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RESEARCH ARTICLE

Sustainable agriculture and sustainability of water resources from the aspect of environmental protection

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***Abstract* -** The international community has recognized soil salinization as one of the biggest global problems when it comes to soil conservation and its fertility, where the quality of water used for irrigation is a very important factor.

Institute of Soil Science in Belgrade conducted research on the properties of agricultural soil and irrigation water sampled at locations under irrigation systems within 6 areas of central Serbia (Braničevska, Podunavska, Pomoravska, Moravička, Mačvanska, and Toplička) in the period 2015-2018. Irrigation water was sampled at the research sites, in which the parameters for assessing its quality were analyzed (pH, electrical conductivity, sodium adsorption ratio, fixed residue). Five different classifications of irrigation water, which define the degree of risk of salinization and alkalization of soil due to the use of water of a certain quality for irrigation purposes, were applied in the paper. It was observed that a number of samples fall into different classes of application possibilities for irrigation according to different classifications. In some areas, the percentage of samples where a mismatch among classifications was observed is not negligible.

Worldwide, priority is given to different classifications depending on practical experience and scientific conclusions. Many factors affect the degree of risk of soil salinization that is subject to change in the conditions of climate change. Having in mind the importance and prevalence of soil salinization, we conclude that the practice of using a number of classifications and their revision over time is a positive example and useful tool in the prevention and combat against soil salinization.

***Keywords* -** soil salinity, soil conservation, water quality, irrigation

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INTRODUCTION

Agricultural production would not be possible in many areas of the world without irrigation. Water must be used rationally as a natural resource, and as its availability is declining, it is necessary to ensure that existing systems are used as sustainably as possible, which largely depends on the proper management. It is well known that unsustainable irrigation practices, especially changes in the chemistry of irrigation water, lead to unacceptable consequences for soils and plants. (Abernethy, 1994). There are many aspects of irrigation sustainability but the first and most important is the quality of water used for irrigation, which is the most important for the preservation of soil and other natural resources, securing high and stable yield production, and obtaining safe food which is crucial for human and animal health. Creating conditions that encourage the sustainable use of water through the reform of irrigation water quality policies is necessary (Wolff, 1999).

Water quality problems can be complex. Water from various sources can be used for irrigation. The use of irrigation water with an imbalanced salt regime can cause secondary salinization and sodification (Belić, 2013).

Saline and sodic soils are collectively referred to as salt-affected soils and they are recognized by the international community as major and widespread challenges that affect global food security and environmental sustainability (Singh, 2021).

Plants grown on saline soils have difficulties absorbing water from the soil due to the increased amount of soluble salts. Sodic soils are characterized by an unfavorable structure caused by a large amount of adsorbed sodium ions. These conditions have a major adverse impact on agricultural productivity and food security. Among the biggest anthropogenic influences on salinization and sodification of soil is irrigation with water of inadequate quality (FAO, 2021).

The "Global map on salt-affected soils" was launched at the Global Symposium on Salt-affected Soils, organized by FAO, which was held virtually in October 2021. The map covers 73% of the earth's surface. According to the data published at the conference, which is cartographically displayed on maps, salt-affected soils cover over 833 million ha, which represents 8.7% of the total earth’s soil surface.

Saline soils cover about 2.7% of the area in the Republic of Serbia, or about 242,200 ha, mainly in the Autonomous Province of Vojvodina (Institute of Soil Science, 1995). Although saline soils represent a relatively small percentage of the area in the Republic of Serbia, prevention and risk assessment are increasingly important. It is probable that the problem of soil salinity and sodification will develop and impact currently unaffected regions in the conditions of climate change, due to the increase of air temperature, decline in relative humidity, and extreme rainfall events (IPCC, 2013).

The risk of soil salinization in irrigation systems in Serbia was observed in earlier studies by Neugebauer (1949), Miljković et al. (1988), Hadžić et al (1989) and Dragović et al (1994), Nešić (2003), Trajković (2004), Belić (2013) and many others.

Producing one universal classification of irrigation water quality is a difficult task because of the complex water-plant-soil relationship (Trajković, 2004). Most-used classifications globally are the ones proposed by the United Nation Food and Agricultural Organization (FAO) and US Salinity Laboratory (USSL). FAO classification is often referred in the literature as modern even though it was proposed by Ayers & Westcot in 1985 because it requires extensive analyses and provides a complex assessment of the usability of the irrigation water from the point of its influence on the soil and the plants.

The US Salinity Laboratory Classification (USSL) was developed in arid climate conditions and it was specifically developed for soil salinization and sodification risk assessment (Thorne and Peterson, 1954). Practice has shown that this classification can be too strict in many areas of the world, since it was developed in arid regions, considering that a significantly smaller amount of water is used for irrigation in more favorable climate conditions (Belić, 2003).

Unlike FAO and USSL classifications that are used throughout the world, Nejgebauer’s classification of water was proposed for the natural conditions of Serbia in 1949. Although this classification has been proven to provide the most realistic assessment of irrigation water quality in the natural conditions of Serbia it is not internationally comparable (Trajković, 2004).

In Serbia, Stebler Irrigation Coefficient and Residual Sodium Carbonate are often determined in practice as an addition to described classifications of irrigation water quality. The Stebler Irrigation Coefficient is widely used because it is easy to apply. Residual Sodium Carbonate provides insight into the toxicity of chloride and nitrate thus contributing to the usability assessment of irrigation water (Belić, 2003).

Just as Neugebauer’s classification was developed and widely applied in Serbia, so scientists from different countries have developed and applied classifications using different combinations of parameters depending on regional specifics, environmental conditions, and needs.

In the ”Handbook for Saline Soil Management” (2018), published by FAO, the methodology for the experimental assessment of soil and water quality from the Laboratory of Fertility of Irrigated and Solonetzized soils of the Institute for Soil Science and Agrochemistry Research in Ukraine was promoted. The methodology provides a comprehensive approach to parameters for soil salinization/sodification risk assessment, salt toxicity to plants, soil buffering capacity, and thermodynamic parameters. This system became a part of legislation in Ukraine.

The aim of this paper is to compare five classifications of irrigation water in relation to the risk of soil salinization on the example of irrigation water samples collected in six areas of the Republic of Serbia to get an insight into which of the applied classifications is most applicable and globally comparable in these conditions.

MATERIALS AND METHODS

The Institute of Soil Science in Serbia conducted a survey of the properties of agricultural soil and irrigation water (2015, 2016, 2017, 2018). Sampling was performed at locations under irrigation systems and on plots where irrigation is planned to be implemented within six areas of central Serbia, in Braničevska, Podunavska, Pomoravska, Moravička, Mačvanska and Toplička areas in the period 2015-2018.

Irrigation water was also sampled at the research sites, in which the parameters for assessing its quality were analyzed: pH (potentiometric - YSSS, 1966), electrical conductivity (electrometric - YSSS, 1966), total dissolved solids content – (gravimetric - Greenberg, 1998 ; YSSS, 1966); CO_3^{2-}, HCO_3^-, Cl^- (volumetric - Greenberg, 1992 ; YSSS, 1966); K^+, Na^+ (flame photometric - Greenberg, 1992 ; YSSS, 1966); SO_4^{2-}, Ca^{2+}, Mg^{2+} (optical emission spectrometer – Thomas, 1982), sodium adsorption ratio (estimated- Rhoades, 1992). Based on the analyzed parameters five different classifications of irrigation water are applied in the paper. Obtained water classes define the degree of risk of salinization and alkalization of soil due to the use of water of a certain quality for irrigation purposes.

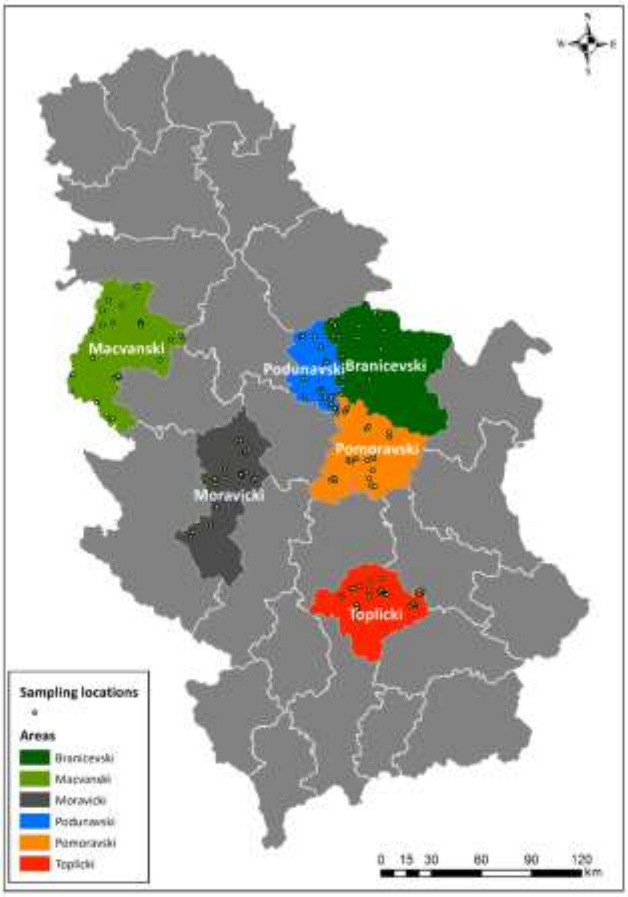

Figure 1. Irrigation water sampling locations in Braničev-ska, Podunavska, Pomoravska, Moravička, Mačvanska and Toplička areas (source: Institute of Soil Science, Serbia)

The Stebler Classification is based on the calculated irrigation coefficient (K). Concentrations of the corresponding ions in meq l^{-1} (rNa^+, rCl^-, rSO_4^{2-}) are used for the calculation of the K on the basis of which class affiliation is determined: Good (K> 18) - can be used without special measures to prevent the accumulation of harmful salts in the soil; Satisfactory (K: 18-6) - special measures are needed to prevent salinization, except for soils with favorable natural drainage; Unsatisfactory (K: 5.9-1.2) - drainage is almost always required; Poor (K <1,2) - not suitable for irrigation (Voitenko, 2017).

The Neugebauer's Classification pays special attention to (Ca + Mg) : Na ratio and dry residue, there are four classes of water according to this classification: Class I - waters with a low salt concentration and a very favorable ratio of divalent cations to the sum of Na. These waters are great for irrigation; Class II - waters with a low salt concentration and with a satisfactory ratio of divalent cations to a sum of Na which is greater than 1; Class III: water usable for irrigation; Class IV: includes four subclasses that are unfavorable for irrigation, both due to high salt concentrations and due to unfavorable ratios of divalent cations to the sum of Na (Dragović, 2000).

The US Salinity Laboratory Classification uses electrical conductivity (ECw) as a parameter to assess the degree of risk of soil salinization, based on which irrigation water is divided into six classes: C1 - low salt water, low risk of soil salinization (ECw≤0.25 dSm^{-1}); C2 - medium salt water, medium risk of soil salinization (ECw 0.25-0.75 dSm^{-1}); C3 - salt water, high risk of soil salinization (ECw 0.75-2.25 dSm^{-1}); C4 - high salt water - high risk of soil salinization (ECw 2.25-4.0 dSm^{-1}); C5 - very high salt water - very high risk of soil salinization (ECw 4.0-6.0 dSm^{-1}); C6 - extremely salty water (ECw> 6.0 dSm^{-1}). Risk of soil sodification is also assessed in USSL Classification and it uses sodium adsorption ratio (SAR) as parameter for defining water classes: S1 - low Na content, low risk of sodification (SAR 0-10); S2 - medium Na content, medium risk of sodification (SAR 11-18); S3 - high Na content, high risk of sodification (SAR 19-26); S4 - very high Na content, very high risk of sodification (SAR> 26) (Thorne & Peterson, 1954).

The FAO Classification uses as parameters electrical conductivity (ECw) and salt concentration (SC): Non-saline (NS) – Drinking and irrigation water (ECw<0.7 dSm^{-1} ; SC<500 mg/l); Slightly saline (SS) – Irrigation water (ECw 0.7-2 dSm^{-1} ; SC 500-1500 mg/l); Moderately saline (MS) – Primary drainage water and groundwater (ECw 2-10 dSm^{-1} ; SC 1500-7000 mg/l); Highly saline (HS) – Secondary drainage water and groundwater (ECw 10-15 dSm^{-1} ; SC 7000-15000 mg/l); Very highly saline (VHS) – Very saline groundwater (ECw 25-45 dSm^{-1} ; SC 15000-35000 mg/l); Brine (B) – seawater (ECw>45 dSm^{-1} ; SC>35000 mg/l) (Ayers & Westcot, 1985).

Residual Sodium Carbonate (RSC) assesses toxicity of chloride and nitrate and it uses residual Na_2CO_3 content as a parameter based on which three main classes are defined: Bad (RSC> 2.50 meq/l); At the limit of usability (RSC 1.25-2.50 meq/l); Good (RSC <1.25 meq/l) (Joshi, 2009).

Based on the obtained laboratory analyzes, the samples were classified according to the above classifications, and recommendations were given regarding the risk of soil salinization due to the use of water for irrigation purposes. Recommendations are graphically presented for each classification in each of the six areas.

RESULTS

Five described classifications of irrigation water quality were applied to 142 samples from six areas of Serbia.

18 samples were colected from Braničevska area; 26 from Mačvanska area; 22 from Moravička area; 22 from Podunavska area; 20 from Pomoravska area; 34 from Toplička area. It was observed that usability for irrigation of a number of samples is described differently according to different classifications. In some areas, the percentage of samples where non-compliance among classifications was observed is not negligible, as shown in the graphs in Figure 2.

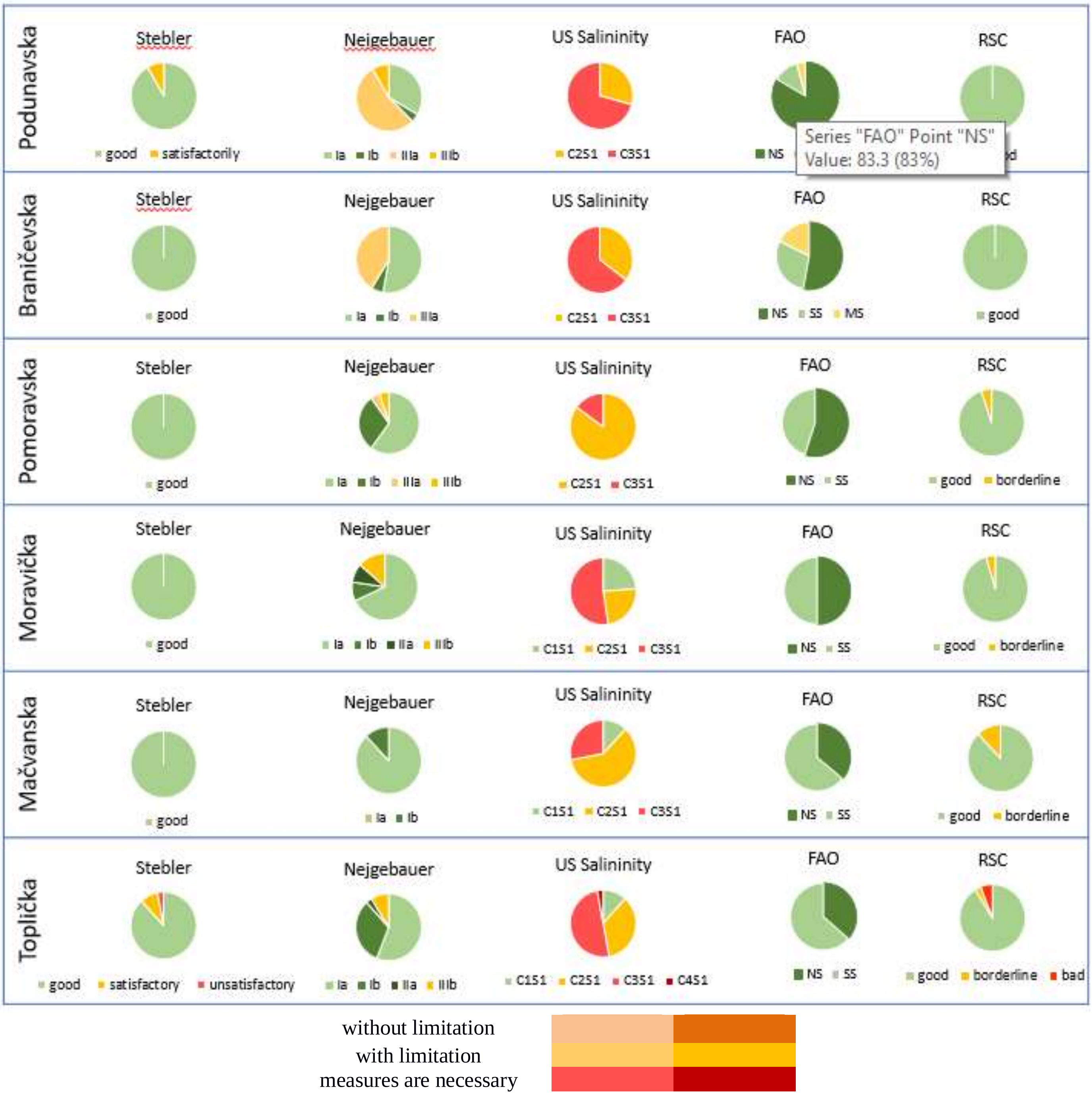

Figure 2: Display of irrigation water quality classifications in Braničevska, Podunavska, Pomoravska, Moravička, Mačvanska and Toplička areas (Pivić 2021)

A large difference was observed between the two globally most widely used classifications, FAO and USSL.

In the Podunavska area, the non-compliance between FAO and USSL classifications is 95.5% (21 / 22 samples), in Branicevska 83.2% (15 / 18 samples), the bigist inconsistency is in Pomoravska 100% (20 / 20 samples), the lowest in Moravicka 77.5% (17 / 22 samples), in Macvanska 88.6% (23 / 26 samples), in Toplicka 88.4% (30 / 34 samples).

Neugebauer's Classification has been widely applied in practice on the territory of Serbia, it has been adapted to the conditions of this area and in the past, it has been shown to provide the most realistic and complete picture within this geographical region. The results obtained using this classification give stricter recommendations for the use of water for irrigation in relation to the FAO and milder in relation to the USSL classification. According to the FAO and Neugebauer's Classification, there are no water samples for the use of which it is necessary to take measures in order to provide conditions for sustainable irrigation within the analyzed areas. On the other hand, the use of the USSL classification recommends the necessary measures in more than 50% of the analyzed locations in as many as four of the six areas of Serbia in which the research was conducted.

More precisely, compatibility between Neugebauer's and FAO classifications in Podunavska area is 40.55% (9 / 22 samples) while compatibility between Neugebauer's and USSL classifications is 27% (6 / 22 samples); in Braničevska area compatibility between Neugebauer's and FAO classifications is 77.6% (14 / 18 samples) while compatibility between Neugebauer's and USSL classifications is 28% (5 / 18 samples); in Pomoravska area compatibility between Neugebauer's and FAO classifications is 90% (18 / 20 samples) while compatibility between Neugebauer's and USSL classifications is 10% (2 / 20 samples); in Moravička area compatibility between Neugebauer's and FAO classifications is 85.5% (19 / 22 samples) while compatibility between Neugebauer's and USSL classifications is 31.5% (7 / 22 samples); in Mačvanska area compatibility between Neugebauer's and FAO classifications is 100% (26 / 26 samples) while compatibility between Neugebauer's and USSL classifications is 11.4% (3 / 26 samples); in Toplička area compatibility between Neugebauer's and FAO classifications is 91.3% (31 / 34 samples) while compatibility between Neugebauer's and USSL classifications is 37.7% (13 / 34 samples).

Stebler and RSC classifications were used as a complementary approach to the assessment of irrigation water quality. Based on these two classifications, almost all tested water samples are suitable for use in sustainable irrigation without the need for additional measures, with the exception of a few locations in the Toplicka area; one location 1 km away from the Municipality of Kuršumlija, which according to Stebler is classified as unsatisfactory, and two locations that are classified as bad according to the RSC classification (10 and 15 km away from the town of Prokuplje.

CONCLUSIONS

Healthy soil is key to the production and the safety of food which is crucial for human and animal health. Soil conservation is defined as one of the priorities of the international community through Sustainable Development Goal 15 - Life on Land. One of the biggest threats to the soil as a resource is the problem of salinization and sodification, which is taking on increasing dimensions in the conditions of climate change.

Long-term observations and systematic monitoring of the quality of water used for irrigation and salt regime in the soil are crucial for the sustainability of agriculture and soil resources. In order to develop reliable criteria for irrigation water quality on a global level, it is necessary to access research conducted in all regions of the world.

Practice has shown that the most reliable classification in the area of Serbia is Neugebauer's classification. This classification is specific to the conditions of Serbia and does not have a wide application outside this geographical region. As such, it is not internationally comparable, and it is necessary to use widely used classifications such as FAO and USSL. A comparative analysis of irrigation water quality using the three classifications processed in this study within the six regions of Serbia, concludes that the FAO and Neugebauer's classifications give significantly more approximate results compared to the USSL classification. As it is impossible to use Neugebauer's classification for the purpose of monitoring that goes beyond the local character, preference should be given to the FAO classification in relation to the USSL when it comes to the territory of Serbia.

Technical Network of the Global Soils Partnership known as the International Network of Salt-Affected Soils announced the development of the water quality criteria for sustainable management of soils to avoid its salinization and sodification during the FAO Global Symposium on Salt-affected Soils in October 2021.

The problem of salinization and sodification of soils and irrigation water quality should be approached rationally, strategically, and systematically at all levels - local, regional and global. Accordingly, it is necessary to respect the guidelines of the scientific international community at the local level. Regardless, priority is given to different classifications depending on practical experience and scientific conclusions worldwide. Comparative analyzes of widely applied practices with local practices which have given good results in the past can be a useful tool in combating global problems.

In the conditions of climate change, a periodic revision of practices is necessary, especially when it comes to issues of environment and sustainable development.

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