

The modified FAO guidelines for interpretation water quality for irrigation (Ayers and Westcot, 1985) include detailed analyses of the effect of salts dissolved in irrigation water on infiltration properties of soil and the toxic effects of certain ions, such as Na^{+} and Cl^{-}, on plants. According to the salinization and infiltration criteria, 57% of the tested samples have satisfactory quality without the need for restriction during use, while 42% of the observed samples are characterized with restrictions in the slight to moderate range. Only one test sample exceeds the values shown for severe restrictions, respectively user will experience soil and cropping problems or reduced yields using this water for irrigation. The FAO classification indicated that a majority of the samples do not have restriction regarding toxicity of Cl (91%) and Na (59%). The rest of samples belong to the group slightly to moderate restriction regarding both toxic elements. Similar findings were obtain by Vranešević et al. (2016) investigating irrigation water quality from artificial reservoirs on Fruška Gora. The FAO classification considered together produced similar results as the USSL water classification. Furthermore, Nejgebauer classification of water suitable for irrigation a bit overestimate FAO guidelines if bout classes are considered together (excellent and good). The results of the FAO classification of water suitability for irrigation obtained were not always in accord with the other estimates (Belić et al., 2003), especially when the hazards of salinization or disturbance of soil infiltration properties were analysed.

CONCLUSION

Based on the analysis of irrigation water quality in Vojvodina, the conclusion is that the vast majority of water samples are good quality and can be used for irrigation without concern. However, a small number of the tested irrigation water samples <10% can have an adverse impact in terms of soil salinization and plant production. Sustainable use of these waters requires special soil management methods, good drainage, high leaching ability or water treatment. Significantly lower values of chloride content in water were found in waters originating from canals (1.26 meq/l) compared to well water and water from reservoirs. The water pH reaction in the study area is neutral to alkaline. HCO^{-3} dominates among anions, while the dominant cations are Na^{+} and Ca^{2+} and Mg^{2+}. Over 83% of the observed samples have a bicarbonate content above 3 meq/l which can have a negative impact on crop production. The USSL water classification produced similar results as FAO classification and RSC index <0, indicating that 57% of investigating samples are without concerns for irrigation use whereas Nejgebauers classification and RSC index 0–1.25 shows that over 75% of analyzed samples are suitable and safe for irrigation and soil properties.

Since the quality of irrigation water significantly affects plant productivity, as it determines the chemical and physical properties of agricultural land, monitoring of water quality for irrigation is of high importance. Further research should include examination of a larger number of parameters, including the content of hazardous and harmful substances.

REFERENCES

Ayers R, Westcot D (1985): Food, Water Quality for Agriculture, Irrigation and Drainage, Agriculture Organization of the United Nations (FAO), Rome: Paper No. 29. Rev. 1, M-56. ISBN 92-5- 102263-1.

Avakumović D (1994): Hidrotehničke melioracije. Navodnjavanje. Beograd: Građevinski fakultet [Hydrotechnical reclamation, Irrigation. Faculty of Civil Engineering, University of Belgrade, Belgrade].

Bauder TA, Waskom RM, Sutherland PL, Davis JG (2011): Irrigation water quality criteria. Colorado State University Extension Publication, Crop series/irrigation. Fact sheet no. 0.506,4 pp [URL: https://extension.colostate.edu/docs/pubs/crops/00506.pdf]

Belić S, Savić R, Belić A (2003): Upotrebljivost voda za navodnjavanje, *Vodoprivreda* 35: 37–49. [Usability of water for irrigation].

Belić S, Belić A, Vranešević M (2013): Water quality as a limiting factor for irrigated agriculture, Understanding Freshwater Quality Problems in a Changing World Proceedings of H04, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, (IAHS Publ. 361, 2013) [URL: https://iahs.info/uploads/dms/15592.34-243-249-361-03-H04_Belic_SBABMV-Geothenburg-konacnoCORR.pdf]

Bošnjak Đ (1994): Osnove kriterijuma ocene kvaliteta vode za navodnjavanje – FAO 1985. *Zbornik radova*, Poljoprivredni fakultet, Institut za ratarstvo i povrtarstvo, 22: 109–117. [Basics of water quality assessment criteria for irrigation – FAO 1985].

Capar G, Dilcan CC, Aksit C, Arslan S, Celik M, Kodal S (2016): Evaluation of irrigation water quality in Gölbaşı District. *Tarim Bilimleri Dergisi – J. Agric. Sci.* 22: 408–421.

Čolić J, Petković A, Tončić J, Nenin T (2016): Mogućnost korišćenja vode akumulacija Međeš, Ljukovo i Borkovac za navodnjavanje sa aspekta kvaliteta vode. *Voda 2016*: zbornik radova

45. godišnje konferencije o aktuelnim problemima korišćenja i zaštite voda, Zlatibor, 15.–17. jun 2016. [Possibility of using water of reservoirs Međeš, Ljukovo and Borkovac for irrigation from the aspect of water quality, 45th conference on current topics of water use and protection "WATER 2016", 15–17. June 2016, Zlatibor, Publisher: Serbian Society for Water Protection, Belgrade], 339–348.

Domenico PA, Schwartz FW (1990): *Physical and chemical hydrogeology*. New York: John Wiley & Sons.

Dragović S, Ćirović M, Hadžić V (1993): Problem zaslanjivanja zemljišta u navodnjavanju i uticaj kvaliteta vode. *Zbornik radova* – Naucni institut za ratarstvo i povrtarstvo 21: 111–126 [The problem of soil salinization in irrigation and the impact of water quality. Proceedings of the Institute of Field and Vegetable Crops]

Dragović S, Božić M, Stević D, Rudić D, Vasić G (2007): Vodno-soni režim zemljišta u navodnjavanju sa aspekta problema zaslanjivanja u Surčinskom donjem polju. *Vodoprivreda* 39: 376–390. [Water-salt regime of soil in irrigation from the aspect of salinization problems in Surčin lower field]

Dragović S, Hadžić V, Maksimović L, Nešić Lj, Belić M (1994): Uticaj kvaliteta vode za navodnjavanje zemljišta u sistemima za navodnjavanje u Vojvodini. *Savremena poljoprivreda* 6: 132–135. [Influence of water quality for soil irrigation in irrigation systems in Vojvodina].

Eshel G, Fine P, Singer MJ (2007): Total soil carbon and water quality: an implication for carbon sequestration. *Soil Sci. Soc. Am. J.* 71: 397–405.

FAO (1994): Water quality for agriculture. FAO Irrigation and drainage paper. 29 Rev.1. Rome.

Follett RH, Soltanpour PN (2002): *Irrigation water quality criteria*. Colorado State University Publication No. 0.506 [URL: https://mountainscholar.org/bitstream/handle/10217/194958/AEXT_ucsu206220506.pdf?sequence=1&isAllowed=y]

Food and Agriculture Organization of the United Nations (1994): The state of food and agriculture 1994. FAO Avriculture Series, no 27, ISBN 93:5-103550-4, Rome.

Gajić B (1999): Influence of sprinkling irigation on the physico-mechanical properties of chernozem and humogley. *Zemljište i biljka* 48: 93–101.

Gao Y, Yu G, Luo C, Zhou P (2012): Groundwater nitrogen pollution and assessment of its health risks: A case study of a typical village in rural-urban continuum, China. *PloS One* 7: e33982. [https://doi.org/10.1371/journal.pone.0033982]

Ghassemi F, Jakeman AJ, Nix HA (1995): *Salinization of Land and Water Resources. Human causes, extent, management and case studies*. Center for Resource and Environmental Studies. Canberra: Australian National University.

Ghoraba SM, Khan AD (2013): Hydrochemistry and groundwater quality assessment in Balochistan Province, Pakistan. *Int. J. Res. Rev. Appl. Sci.* 17: 185.

Hadžić V, Nešić L, Sekulić P, Ubavić M, Bogdanović D, Dozet D, Belić M, Govedarica M, Dragović S, Verešbaranji I (2004): Kontrola plodnosti zemljišta i utvrđivanje sadržaja štetnih i opasnih materija u zemljištima Vojvodine. *Zb. rad. – Nauč. inst. ratar. povrt.* 40: 57–64. [Soil fertility control and determination of the content of harmful and dangerous substances in the lands of Vojvodina]

Hopkins BG, Horneck DA, Stevens RG, Ellsworth JW, Sullivan M (2007): *Managing Irrigation Water Quality for crops production in the Pacific Northwest*. Washington: Pacific Northwest Extension Publication. [URL: https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw597.pdf]

Ilić M, Vranešević M, Bezdan A, Blagojević B (2019): Classification of Water Quality of Banat Watercourses in Serbia for the Needs of Irrigation. *J. Environ. Geogr.* 12: 51–57.
Läuchli A, Epstein E (1990): Plant responses to saline and sodic condi-tions. In: *Agricultural salinity assessment and management* (ed. KK Tanji), ASCE Manuals and Reports on Engineering Practice, ASCE, Reston 71: 113–137.
Maral N (2010): *Soil and water analysis techniques for agricultural production*. Master of Science Thesis, Middle East Technical University (Basılmamış), Turkey.
Mateo-Sagasta J, Burke J (2010): Agriculture and water quality interactions: a global overview. SOLAW Background Thematic Report—TR08. Food and Agriculture Organization of the United Nations, Rome, 46.
Miljković N (1986a): Klasifikacija površinskih i podzemnih voda u Vojvodini sa aspekta njihove primene za navodnjavanje. u: *Kongres o vodama Jugoslavije* (II), Ljubljana–Beograd: Jugoslovensko društvo za odvodnjavanje i navodnjavanje, 1360–1373. [Classification of surface and groundwater in Vojvodina from the aspect of their application for irrigation].
Miljković N (1986b): Savremeni pristup proceni kvaliteta vode za navodnjavanje. *Vodoprivreda* 21: 307–312.
Miljković N (1988): Appearance of the Secondary Salinization of Soils in Yugoslavia. *Procedings of the International Symposium on Solonetz Soils*, Osijek, 339–346.
Morgan KT, Graham JH (2019): Nutrient Status and Root Density of Huanglongbing-Affected Trees: Consequences of Irrigation Water Bicarbonate and Soil pH Mitigation with Acidification. *Agronomy* 9: 746. [DOI: 10.3390/agronomy9110746]
Nejgebauer V (1949): Upotrebljivost površinskih i podzemnih voda za navodnjavanje i njihova klasifikacija u prirodnim prilikama Vojvodine. *Radovi poljoprivrednih naučnoistraživačkih ustanova* [The Use of Surface and Groundwater for Irrigation and Their Classification in the Natural Conditions of Vojvodina].
Nešić Lj, Hadžić V, Sekulić P, Belić M (2003): Kvalitet vode za navodnjavanje i salinitet zemljišta u intenzivnoj povrtarskoj proizvodnji, *Letop. naučn. rad.*, Poljoprivredni fakultet u Novom Sadu, 27: 5–10. [Irrigation water quality and soil salinity in intensive vegetable production].
Ray C, Jain RK (1998): Nitrate pollution of wells: pollution prevention policy options. *Environ. Eng. Policy* 1: 165–173. [DOI:10.1007/s100220050018]
Richards LA (ed.) (1954): Diagnosis and improvement of saline and alkali soils. USDA Agriculture Hand Book No 60. [URL: https://www.ars.usda.gov/ARSUserFiles/20360500/hb60_pdf/hb60complete.pdf]
Sanderman J (2012): Canmanagement induced changes in the carbonate systemdrive soil carbon sequestration? A review with particular focus on Australia. *Agric. Ecosyst. Environ.* 155: 70–77.
Savić R, Belic A, Belic S (1997): Water quality of the Danube through the Vojvodina Province in view of the irrigation needs. *32 Konferenz der IAD*, Wien, 415–418.
Shahid SA, Mahmoudi H (2014): National strategy to improve plant and animal production in the United Arab Emirates. *Soil and water resources*. Annexes.
Shahabi A, Malakouti M, Fallahi E (2005): Effects of Bicarbonate Content of Irrigation Water on Nutritional Disorders of Some Apple Varieties*. *J. Plant Nutr.* 28: 1663–1678.
Shakoor A, Arshad M, Bakhsh A, Ahmed R (2015): GIS based assessment and delineation of groundwater quality zones and its impact on agricultural productivity. *Pak. J. Agri. Sci.* 52: 837–843.

Službeni list Republike Srbije [*Official gazette of RS*] (2017): Strategije upravljanja vodama na teritoriji Republike Srbije do 2034. godine, 3/2017. [Water Management Strategy on the territory of the Republic of Serbia until 2034].

Sreedevi PD, Sreekanth PD, Ahmed S, Reddy DV (2018): Evaluation of groundwater quality for irrigation in a semi-arid region of South India. *Sust. Water Res. Manag.* 5: 1043–1056.

Suarez DL (1999): Impact of agriculture on CO_2 as affected by changes in inorganic carbon. In: R. Lal, JM Kimble, H. Eswaran, BA Stewart (Eds.), *Global Climate Change and Pedogenic Carbonates*. CRC Press, Boca Raton, FL, 257–272.

Suthar S, Bishnoi P, Singh S, Mutiyar PK, Nema AK, Patil NS (2009): Nitrate contamination in groundwater of some rural areas of Rajasthan, India. *J. Hazard. Mater.* 171: 189–199.

Thompson M, Brandes D, Kney A (2012): Using electronic conductivity and hardness data for rapid assessment of stream water quality. *J. Environ. Manage.* 104: 152–157.

Todd DK, Mays LW (2005): *Groundwater hydrology*. New York: John Wiley & Sons, 3rd ed.

United Nations Development Program (UNDP) (2019): Crop heating – how to respond? Impacts of climate change on Serbian agriculture. United Nations Development Program in Serbia, Belgrade.

US Salinity Laboratory Staff (1954): *Diagnosis and improvement of saline and alkali soils*. Washington, DC: US Department of Agriculture Handbook 60.

Vranešević M, Blagojević B, Bezdan A, Savić R (2016): Kvalitet vode za navodnjavanje sa fruškogorskih akumulacija. *Letop. Naučn. Rad.* (Ann. Agr.), 40: 15–20. [Irrigation water quality from artificial reservoirs on Fruška Gora].

Vučić N, Vučić J (1965): Problems of evaluating irrigation water. *Arhiv za polj. n.*, 18: 67–76.

Vučić N (1976): *Navodnjavanje poljoprivrednih kultura: osnove dopunskog navodnjavanja*. Novi Sad: Poljoprivredni fakultet, Univerzitet u Novom Sadu. [Irrigation of agricultural crops].

Vučić N (1987): *Vodni, vazdušni i toplotni režim zemljišta*. Novi Sad: Vojvođanska akademija nauka i umetnosti [Water, air and heat regime of the soil].

Vuković A, Vujadinović M, Rendulić S, Đurđević V, Ruml M, Babić V, Popović D (2018): Global warming impact on climate change in Serbia for the period 1961–2100. *Therm. Sci.*, 22: 2267–2280.

World Water Assessment Programme (WWAP) (2013): The United Nations World Water Development Report 2013. United Nations World Water Assessment Programme (WWAP). Paris, United Nations Educational, Scientific and Cultural Organization.

Zaman M, Shahid SA, Heng L (2018): Irrigation Water Quality. *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, 113–131. [DOI: 10.1007/978-3-319-96190-3_5]

ОЦЕНА КВАЛИТЕТА ВОДЕ ЗА НАВОДЊАВАЊЕ
СА ТЕРИТОРИЈЕ АП ВОЈВОДИНЕ

Станко Б. МИЛИЋ[1], Душана Д. БАЊАЦ[1], Јовица Р. ВАСИН[1],
Јордана М. НИНКОВ[1], Боривој С. ПЕЈИЋ[2], Ивана Б. БАЈИЋ[1], Бранка Љ. МИЈИЋ[1]

[1] Институт за ратарство и повртарство,
Институт од националног значаја за Републику Србију,
Максима Горког 30, Нови Сад 21000, Србија
[2] Универзитет у Новом Саду, Пољопривредни факултет,
Департман за ратарство и повртарство,
Трг Доситеја Обрадовића 8, Нови Сад 21000, Србија

РЕЗИМЕ: У интензивним системима гајења биљака, поред контроле физичких и хемијских особина земљишта, неопходно је вршити и континуирано праћење квалитета воде за наводњавање. У светлу надолазећих климатских промена, као и забрињавајућег опадања садржаја органске материје, не смеју се занемарити и неповољне последице примене воде неодговарајућег квалитета на наводњавано земљиште, гајене биљке и опрему за наводњавање. У раду су приказани резултати квалитета воде која се користи за наводњавање, прикупљени током 2018. и 2019. године. Истраживање је обухватило 140 узорака воде из различитих водозахвата пореклом из површинских бунара, каналске мреже и акумулација за наводњавање. За оцену квалитета воде анализирани су следећи параметри: pH вредност, електропроводљивост (EC), суви остатак, јонски биланс, као и коефицијент адсорпције натријума (SAR) и вредност резидуалног натријум-карбоната (RSC). Уобичајено је да се за ову намену користи и класификација према Америчкој лабораторији за слатине (USSL) као и FAO процена квалитета воде за наводњавање. За просторе АП Војводине развијена је и Нејгебауерова класификација коју смо такође искористили за потребе оцењивања. На основу резултата минерализације воде за наводњавање, утврђене су следеће вредности посматраних параметара: просечно израчуната pH вредност анализираних вода износила је 7,89 (min=7,14, max=9,01), вредности електропроводљивости кретале су се у опсегу од 0,10 до 3,50 dS/m, са просечном вредношћу 0,85 dS/m. У односу на вредности сувог остатака, испитиване вредности кретале су се у широком опсегу, од 112 mg/l до 2.384 mg/l, с просечном вредношћу 529,22 mg/l. SAR вредности варирале су у опсегу 0,04–16,52 и задовољавајућим просеком од 1,97. Класификација према Америчкој лабораторији за слатине (USSL) показује сличне резултате као ФАО класификација и RSC индекс <0, указујући на то да 57% истраживаних узорака није забрињавајуће за употребу у наводњавању. Нејгебауерова класификација и RSC индекс 0–1,25 показују да је преко 75% анализираних узорака погодно и за наводњавање и сигурно за очување физичко хемијских својстава земљишта. Будући да квалитет воде за наводњавање значајно утиче на продуктивност биљака, као и да значајно може утицати на хемијске и физичке особине пољопривредног земљишта, праћење квалитета воде за наводњавање од изузетне је важности.
КЉУЧНЕ РЕЧИ: EC, јонски биланс, квалитет воде за наводњавање, SAR