Water quality as a limiting factor for irrigated agriculture

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Abstract Water quality for irrigation is evaluated for specific watercourses in the area of Vojvodina, Serbia. The classifications used to assess the usability of irrigation water of various qualities are the FAO classification, USSL classification, the classification according to Neigebauer and the chloride classification of irrigation water. An additional assessment of the usability of irrigation water was also used and included determining the value of the sodium adsorption ratio (SAR), sodium percentage (SSP), residual sodium carbonate (RSC), residual sodium bi-carbonate (RSBC), magnesium content (MAR), permeability index (PI), and Kelly's ratio (KR). The overall assessment is that water analysed for the irrigation systems cannot be used because of its inappropriate effects on soil salinity. An analysis of the suitability of the phreatic aquifer for irrigation showed its inappropriate characteristics. Only a small number of water samples could be recommended for irrigation.

Key words Danube-Tisza-Danube Hydro System; water quality; irrigation; classification; sustainability

INTRODUCTION

When we consider the soil, climatic, hydrological and sociological potentials of the Pannonian Plain, it becomes understandable why it is regarded as the granary of Europe. The plain is shared between ten countries. One of them is Serbia, whose northern part, Vojvodina Province, occupies the southern part of the plain. At the end of the 19th century, when dams were built to protect the territory of Vojvodina from high waters of the rivers that border and intersect it (Danube, Tisza, Sava, Zlatica, Krivaja, Tamis, Begej, Nera, Brzava, etc.), conditions were created to intensify crop production on the quality agricultural land. Furthermore, the construction of drainage systems, which today cover the whole of the province, helped to regulate the water–air regime of the soil. In addition to these extensive drainage works, which changed the original natural ecosystems, a need was felt to construct irrigation systems that would stabilize crop yields at an optimal level and which would provide large amounts of food to help alleviate the problem of hunger in the world. The numerous watercourses provide Vojvodina with sufficient amounts of water suitable for irrigation. In the last three decades, however, changes in water quality have been observed (Belic *et al*., 2011). These changes were brought about by nonpoint-source pollution, primarily of agricultural origin, and point-source pollution from industrial facilities and urban areas. The deterioration of water quality has imposed limitations on water use, even for agricultural purposes. There are several reasons for concern. In the first place, the awareness of the importance of water conservation as a natural resource important for further development of the province is not at a satisfactory level. Further, the legislation does not keep abreast with the scientific advances in the world or in Serbia. The existing laws do not adequately regulate the protection and use of water in general and in agriculture in particular.

Irrigation practice is a major factor that brings advances to crop production at a global level. However, irrigation activities cause salinization and alkalization, which result in extensive soil and water degradation everywhere where irrigation is practiced. There are well-known cases where changes in the chemistry of irrigation water have caused unacceptable effects in soils and plants. This means that the practices which caused these unwanted effects were not sustainable (Abernethy,1994). Obviously, irrigated agriculture needs to be sustained and rejuvenated (Rhoades, 1997). Sustaining irrigation systems is a broad general statement. Various attributes could be considered as objects for sustainability, such as irrigation facilities, production potential, operational performance, but first of all irrigation water quality. The reform of irrigation water quality policies is thus the first and most important step towards creating conditions that encourage the sustainable use of water (Wolff, 1999). The use of the existing classifications and the introduction of an additional procedure for water suitability assessment are avenues towards sustainable irrigation.

Vojvodina, the northern province of the Republic of Serbia, has large potential for intensive development of irrigation. There are 1.67 million ha of arable land (about 75% of the total area of Vojvodina), of which practically all are suitable for irrigation. The introduction of irrigation is an actual necessity because, on average, the agricultural crops require from 100 to 300 mm of water more than provided by natural rainfall during the growing season. At present, the main source of irrigation water is watercourses (over 90%), and the dominant irrigation method is sprinkling (80–90%). The irrigated acreage predominantly includes agricultural plots and gardens (95%) while the remaining 5% are irrigated orchards (Belic *et al.*, 2001, 2011). Water quality plays an important role in irrigation practice. Irrigation practice brings some hazards, which are most commonly manifested as secondary salinization and alkalization, typically caused by increased concentrations of salts in irrigation water. It happens frequently that different methods of water quality classification provide contradictory results. This problem may be solved by introducing an additional, corrective procedure for irrigation water assessment (Lijklema, 1995).

MATERIALS AND METHODS

The evaluation of water quality for irrigation included several watercourses considered characteristic of Vojvodina. The evaluation was based on official monitoring programmes in the period 1980–2009; data were presented in hydrological yearbooks for water quality published by Hydro-Meteorological Service of the Republic of Serbia (www.hidmet.gov.rs). During the observed period, water samples were taken 6–24 times per year, depending on the sampling point in question. The sampling included 30 points located in the major watercourses of Vojvodina (Fig. 1).

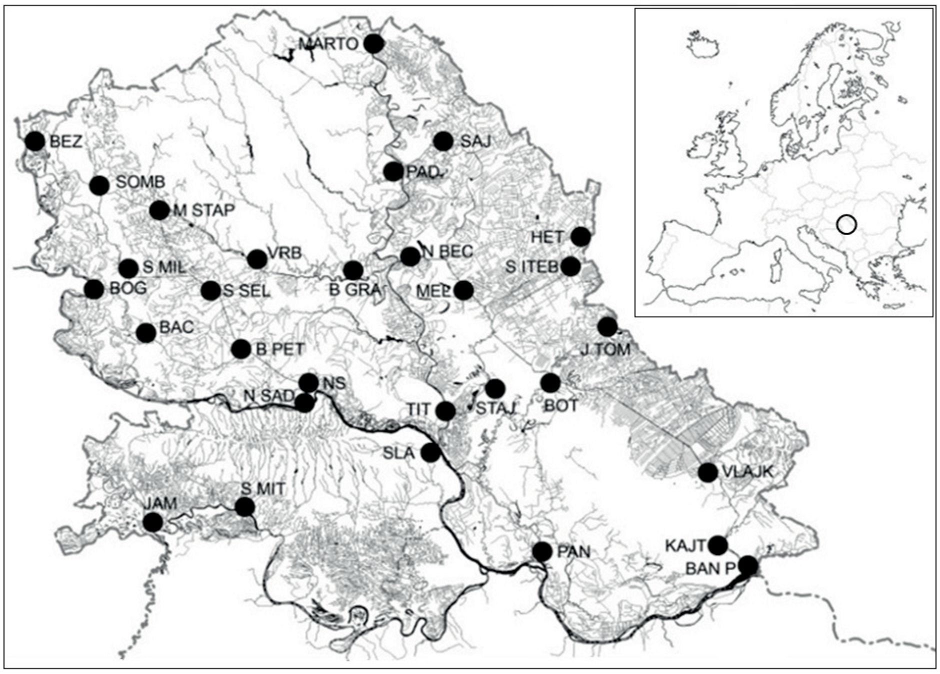

Fig. 1 Location of water sampling points in Vojvodina Province.

The irrigation water quality classifications used in this study were the FAO classification, the US Salinity Laboratory Classification (USSL) classification, the classification according to Nejgebauer and the irrigation water classification according to chloride content (Kirda, 1997; Johnson & Zhang, 2009). An additional procedure for irrigation water assessment was also used, which included the determination of sodium adsorption ratio (SAR), sodium percentage (SSP), residual sodium carbonate (RSC), residual sodium bi-carbonate (RSBC), magnesium content

(MAR), permeability index (PI), and Kelly's ratio (KR). Sodium adsorption ratio (SAR) was calculated by the following equation, where all ions are expressed in meq/L (Prasad *et al*., 2001; Van de Graff & Patterson, 2001; Seilsepour *et al*., 2009):

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Another way to examine the irrigation water is to estimate the residual sodium carbonate (RSC) as (Obiefuna & Sheriff, 2010):

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

The residual sodium bi-carbonate (RSBC) was calculated by the following equation:

$$RSBC = HCO_3 - Ca$$

The level of Na^+ measured against Ca^{2+} and Mg^{2+} is known as Kelley's ratio, based on which irrigation water can be rated:

$$KR = \frac{Na}{Ca + Mg}$$

The level of Na^+ and K^+ measured against all cations, known as the soluble sodium percentage (SSP), was calculated by the following equation:

$$SSP = \frac{Na + K}{Ca + Mg + Na + K} \times 100$$

Magnesium adsorption ratio (MAR) was calculated as:

$$MAR = \frac{Mg}{Mg + Ca} \times 100$$

The permeability index (PI) was calculated by the following equation (Kirda, 1997):

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100$$

RESULTS AND DISCUSSION

According to the classifications of FAO, Nejgebauer and USSL, the waters of all tributaries of the Danube River in Serbia can be considered as suitable for irrigation (Table 1). The previous statement is contrary to the part of the FAO classification which refers to the restricted use of water prone to salinization. This was also confirmed by the value of SSP, a parameter in the additional assessment of irrigation water quality (Table 2), which was near to threshold that distinguishes favourable from unfavourable irrigation water. However, the values of RSC and PI indicated that the analysed waters could be used for irrigation without restriction. A general conclusion was drawn that the Danube River water can be used for irrigation, provided that the status of water used and treated soils are systematically monitored.

According to Nejgebauer's classification, more than two thirds of the samples taken from the Tisza River were not suitable for irrigation, or this water may be used only for well-drained soils while ensuring that the status of these soils is monitored systematically and comprehensively. These findings may cause concern, since irrigation systems are planned to be established on considerable acreages along the Tisza River in both the Backa and Banat regions, and these systems will be used for the production of field crops, especially vegetables. The FAO classification considered together produced similar results. Potential problems with the water from the Tisza River have also been hinted at by the values of SSP, RSC and PI, which were above the allowable limits.

Table 1 Suitability of irrigation water according to the classifications used in the study.

Watercourse/ classification		Nejgebauer* Class	USSL Class	Cl Restriction on use	FAO			
					Salinity	Infiltration	Na toxicity	Cl toxicity
					Restriction on use			
Danube	Max	II	C3-S1	None	Slight to moderate	Slight to moderate	None	None
	Min	Ia	C1-S1	None	None	None	None	None
Tisza	Max	IIIb	C3-S1	For sensitive plants	Slight to moderate	Severe	Slight to moderate	Slight to moderate
	Min	II	C1-S1	None	None	None	None	None
Sava	Max	Ib	C3-S1	None	Slight to moderate	Severe	None	None
	Min	Ia	C1-S1	None	None	None	None	None
Tamis	Max	II	C3-S1	For sensitive plants	Slight to moderate	Severe	Slight to moderate	None
	Min	Ia	C1-S1	None	None	None	None	None
Begej	Max	IVb	C4-S2	For semi-tolerant plants	Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate
	Min	II	C1-S1	None	None	None	None	None
Zlatica	Max	IVb	C4-S3	Should not be used	Severe	Slight to moderate	Slight to moderate	Slight to moderate
	Min	II	C2-S1	None	None	None	None	None
DTD HS	Max	IVb	C4-S2	For semi-tolerant plants	Slight to moderate	Severe	Slight to moderate	Slight to moderate
	Min	II	C1-S1	None	None	None	None	None

*According to this classification, irrigation water is divided into four classes, according to the amount of Total Dissolved Solids(TDS) and ratio (Ca+Mg):Na. First class – excellent water quality (Ia: TDS <700mg/L, (Ca+Mg):(Na+K)>3; Ib–Ia: TDS <700mg/L, (Ca+Mg):Na>3). Second class – good water quality (TDS <700mg/Ll, (Ca+Mg):Na>1). Third class –water quality should be tested (IIIa: TDS =700–3000mg/L, (Ca+Mg):Na>3; IIIb: TDS =700–3000mg/L, (Ca+Mg):Na>1). Fourth class – unsuitable water quality (IVa: TDS <700mg/L, (Ca+Mg):Na<1; IVb: TDS =700–3000mg/L, (Ca+Mg):Na<1; IVc: TDS >3000mg/L, (Ca+Mg):Na< 1).

Similar to the water from the Tisza River, the water from the Sava River was found to be potentially capable of causing problems with soil infiltration and salinization. However, according to parameters in the other classifications, including the additional one, the suitability of Sava water was not subject to any restrictions. The USSL classification produced similar results. Most of the samples of water from the Danube, Tisza and Sava rivers were placed in C2-S1 class, indicating that these waters can be safely used for irrigation. Several samples that fell into C3-S1 class indicated a threat of alkalization of soils irrigated with such water.

The US Salinity Laboratory Classification (USSL) is the result of many years of team work. It involves a procedure for evaluation of irrigation water quality, including consideration of the hazards of salinization and alkalization of irrigated soils. The classification is based on the values of electrical conductivity as an indicator of salt concentration and SAR values as an indicator of the relative activity of water-soluble Na in the adsorption reactions with soil. Nejgebauer's classification of water was proposed for the natural conditions of Vojvodina in 1949. This classification placed special emphasis on the ratio (Ca + Mg):Na. The FAO classification (Ayers & Westcot, 1985) includes 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.

Given the plans to increase the irrigated acreage in Banat, it is definitely important to estimate the status of the watercourses in that region. While the waters of the Danube, Sava and Tisza were considered as of generally favourable quality, the waters of the Zlatica and partly of the Begej and Tamis rivers were recognized by all the classifications used as unfavourable for irrigation. According to Nejgebauer, most of the analysed waters were in classes II or III, with occasional samples in class IVb. According to the USSL classification, the analysed waters were class C3S1 or worse. The FAO classification indicated that a significant number of the samples posed a hazard of salinization that could be associated with deterioration of soil infiltration properties and, in some instances, there was a hazard of toxic ions. Concerning the additional assessment of irrigation water quality, the recorded SSP and SAR values indicated the presence of significant amounts of sodium. Even the values of RSC, RSBC and PI were significantly over the recommended limit values.

The canal network of the Danube-Tisza-Danube Hydro System (DTD HS) should play an important role in the development of irrigation in Vojvodina. Therefore, it is important to establish the current water quality status of the canal network. There was a mild decreasing trend in water quality and an increasing mineralization trend in most of the analysed samples. In the region of Backa, about one third of the waters were classified as C3S1 (USSL). Two thirds of the waters were in class II according to Nejgebauer. These waters can be used for irrigation. Unfavourable SSP ratios, frequently accompanied by unfavourable RSC values, were simultaneously recorded at the same locations. Based on these results, the waters in DTD HS in the region of Backa can be recommended for irrigation of well-drained soils, providing that the status of the irrigated soils is systematically monitored. A similar situation was found for the DTD HS locations analysed in the region of Banat; the dominant classes were C3S1 according to the USSL and class II according to Nejgebauer. In the Banat locations, SSP values were as a rule significantly higher than the recommended values.

The irrigation water quality results according to three classifications (Nejgebauer, Cl, and USSL), and their trends are shown for one locality (Hetin Begej) in Fig. 2. In order to simplify the figure, every chosen classification was reduced to five categories. Taking into consideration the longer period of time, the results do not indicate a deterioration of irrigation water quality. Yields from agricultural fields were not included in these investigations. However, continuous investigation of irrigation water quality is very important. Also, inclusion of some new parameters like soil, climate, and quantity and quality of yields, are desirable.

The results presented in Tables 1 and 2 show how variable and inconsistent the analysed assessment procedures were. It can be concluded that, for the period and locations analysed, Nejgebauer's classification was the most stringent (Table 1), defining a significant portion of the analysed samples as unsuitable for irrigation use. The waters of the Danube, Tisza, and Begej were found to be acceptable for irrigation, except in some cases where it was recommended to monitor the changes in soil chemistry due to the potential adverse effects of these waters. The results of the FAO classification of water suitability for irrigation obtained were not always in accord with the other estimates, especially when the hazards of salinization or disturbance of soil infiltration properties were analysed. Perhaps this can be understood if we take it into account that different irrigation standards were used during this classification procedure.

As the results above show, when the additional procedure for water suitability estimation (Table 2) is considered integrally, it makes the assessment more reliable. In this particular case, the

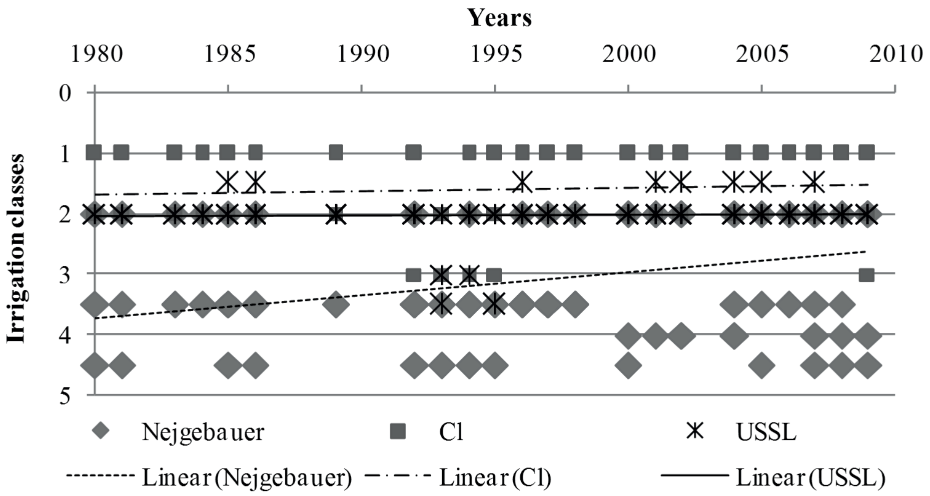

Fig. 2 Irrigation water quality as result of different classification applied on location Hetin-Begej.

Table 2 Additional procedure for irrigation water assessment.

Additional irrigation water assessment		MAR (%)	SSP (%)	RSC (meq/L)	RSBC (meq/L)	PI (%)	KR (meq/L)	SAR (meq/L)
Danube	Max	86.96	31.87	2.00	2.74	128.96	0.56	1.52
	Min	15.15	5.09	–3.26	–1.72	33.79	0.04	0.11
Tisza	Max	76.92	62.06	4.50	4.69	98.57	1.55	2.31
	Min	8.37	3.66	–3.15	–0.89	33.71	0.03	0.10
Sava	Max	81.37	22.54	1.29	2.87	78.70	0.27	0.80
	Min	7.60	3.34	–3.15	–0.83	31.83	0.03	0.08
Tamis	Max	62.19	68.88	2.32	3.89	93.57	2.17	5.67
	Min	9.20	6.51	–1.92	–1.42	41.29	0.06	0.14
Begej	Max	85.10	69.42	12.93	18.43	95.92	1.99	5.52
	Min	18.51	9.96	–3.56	–0.54	37.32	0.07	0.19
Zlatica	Max	53.67	74.96	3.39	5.55	84.83	2.81	10.58
	Min	26.75	29.78	–3.64	–1.21	56.89	0.39	1.12
DTD HS	Max	82.54	96.96	8.49	9.05	119.63	2.40	7.47
	Min	2.97	3.01	–6.95	–2.65	14.69	0.01	0.04

values of SSP were unfavourable for most samples. A similar situation was observed for PI. The values of SAR and RSC were unfavourable in a small number of the samples. Thus, most of the analysed samples showed good agreement between the results of the additional assessment and the USSL classification. The results of the additional assessment were only partially in agreement with the FAO classification, although a significant number of samples showed good agreement between the values of the additional assessment and Nejgebauer's classification of irrigation water.

The specific suitability of water for irrigation is determined above all by the features of every location, which depend on climate and soil characteristics, and also the water added to plants. This multi-criteria relationship demands adaptation of existing classifications to local conditions, but also to the type of plants cultivated. It is difficult, almost impossible, to be categoric about an assessment. Therefore, this attempt to apply and compare several classifications offers a general assessment of water conditions. There was no systematic observation of the influence of water quality on cultivated plants at the localities investigated, but processes of secondary salinization would be recognized after 20+ years application of water which, according to USSL and Nejgebauer's classifications, was inappropriate for irrigation.

CONCLUSION

The quality of irrigation water has an immense impact on the preservation of natural resources, primarily of soil, and it creates favourable conditions for securing high and stable yields as well as high quality agricultural products. The usefulness of irrigation water is directly related to the quantity and quality of water. Elsewhere in the world, water availability is frequently a limiting factor. When evaluating water availability in Vojvodina, water quality emerges as a constraint for several reasons. Deterioration of water quality takes place under the influence of point- and nonpoint-source pollution. The problem of water usefulness also has a social aspect due, in the first place, to inadequate education of land users in this region; as a result, water of inferior quality is used to regulate the water–air regime of soil.

The additional procedure for irrigation water assessment may be implemented for evaluation of irrigation water quality in combination with the generally-used classifications to identify whether water is within the sustainability framework for irrigation practice. The main purpose of the additional assessment was to confirm or correct the results obtained by the conventional classifications. In this study, there was good agreement between the results of the additional assessment and those of the USSL and Nejgebauer's classifications. The additional assessment was found to be necessary to amend the results of the FAO classification and the water classification according to chloride content when testing the suitability of surface waters from Vojvodina for irrigation.

Use of inferior irrigation water leads to changes in soil quality, most frequently to secondary salinization due to the imbalanced salt regime. If this setback combines with soil compaction below the plough pan, the irrigated land may become waterlogged in the humid part of the year, which would hinder or obstruct the timely performance of cultivation practices and significantly diminish crop production. The process of land degradation is difficult to perceive without systematic monitoring of water quality and the salt regime in the soil, i.e. without long-term observations. Restoring such land back to normal is an expensive and time-consuming process, which often cannot be accomplished at all.

Systematic monitoring of water quality is needed in order to make an overall assessment of its applicability for irrigation. Also, it is necessary to use one's own research results and experience from other parts of the world to develop reliable criteria for assessing the usefulness of water for irrigation. Based on these criteria, appropriate laws should be legislated and their application in practice should be enforced. At the same time, major efforts should be invested in upgrading the education level of irrigation water users.

For the period 1980–2010, for which there are series of systematic water quality observations, a mild decreasing trend of electro-conductivity can be noticed (Belic *et al*., 2011), and also a neutral trend in SAR value on the Bezdan-Danube River profile for 1969–1996 (Savic *et al*., 1997). Analysing parameters of macro-mineralisation shows that the deterioration of water quality is not significant over these long periods. This suggests that the impact of climate changes will only be to reduce the quantity of water available for irrigation.

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