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Original scientific paper

COMPARATIVE ASSESSMENT OF WATER QUALITY FOR IRRIGATION IN THE KARST AREA OF THE RIVER BASIN OF SLATINSKA REKA

Biljana Gičevski[1*], Slavčo Hristovski[2], Vojo Mirčovski[3], Gjorgji Dimov[3]

[1]*Exploring Society "Ursus speleos", Dobromir Hrs 20a, 1000 Skopje, Republic of N. Macedonia*
[2]*Institute of Biology, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Arhimedova 3, 1000 Skopje, Republic of N. Macedonia*
[3]*Faculty of Natural and Technical Sciences, University "Goce Delcev", Blvd. Goce Delčev 89, 2000 Štip, Republic of N. Macedonia*
biljana_speleo@yahoo.com

A b s t r a c t: This study used available hydrochemistry data to determine the suitability of water bodies in the lower karst area in the river basin of Slatinska Reka for irrigation. Surface rivers Kruševska Reka, Markoska Reka (two points), and Slatinska Reka, as well as the springs Slatinski Izvor and Solenica, were observed between December 2011 and November 2013, and water samples were taken from each point. Irrigation quality parameters, such as Sodium Absorption Ratio (SAR), Sodium Percentage (Na%), Magnesium Adsorption Ratio (MAR), Kelly Ratio (KR), and Total Hardness (TH), were analyzed for suitability for irrigation. All analyzed parameters pointed out that surface rivers and the karst spring Slatinski Izvor were suitable for irrigation, whereas most of the water samples taken from the Solenica spring were not suitable for irrigation purposes. Also, the Solenica spring downstream of Markoska Reka influenced the irrigation properties of the river water, especially during the low waters. The process of karstification had a significant impact on the chemical composition of the water in the basin.

Key words: irrigation water quality; river basin of Slatinska Reka;l karst area

INTRODUCTION

Water is an essential environmental resource, critical for sustaining human life and supporting essential activities such as drinking water, irrigation, industry, and domestic use.

In karst landscapes, water resources play a vital role in human life. However, the quantity and quality of karst waters (ex. springs) exhibit significant temporal variability, which distinguishes them from other rock formations (Kresic and Stevanovic, 2010), complicating their management. At last, they are vulnerable to contamination due to the distinctive hydrogeological characteristics of karst systems.

The geological composition of the recharge area plays an essential role in the geochemistry characteristics of water (Deshmukh and Aher, 2016; Arulbalaji et al., 2019). At the same time, the porosity and permeability of sub-surface formations directly impact aquifer formation and water quality. Thus, gravel, sand, sandstone, and alluvial deposits, characterized by larger grain size and higher porosity, facilitate faster infiltration compared to schists, granite, and other rocks, which have lower permeability. Additionally, carbonate rocks and weatherable minerals tend to neutralize acidity, further influencing water chemistry (Taylor et al., 1982).

When water flows from a non-carbonate to a carbonate environment, its aggressiveness increases, dissolving carbonate rocks and thereby contributing to a higher mineralization of the water. As groundwater percolates through various soil and rock strata, it acquires dissolved minerals, with concentrations generally increasing with depth under conducive conditions. In contrast, surface waters contain lower levels of dissolved minerals. The infiltration of precipitation through soil and rock layers instigates a range of chemical, physical, and biological processes that alter water quality (Azadeh et al., 2010). These complex interactions underscore the need for a comprehensive understanding of geological and hydrological dynamics in karst areas to sustainable manage water resources.

The lower part of the Slatinska Reka catchment is mainly arable farmland. Water from rivers and the Slatinski Izvor spring is used to irrigate farmland, which was the impetus for writing this paper and determining the quality of water used for irrigation purposes.

Consequently, this study aims to present a comparative assessment of hydrochemical characteristics and water quality in karst aquifer in the lower part of the river basin of Slatinska Reka, and to evaluate the suitability of water for irrigation.

STUDY AREA

The river valley of Slatinska Reka is located in the Poreče basin, in the middle part of the Treska river drainage basin. Slatinska Reka, a left tributary of the Treska river, is created with the confluence of the Kruševska Reka and Markoska Reka rivers. The sources of both rivers are on the Pesjak mountain. Both rivers confluence downstream near the Slatina village (Figure 1). The upper part of the river basin of Slatinska Reka is a mountainous area. A portion of the lower part of the catchment area consists of plains that are used as farmland by the local population.

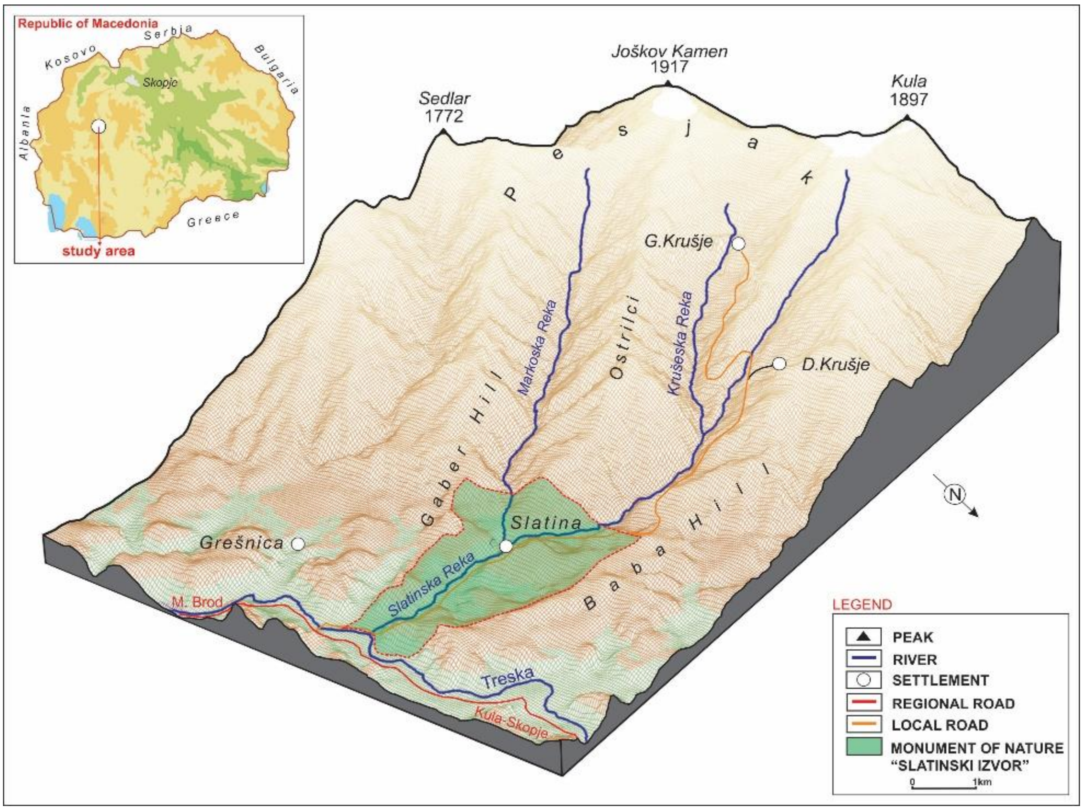

Fig. 1. Geographical position of the study area

The lower part of the river valley is composed of Precambrian dolomite marble which is tectonically crushed and well developed underground karst relief. Paleozoic quartz-sericite schists and metasandstones, metarhyolite tuffs, muscovite-chlorite-quartz schists and epidote-chlorite-amphibole schists prevail in the upper part, which are moderately-permeable rocks with fissure porosity. Between the marble and the Paleozoic rocks, Mesozoic aplitic granite with fissure porosity can be found. The carbonate rocks are covered with Pliocene sediments (gravel, sands, clay) which are highly permeable rocks with intergranular porosity. Quaternary sediments are represented by moraines on the upper parts of the Pesjak mountain and alluvial deposits that fill the river bed of Slatinska Reka (Dumurdžanov et al., 1978, 1979) – both of these units have intergranular porosity (Figure 2).

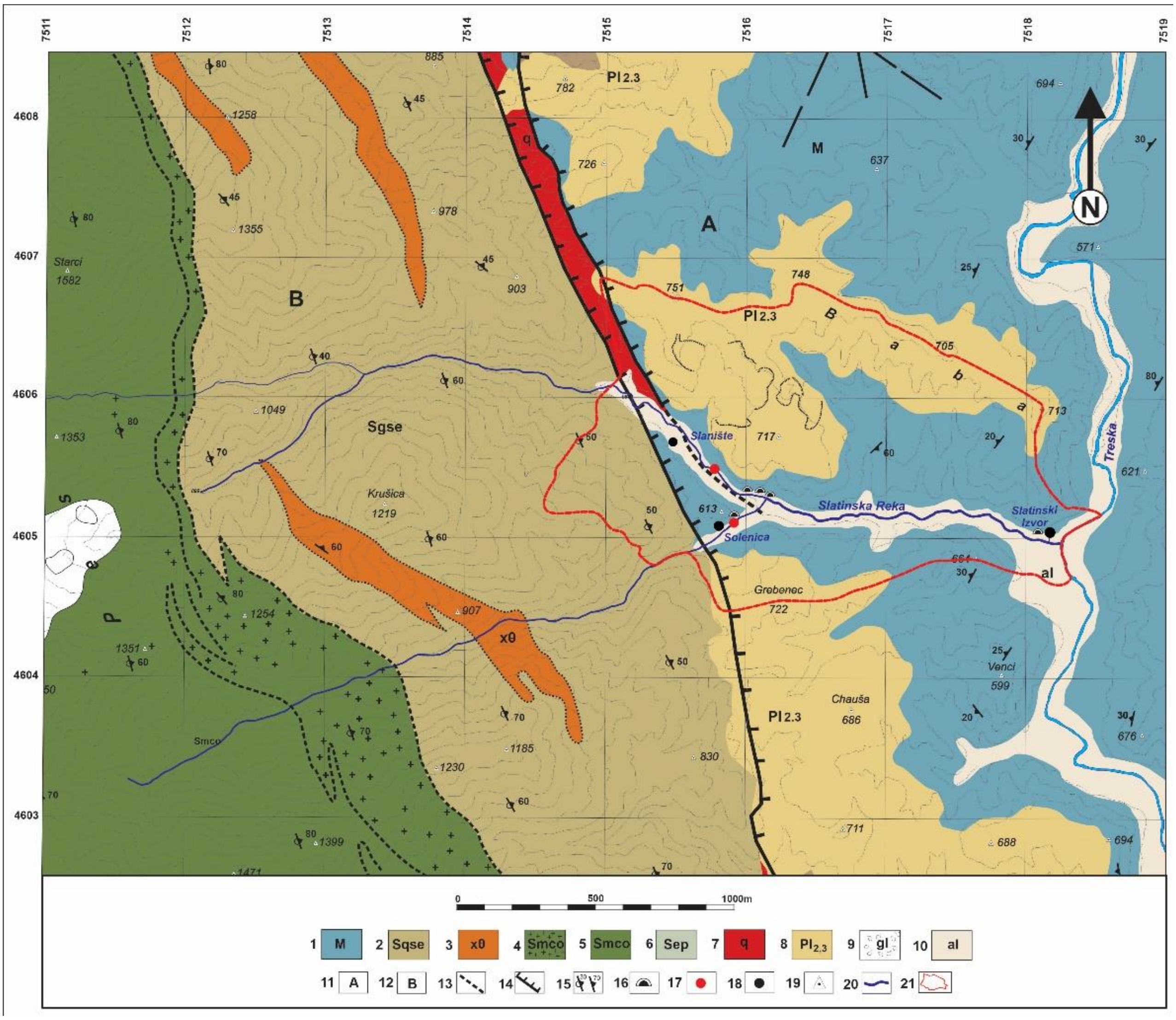

Fig. 2. Geological map of the study area (Dumurdžanov et al., 1978)

Legend: **Pre-Cambrian:** 1. M – Dolomite marbles; **Paleozoic:** 2. Sqse – Quartz-sericite schists and metasandstones, 3. xθ – Metarhyolite tuffs, 4. Smco – Feldspar-epidote-chlorite-amphibole, 5. Smco – Muscovite-chlorite-quartz schists, 6. Sep – Epidote-chlorite-amphibole schists; **Mesozoic:** 7. q – Aplitic granite; **Pliocene:** 8. $Pl_{2,3}$ – Pliocene sediments; **Quaternary:** 9. gl – Moraines, 10. al – Alluvium; 11. Pelagonian horst-anticlinorium, 12. Western Macedonian zone, 13. Fault without a mark on the character: covered, 14. Fault lowered block assumed, 15. Dip of foliation: normal and inverse, 16. Cave, 17. Ponor, 18. Spring, 19. Peak, 20. River, 21. Protected area Monument of nature Slatinski Izvor

The sources of the Krušeska Reka and Markoska Reka rivers are in a non-carbonate environment. At the contact with carbonate rocks the waters sink underground as a point input into the karst system, and continue to flow underground. The hydrological characteristics of Krušeska Reka, Markoska Reka, and Slatinska Reka are not regularly monitored. The highest discharges (between 900 and 1500 l/s) are in March and April because of the snow melt on the Pesjak mountain, as well as the rain events. Opposite, the lowest discharges are during the summer months, from August to September. At the contact between non-carbonate and carbonate rocks, there are the ponors in Slatinska Reka whose capacity is low (nearly 0.09 m^3/s), and downstream the river water losses constantly increase. The river bed downstream of the Slatinski Izvor spring has a small amount of water due to the feeding of the spring, while the upstream parts from the spring are dry (Gičevski and Hristovski, 2019).

Nowadays, the karst spring of Slatinski Izvor represents the main outflow of groundwater from this karst system (Gičevski & Hristovski, 2015; Gičevski et al., 2016). It is the largest and most important spring in the study area. Its discharge is between 0 and 100 l/s, and it is captured for water supply. On the tectonic contact between carbonate and non-carbonate rocks, the salt spring (brine) of Solenica is located. It never dries and its discharge is between 0.06 and 0.10 l/s (Gičevski et al., 2015). In the past, the Solenica spring was guarded by the local population and its water was used for kneading bread. Today, the spring has lost this function and flows freely into the Markoska Reka river.

The flattened areas in the lower part of the Slatinska Reka catchment area are arable farmland (Figure 3) where corn, beans, potatoes, and other crops are grown. The total arable land in village of Slatina occupies about 100 ha (Panov, 1998). The population of the village dropped from about 300 inhabitants in 1948 to only 30 in 2002 and 13 in 2021 (Makstat, 2025).

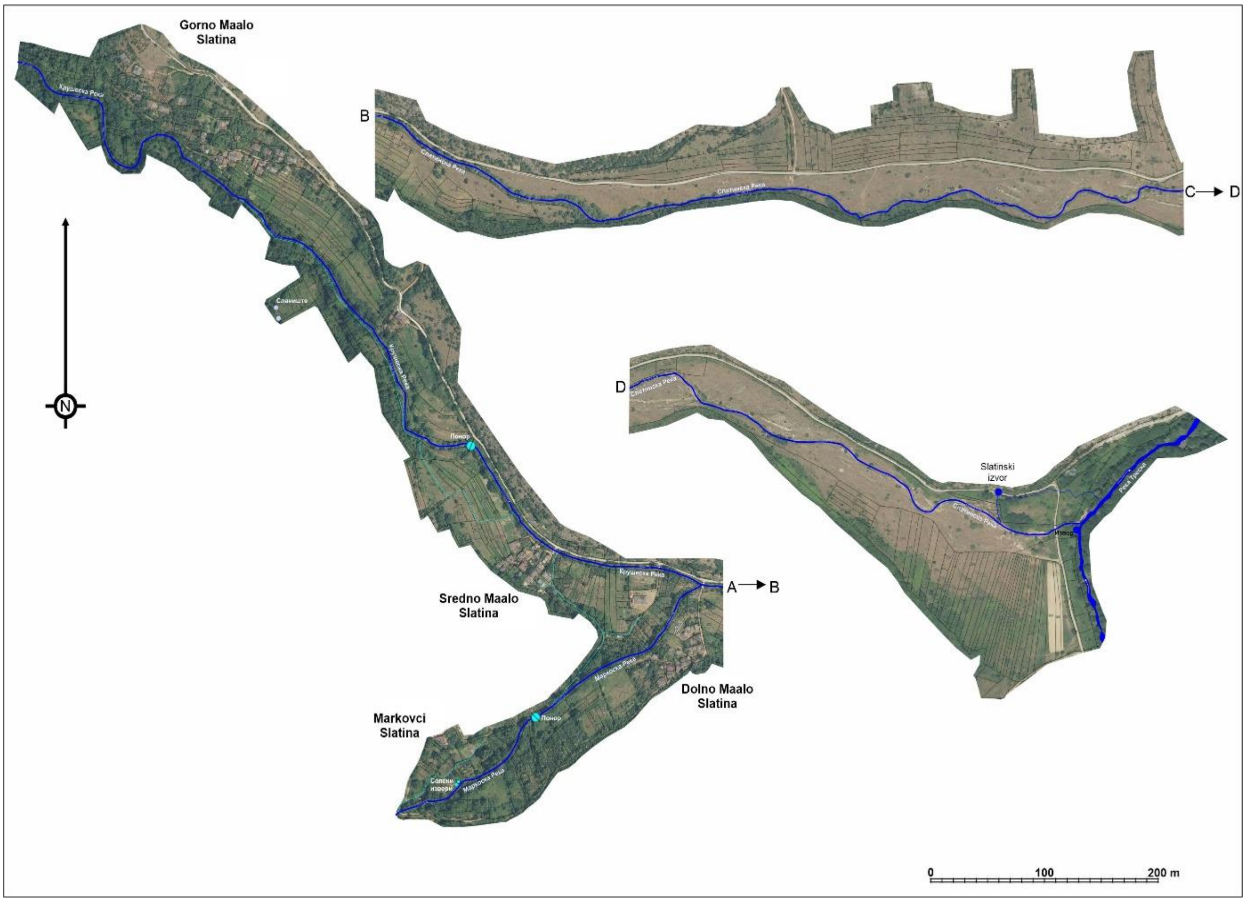

Fig. 3. Arable agricultural lands in the lower part of the river basin of Slatinska Reka

METHODS AND MATERIALS

The water samples were collected every month between December 2011 and November 2013. A total of 112 water samples were collected from all surface streams and springs in the study area. A total of 40 water samples were collected from the Markoska Reka river, which were taken at two sampling points: the first one at 150 m upstream from the spring of Solenica (MR1), and the second one at 100 m downstream from the same spring (MR2). A total of 19 water samples were collected from the Kruševska Reka river (KR) immediately before the active ponor, and 10 water samples from Slatinska Reka (SR) before the inflow into the river of Treska. From the Slatinski Izvor (SI) karst spring 21 water samples were collected, and 22 water samples were taken from the Solenica (SOL) salt spring (Figure 4).

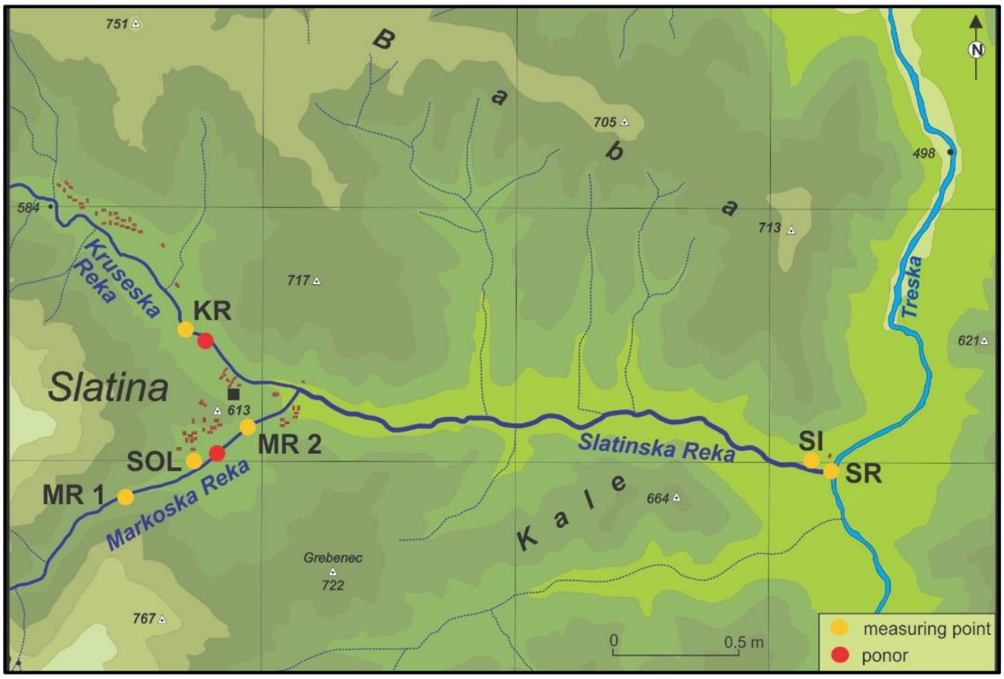

Fig. 4. Map of surface rivers and springs with measuring points marked

Specific electrical conductivity (EC) was measured at the time of sample collection using a handheld field instrument Lovi bond CHECKIT Micro. Samples were collected in polyethylene bottles. The hydrochemical properties were analyzed at the Institute of Biology, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University in Skopje.

The water quality parameters used to assess the suitability of water for irrigation include Sodium Absorption Ratio (SAR), Sodium Percentage (Na%), Magnesium Adsorption Ratio (MAR), Kelly Ratio (KR), and Total Hardness (TH).

Sodium absorption ratio (SAR) value is a widely used indicator for measuring the suitability of surface and groundwater for irrigation, as it indicates the alkali/sodium hazard of crops. The SAR value of irrigation water quantifies the proportion of sodium to calcium and magnesium. SAR was calculated by the following equation (Richards, 1954):

$$SAR = \frac{\mathrm{Na^+}}{\sqrt{(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}})/2}},$$

where concentrations are expressed in meq/l.

The sodium percentage (Na%) is used to determine the suitability of water for irrigation. A high Na^+ content in water can negatively affect the permeability of the soil (Wilcox, 1948) and restrict the flow of air and water. Na% is calculated according to Todd (1980) as:

$$\mathrm{Na\%} = \frac{(\mathrm{Na^+} + \mathrm{K^+})}{(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^+} + \mathrm{K^+})} \times 100$$

in which the concentrations are expressed in meq/l.

Magnesium adsorption ratio (MAR) is one of the essential parameters in evaluating water suitability for irrigation purposes. It is calculated by the equation of Raghunath (1987):

$$\mathrm{MAR} = \frac{\mathrm{Mg^{2+}}}{\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}} \times 100,$$

where all the ionic concentrations are expressed in meq/l.

Kelly ratio (KR) is among the most important parameters for determining the hazardous effect of sodium on water quality which indicates the balance among Na^+, Ca^{2+}, and Mg^{2+} ions in water. Kelly (1963) presents ration of sodium against calcium and magnesium:

$$\mathrm{KR} = \frac{\mathrm{Na^+}}{\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}},$$

where all the ionic concentrations are expressed in meq/l.

Total hardness, TH (as mg/l $CaCO_3$) of water samples was calculated by using the following equation (Raghunath, 1987; White, 2010):

$$\mathrm{TH\ (CaCO_3)} = 2.5\ (\mathrm{Ca^{2+}}) + 4.1\ (\mathrm{Mg^{2+}}).$$

RESULTS AND DISCUSSION

The results of the water quality analysis for the water bodies located in the karst area in the river basin of Slatinska Reka showed variations in the values for irrigation purposes. The values from the analyzed irrigation quality parameters are shown in Table 1.

Table 1.

Results of irrigation water quality parameters for the water bodies in the river basin of Slatinska Reka

Location name	Number of water samples	SAR range	Na% range	MAR range	KR range	TH range
River of Kruševska Reka (KR)	19	0.09–0.51	7.60–39.28	3.57–34.09	0.07–0.61	14.73–61.10
River of Markoska Reka 1 (MR1)	21	0.11–0.23	9.00–25.58	7.69–25.64	0.08–0.28	13.54–54.06
Spring of Solenica (SOL)	22	1.74–68.82	31.60–95.69	2.16–19.86	0.44–22.17	206.41–835.11
River of Markoska Reka 2 (MR2)	19	0.16–1.55	13.69–52.27	2.70–29.03	0.14–1.06	13.32–70.41
River of Slatinska Reka (SR)	10	0.09–0.19	6.84–18.60	15.90–40.74	0.06–0.16	17.58–102.44
Spring of Slatinski Izvor (SI)	21	0.15–0.55	10.48–25.77	22.52–68.16	0.10–0.33	71.68–133.97

Sodium absorption ratio (SAR) is an important parameter to measure the sodium hazard for water having high bicarbonate concentration. Water with high sodium absorption rates is not suitable for irrigation as it can damage the soil structure and cause permeability problems. If the SAR value < 10, the water is safe for irrigation (Wilcox,1955). All levels of SAR in the river basin of Slatinska Reka were within the allowed range for irrigational use (Table 1). Kruševska Reka, Markoska Reka, Slatinska Reka, and the Slatinski Izvor spring indicate excellent quality for irrigation purposes. The Solenica spring was not suitable for irrigation purposes, as only two water samples had values below 10, while the rest of the water samples had higher values.

To further interpret the results, the computed SAR values and the measured electrical conductivity values were plotted in the USSL (the United States Salinity Laboratory) diagram (Figure 5) (Richards, 1954). According to USSL diagram, the quality of irrigation water is categorized in 16 zones. The diagram indicates that all water samples from the rivers were within the C1-S1 class, indicating low salinity and low sodium hazard. The surface water was suitable for irrigation. The water samples from the Slatinski Izvor spring belong to the C1-S1 and the C2-S1 classes indicating low sodium hazard and low to medium salinity hazard, and the spring water is suitable for irrigation. Most of the water samples from the Solenica spring fall into the C4-S4 class, indicating very high salinity hazard and very high sodium hazard, and only one sample fall into the C4-S1 class indicating very high salinity hazard and low sodium hazard. The spring water is not suitable for irrigation.

Sodium percentage (Na%) is another parameter that relates to sodium hazard. Higher values of sodium percentage produce sodium hazards. There are no reference values mentioned by FAO-UN for which restrictions on using water may be decided. However, soils with high sodium concentrations do not support plant growth (Todd and Mays, 2005). Wilcox (1948) classified irrigation water to the concentration of sodium percent as excellent (SP < 20), good (SP 20 – 40), permissible (SP 40 – 60), doubtful (SP 60 – 80), and unsuitable (SP > 80). All water samples from the river of Slatinska Reka were classified into excellent water classes, water from the Kruševska Reka and Markoska Reka rivers (upstream from the Solenica spring) and from the Slatinski Izvor spring belonged into excellent and good water classes. Only two water samples from the Solenica spring belonged to the good water class, and the rest of water samples were in the unsuitable water class. At low water, the influence of the Solenica spring on the Kruševska Reka river was significant, which is why four water samples belonged to the permissible water class. At high water levels, the influence of the Solenica spring on surface flow is less pronounced. However, the values for this parameter downstream of the spring are always higher than upstream of the spring. Twenty water samples from the river belonged to the good water class, and only three water samples were in the excellent water class.

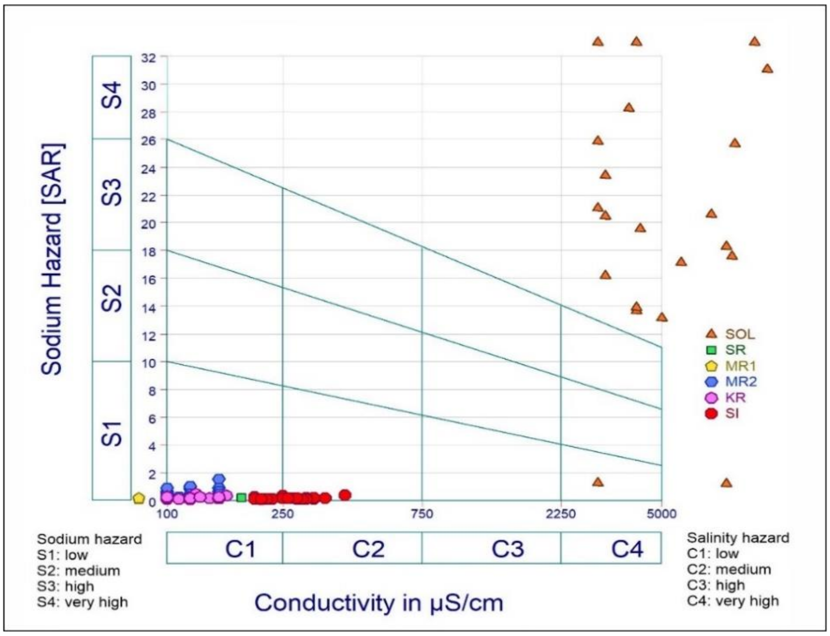

Fig. 5. USSL diagram for irrigation classes

Also, Wilcox (1948) used sodium percentage and electrical conductivity to categorize different types of irrigation water. By plotting water samples on the Wilcox diagram, they can be classified into different irrigation water quality classes: Class I (excellent to good), Class II (good to permissible), Class III (permissible to doubtful), Class IV (doubtful to unsuitable), and Class V (unsuitable). According to this classification, all water samples in the study area fell into the excellent to good category, except the Solenica spring whose water was unsuitable for irrigation (Figure 6).

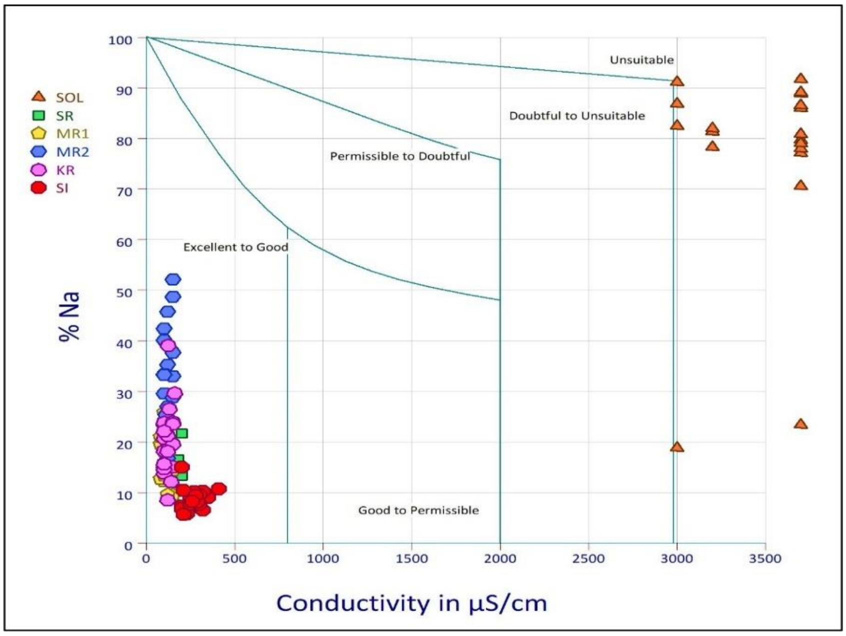

Fig. 6. Wilcox diagram for the classification of irrigation water based on electrical conductivity and percent sodium

The classification of water samples based on Magnesium Adsorption Ratio (MAR) or Magnesium Hazard is listed in Table 1. MAR indicates a harmful impact on the soil when it exceeds 50 (Raghunath, 1987). The values of this parameter of the water samples of the Krušeska Reka river, of the

Markoska Reka (MR 1) river, of the Solenica spring, of the Markoska Reka 2 (MR2) river, and of the Slatinska Reka river were in the ranges of 3.57–34.09, 7.69–25.64, 2.16–19.86 2.70–29.03, and 15.90–40.74, respectively. All water samples were within the allowable limit value of <50 meq/l and were suitable for irrigation. The water samples of the Slatinski Izvor spring were between 22.52 and 68.16. Seventeen water samples were suitable for irrigation, whereas four water samples had higher values. During low water levels, the water remains in the karst system for longer, which is why the spring water had a high Mg^{2+} content.

Soil conditions that show no permeability problems are characterized by Kelly ratio values <1. The classification of the water samples based on Kelly ratio is listed in Table 1. All water samples taken from the rivers and the Slatinski Izvor spring during the analyzed period, had values of less than one and are suitable for irrigation. Only one water sample from Markoska Reka, downstream of the Solenica spring, showed a value bigger than one in July 2012. Only two water samples from the Solenica spring had values of less than one, while the other water samples had values of more than one, indicating excess sodium and were not suitable for irrigation. This parameter shows that at low water levels, the Na^+ concentration in the Solenica spring downstream of Markoska Reka is significant and influences the irrigation properties of the river water.

Based on total hardness (TH) values, four types of water are classified: <50 mg/l $CaCO_3$ as soft; 50–150 mg/l $CaCO_3$ as moderately hard; 150–300 mg/l $CaCO_3$ as hard; and >300 mg/l $CaCO_3$ as very hard (Sawyer & McCarthy, 1967). Waters with hardness over 500 mg/l are not suitable for most domestic purposes. The total hardness values of the surface waters in the river basin of Slatinska Reka are presented in Table 1. Most of the water samples from Krušeska Reka, Markoska Reka (two measuring points), and Slatinska Reka belonged to the soft group of water, and part to the moderately hard group. Downstream the rivers, total hardness values raised which shows that the process of karstification influences the chemical composition of the water. All water samples from the Slatinski Izvor spring fall into moderately hard. All the above-mentioned water bodies had suitable values for irrigation. Most of the water samples from the Solenica spring belonged to very hard types. Only two water samples belonged to the hard type of water, whereas 11 water samples had values over 500 mg/l. According to this parameter, the Solenica spring is not suitable for irrigation and domestic purposes.

CONCLUSION

This study assessed the irrigation water quality in the river basin of Slatinska Reka, focusing on various well-established irrigation water quality parameters, including Sodium Absorption Ratio (SAR), Sodium Percentage (Na%), Magnesium Adsorption Ratio (MAR), Kelly Ratio (KR), and Total Hardness (TH). The study was applied in the lower part of the river basin which represents a well-developed karst area. The research pointed out that the majority of water samples from Krušeska Reka, Markoska Reka, Slatinska Reka, and the Slatinski Izvor spring, are suitable for irrigation, with values falling within acceptable limits across all parameters. These water bodies consistently exhibit excellent to good water quality, making them appropriate for agricultural use.

The Solenica spring showed consistently high SAR and Na% values, classifying its water unsuitable for irrigation. During low flow conditions, the Solenica spring had an evident impact on the water quality of Markoska Reka downstream of the spring. Precisely, the water of Markoska Reka downstream of the spring was significantly affected, showing higher values of SAR and Na% compared to samples taken upstream of the spring. This suggested that the Solenica spring significantly influenced the river water chemistry.

The study highlighted the role of karstification processes in altering water chemistry, with total hardness increasing downstream in the river basin. TH analysis demonstrated that most water samples from analyzed rivers fell within the soft to moderately hard categories, with the Slatinski Izvor spring categorized as moderately hard. In contrast, water from the Solenica spring was classified as very hard, which indicated poor suitability for both irrigation and domestic use.

In conclusion, the water bodies in the river basin of Slatinska Reka provided water of generally acceptable quality for irrigation. Only the Solenica spring had poor-quality water that was unsuitable for irrigation. The results underscore the need for targeted water quality management strategies, particularly in mitigating the effects of the Solenica spring, to maintain sustainable irrigation practices in the basin.

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Р е з и м е

КОМПАРАТИВНА ПРОЦЕНА НА КВАЛИТЕТОТ НА ВОДАТА ЗА НАВОДНУВАЊЕ ВО КАРСНИОТ ПРЕДЕЛ ОД РЕЧНИОТ СЛИВ НА СЛАТИНСКА РЕКА

Билјана Гичевски[1*], Славчо Христовски[2], Војо Мирчовски[3], Ѓорѓи Димов[3]

[1]*Истражувачко друштво „Урсус спелеос“, Добромир Хрс 20а, 1000 Скопје, Република С. Македонија*
[2]*Институт за биологија, Природно-математички факултет, Универзитет „Св. Кирил и Методиј“, Архимедова 3, 1000 Скопје, Република С. Македонија*
[3]*Факултет за природни и технички науки, Универзитет „Гоце Делчев“, Гоце Делчев 89, 2000 Штип, Република С. Македонија*
biljana_speleo@yahoo.com

Клучни зборови: иригација; речен слив на Слатинска Река; карстен предел

Оваа студија го проценува квалитетот на водата за наводнување во карсниот предел од сливот на Слатинска Река, лева притока на Треска. Фокусот е ставен на често применуваните параметри за определување на квалитетот на водите за иригација, и тоа: сооднос на апсорпција на натриум (SAR), процент на натриум (Na%), сооднос на атсорпција на магнезиум (MAR), Келиев сооднос (KR) и вкупна тврдост (TH).

Истражувањето покажа дека најголемиот дел од примероците на вода од Крушеска Река, Маркоска Река, Слатинска Река и од Слатински Извор се погодни за наводнување, со вредности кои се во прифатливи граници според сите параметри. Овие водни тела постојано покажуваат одличен до добар квалитет на водата, што ги прави соодветни за земјоделска употреба.

Изворот Соленица покажа постојано високи вредности за SAR и Na%, класифицирајќи го како несоодветен за наводнување. Во услови на слаб проток, изворската вода има евидентно влијание врз квалитетот на водата на Маркоска Река, низводно од изворот. Така, водата од Маркоска Река, низводно од изворот, е значително понепогодна за наводнување, покажувајќи повисоки вредности за SAR и Na%, во споредба со примероците земени спротиводно од изворот. Ова сугерира дека изворот Соленица значително влијае на хемискиот состав на речната вода.

Студијата ја истакна улогата на процесот на карстификација врз хемијата на водите, при што вкупната тврдост се зголемува низводно во сливот на реката. Анализата на тврдоста покажа дека повеќето примероци од речните води припаѓаат во категориите меки до умерено тврди, а изворот Слатински Извор е категоризиран како умерено тврд. Спротивно, водата од изворот Соленица е класифицирана како многу тврда, што посочува дека е непогодна за наводнување и домашна употреба.

Како заклучок, водните тела во речниот слив на Слатинска Река имаат општоприфатлив квалитет за наводнување, со исклучок на изворот Соленица кој е несоодветен за наводнување. Резултатите ја нагласуваат потребата од насочена стратегија за управување со квалитетот на водата, особено за ублажување на ефектите од изворот Соленица, заради потребата од наводнување во сливот.