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Groundwater and surface water interaction in the City of Slavonski Brod, Croatia

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Abstract

Alluvial aquifers, mostly related to the Sava and Drava rivers, are protected by the Republic of Croatia which has designated them as strategic water reserves. In the Pannonian part of Croatia, they present main source of potable water for their inhabitants. Their relationship can be very dynamic, which is especially pronounced in the shallow unconfined aquifers. This research has been focused to the examination of groundwater and surface water interaction in the area of the City of Slavonski Brod using hydrological and hydrogeological analyses, cross-correlation analysis, and stable isotopes of water (δ^2H and $\delta^{18}O$). Results showed that aquifer response is faster in high water levels with respect to low water levels, while isotopic composition of all observed water showed that Sava River presents main source of recharge for the investigated aquifer. Additionally, it has been shown that within the long duration of low water levels Sava River influence is not that dominant. Furthermore, results also showed that more hydrological and hydrogeological investigations are necessary in the wider study area, in order to get more detailed and precise results. This is also important due to existence of transboundary water resources in the great part of the Sava River basin and if sustainable management of water resources wants to be achieved.

Keywords: Sava River; groundwater; cross-correlation analysis; stable isotopes of water; City of Slavonski Brod

1. Introduction

Alluvial aquifers in the Republic of Croatia are designated as strategic water reserves and are protected by Crotian state. They present main source of potable water in the Pannonian part of the Republic of Croatia. Their relationship can be very dynamic which is especially pronounced in the shallow unconfined aquifers. Most of the scientific research has been focused to the Zagreb (**Posavec et al., 2017; Parlov et al., 2019; Kovač et al., 2022a**) and Varaždin (**Marković et al., 2022**; **Karlović et al., 2022**) aquifers, while in the eastern Pannonian part of Croatia, in the Sava basin area, hydrogeological and hydrogeochemical research was mainly focused to Sikirevci well field (**Briški et al., 2013; Kopić et al., 2016; Filipović et al., 2022**). Regarding the research in the area of the City of Slavonski Brod, hydrogeological research has been done in recent time which suggested fast change of groundwater levels after the rise of Sava River water levels (**Perić, 2023**). The goal of this research is to evaluate groundwater and surface water interaction in the area of the City of Slavonski Brod using hydrological, hydrogeological, statistical analyses, mainly cross-correlation analysis, and stable isotopes of water (δ^2H and $\delta^{18}O$). Cross-correlation analysis presents the method which is used for the definition of similarity of two series, i.e. it defines the degree to which two series are correlated with respect to lag of one relative to the other (**Davis, 2002**). It has been shown in many cases that cross-correlation analysis can be used in different hydrogeology and meteorology research (**Crosbie et al. 2005, Ford & Williams, 2007; Lee et al. 2013, Welch et al. 2013, Kovač et al., 2023**). On the other hand, stable isotopes of water are often used in the examination of groundwater and surface water interaction (**Parlov et al., 2019; Petersen et al., 2023**), but can also be used in different hydrology research, for example soil hydrology (**Kovač et al., 2022b; Kovač et al., 2023**). Although hydrogeological research in this area is not often performed, it must be emphasized that in this area well field Jelas exists, which pumps groundwater for the public water supply of the City of Slavonski Brod and surrounding settlements. This research was done within the regional IAEA (International Atomic Energy Agency) project RER 7013 (*„Evaluating Groundwater Resources and Groundwater-Surface-Water Interactions in the Context of Adapting to Climate Change“*).

2. Data and methods

Sava River water levels were assigned by Croatian Meteorological and Hydrological Service as daily data (hydrological station Slavonski Brod), while groundwater levels were measured at observation well P-9 which is located approximately 1000 m north of the Sava River (**Figure 1**). Groundwater levels were measured using logger which was set to measure in hourly interval. To get daily data, which were compared to the Sava River water levels, hourly data was averaged. For the calculation purposes, data from hydrological year 2021/2022 (1/10/2021 – 30/9/2022) were used. Groundwater and surface water interaction was evaluated using cross-correlation analyses in different time periods. Firstly, all data from whole hydrological year were used, while other statistical analyses were focused to the evaluation of the relationship between groundwater and surface water in periods with high and low water levels. For the high water level (hwl) periods 15 days before and after the peak were considered, while for the testing of the mentioned relationship in the low water level (lwl) periods 30 days before the low Sava River water level were taken into account. In some cases, less data was used (hwl 1 and hwl 6) because peaks were observed at the beginning and the end of the investigated period. In total, 11 cross-correlation analyses were done, one for all data, six for high water levels (hwl 1 to hwl 6) and four for low water levels (lwl 1 to lwl 4), based on the water level variation (**Figure 2**). Cross-correlation analyses was done using Visual Basic for Applications (VBA) code (**Posavec et al., 2017**), where the strength of the relationship between time series is determined by the correlation coefficient.

Stable isotopes of water (δ^2H and $\delta^{18}O$) were determined for surface water, groundwater and precipitation using a Liquid Water Isotope Analyzer (LWIA-45-EP, Los Gatos Research) at the Laboratory for Spectroscopy of the Faculty of Mining, Geology, and Petroleum Engineering, University of Zagreb. Before measurement, samples were stored in fridge and filtrated with 0.2 µm nylon filters. Data was prepared and interpreted using the Laboratory Information Management System (LIMS for lasers 2015; **Coplen & Wassenaar, 2015**), while the measurement precision of duplicate samples using nine injections was ±0.19 ‰ for $\delta^{18}O$ and ±0.9 ‰ for δ^2H. All results are presented with respect to VSMOW (Vienna Standard Mean Ocean Water). For the interpretation purposes Local Meteoric Water Line (LMWL) for the City of Slavonski Brod was constructed, and compared to LMWL Zagreb, which is made based on the long-term data series (**Krajcar-Bronic et al., 2020**). All water was sampled in a monthly interval. Groundwater was sampled from the observation well P-9, while precipitation was sampled with Palmex RS-1 precipitation sampler. Previous research showed that RS-1 can protect water sample from evaporation and can be used in most hydrology studies (**Grönnigen et al., 2012; Michelsen et al., 2018**).

For the quantitative evaluation, i.e., quantification of recharge sources, two or three-end mass balance equations can be used (**Peng et al., 2010; Vrzel et al., 2018; Parlov et al., 2019**). In these equations sum of the end member contributions are expressed as fractions (f) equal to 1. In this research two-component mixing model was used which assumes that aquifer recharge comes from two main sources, Sava River and precipitation. For the quantification of recharge, average values from the hydrological year 2021/2022 were used, for both δ^2H and $\delta^{18}O$, based on the following **Equations 1** and **2**:

$$f_{river} + f_{precipitation} = 1 \quad (1)$$

$$f_{river} \times \delta^{18}O_{river} + f_{precipitation} \times \delta^{18}O_{precipitation} = \delta^{18}O_{groundwater} \quad (2)$$

where are:

f_{river} and $f_{precipitation}$ - present Sava River and precipitation fractions respectively,
$\delta^{18}O_{groundwater}$ - presents isotopic composition of oxygen in the observation well P-9, while
$\delta^{18}O_{river}$ and $\delta^{18}O_{precipitation}$ - present isotopic compositions of oxygen in Sava River and precipitation respectively.

Calculations and figures creations were done using Microsoft© Office tools, except for **Figure 1** which was produced using ArcMap 10.8.1 with the georeferenced orthophoto image which was obtained from the geoportal of the Croatian Geodetic Administration. Map is presented using the official coordinate system of the Republic of Croatia (HTRS96/TM).

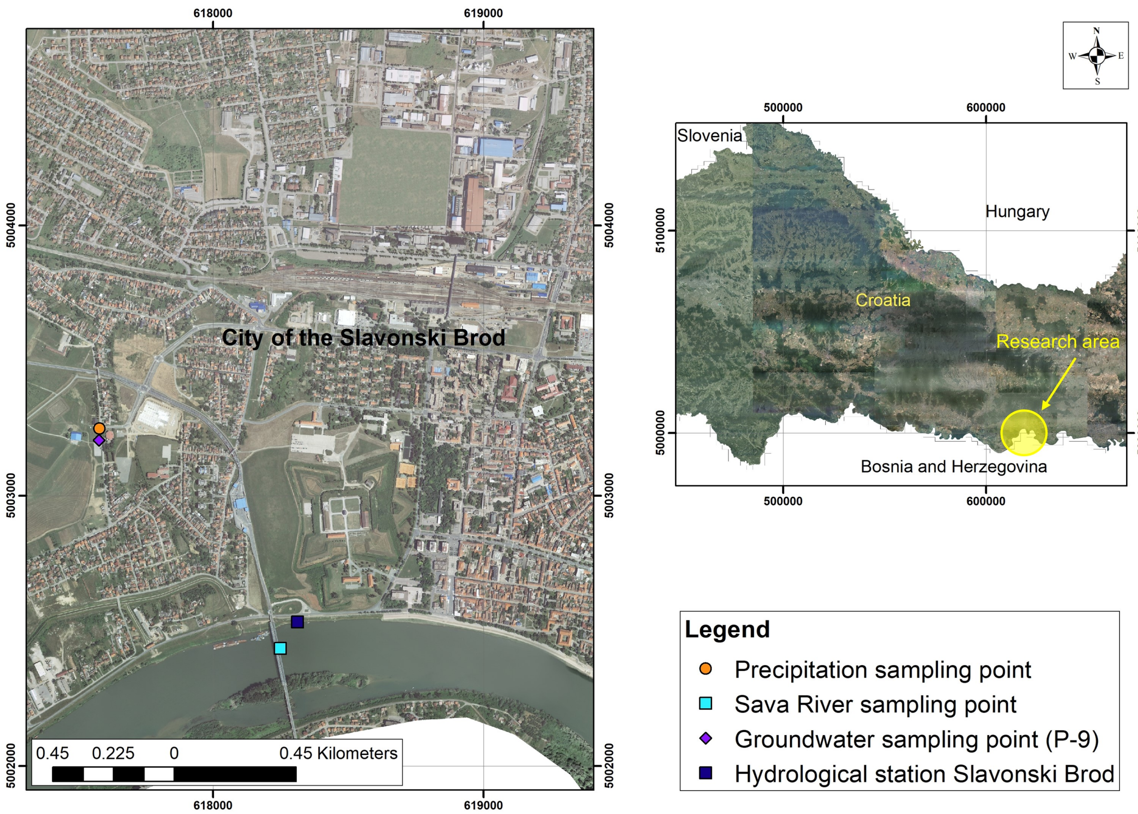

Figure 1: Location of the research area and sampling points

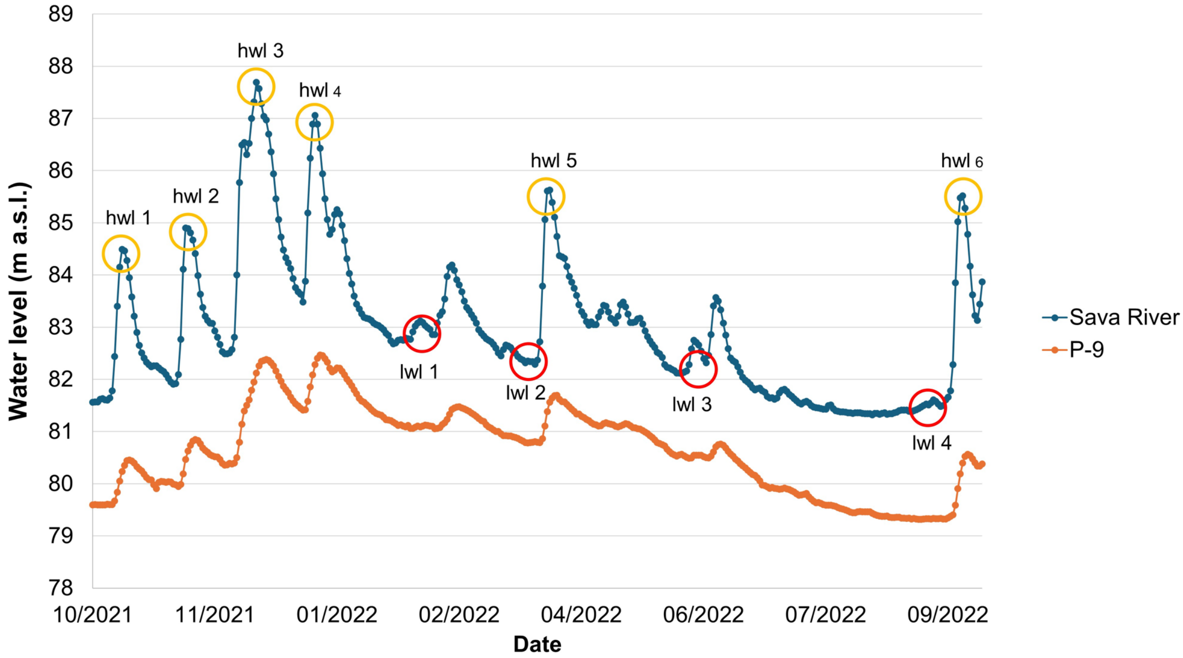

Figure 2: Variation of the Sava River and groundwater levels at observation well P-9 in hydrologic year 2021/2022

3. Results and discussion

In **Table 1** results of all cross-correlation analyses can be seen, while in **Figure 3** example of cross-correlation analysis for hwl 2 is presented. In general, all results show very high correlation coefficients, above 0.8. If all data is examined together, results suggest very fast reaction of the aquifer, where groundwater levels change with the delay of the 3 days, which corresponds to the results of the previous research (**Perić, 2023**). It can be clearly seen that in the high water levels transfer of pressure is much faster (2-3 days) than in the low water levels (2 to 8 days). Additionally, when very long duration of low water levels is present (lwl 4, **Table 1**), results showed negative correlation, which indicates that groundwater flow direction can be also to the Sava River. However, groundwater flow directions can be defined only if data from multiple observation wells exists that can enable construction of the equipotential maps in different hydrological conditions, which could not be used in this research due to lack of these type of data. In **Figure 4** LMWL Slavonski Brod for the hydrological year 2021/2022 is present as well as average values for all observed types of water. Slope of the LMWL Slavonski Brod (6.25) is lower than LMWL Zagreb (7.74) and corresponds to the warm (year 2021) and extremely warm (year 2022) period based on the average yearly air temperature as stated on the website of the Croatian Meteorological and Hydrological Service (**URL 1**).

Table 1: Summary results of cross-correlation analyses

Name	Date of the peak	Lag (day)	r_{lag} max.
All period	-	3	0.850
hwl 1	13/10/2021	3	0.942
hwl 2	8/11/2021	2	0.939
hwl 3	7/12/2021	3	0.947
hwl 4	31/12/2021	2	0.910
hwl 5	6/4/2022	2	0.972
hwl 6	22/9/2022	2	0.945
lwl 1	18/2/2022	8	0.920
lwl 2	31/3/2022	2	0.981
lwl 3	9/6/2022	7	0.924
lwl 4	13/9/2022	-8	-0.820

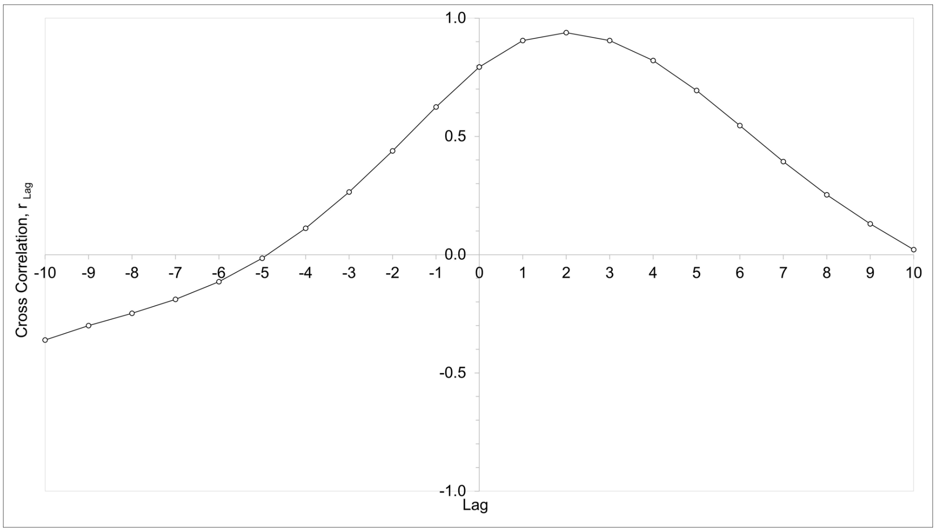

Figure 3: Cross-correlogram for hwl 2

Furthermore, results suggest that isotopic composition of groundwater is more similar to Sava River with respect to the precipitation. Average value of δ^2H in groundwater, Sava River and precipitation is -58.83 ‰, -61.11 ‰ and -48.06 ‰ respectively. Average value of $\delta^{18}O$ in groundwater, Sava River and precipitation is -8.32 ‰, -9.22 ‰ and -6.77 ‰ respectively. This corresponds to the results of two-component mixing models (**Table 2**) which suggest that Sava River presents the main source of recharge for the investigated aquifer, with percentage of recharge which varies from 63 % to 90 % for $\delta^{18}O$ and δ^2H respectively. This corresponds to the results of the cross-correlation analyses which in general showed very fast change in groundwater levels after the rise of Sava River water levels. This is not that pronounced in the low water levels, especially when low water levels last for a longer period. Here it must be noted that this research has been done only in one hydrological year, in which extremely warm meteorological conditions prevailed. More observation wells and more detailed hydrogeological research should be adopted in the study area, as well as continued monitoring, in order to get more detailed insight into the groundwater and surface water interaction. Additionally, as recognized in the previous research, vertical stratification is possible in the wider study area (**Kopić et al., 2016; Nakić et al., 2016; Filipović et al., 2022**), which provides necessity for the evaluation of water from the deeper parts of the aquifer and identification of aquifer layers of different origin. Furthermore, future research should include identification of depth till which infiltration from the Sava River is dominant, as well as cooperation with neighbouring Federation of Bosnia and Herzegovina due to existence of transboundary water resources.

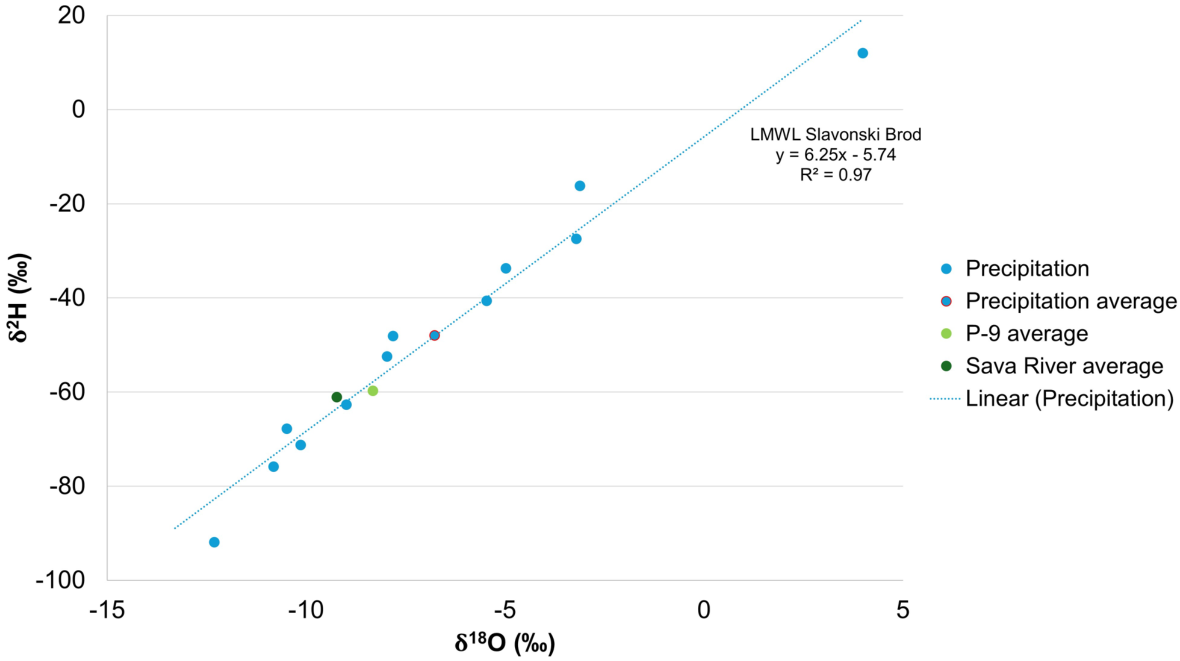

Figure 4: Isotopic composition of precipitation, Sava River, groundwater from the observation well P-9 and LMWL Slavonski Brod

Table 2: Results of two-component mixing models

Location	δ^2H (‰)	$\delta^{18}O$ (‰)
Observation well P-9	-59.83	-8.32
Sava River	-61.11	-9.22
Precipitation	-48.06	-6.77
	Recharge (%)	
Sava River (%)	90	63
Precipitation (%)	10	37

4. Conclusions

Evaluation of relationship between alluvial aquifers and surface waters present very important theme in Croatia, as well as in other countries. In the Pannonian part of Croatia alluvial aquifers, mostly related to the Sava and Drava rivers, present strategic water reserves. Research about this subject is neglected in some parts of Croatia except in the areas of big cities, mostly City of Zagreb and City of Varaždin. This research is located in the area of the City of Slavonski brod where Sava River water levels and groundwater levels, as well as their isotopic composition, were compared in order to define their relationship. Results showed different aquifer response in high water levels with respect to low water levels. As expected, response was faster in high water levels, resulting in lag times of 2 to 3 days. Isotopic composition of all observed water showed that Sava River presents main source of the recharge for the investigated aquifer, while long duration of low water levels suggest that Sava River is not that dominant in all hydrologic conditions. Although preliminary, these results provide new insight into the groundwater and surface water interaction in the study area which also showed that more detailed hydrogeological inspection of selected relationship, as well as inspection of the existing aquifer and its vertical stratification, is necessary. This is also extremely important due to transboundary water resources and in order to provide basis for sustainable management of water resources in the whole Sava River basin. In the future research continuation of monitoring is necessary to get data from more years and from different hydrological and meteorological conditions. Additionally, all available data from whole Sava River basin should be compared to identify areas of main sources of recharge of alluvial aquifers, especially those which are used for the public water supply.

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SAŽETAK

Odnos podzemne i površinske vode na području grada Slavonskog Broda, Hrvatska

Aluvijalni vodonosnici, većinom vezani uz rijeke Savu i Dravu, zaštićeni su od strane Republike Hrvatske koja ih je proglasila strateškim vodnim rezervama. U panonskom dijelu Hrvatske one predstavljaju glavni izvor pitke vode za svoje stanovnike. Njihov odnos može biti vrlo dinamičan, što je posebno izraženo u plitkim otvorenim vodonosnicima. Ovo istraživanje je usmjereno na istraživanje odnosa podzemne i površinske vode na području grada Slavonskog Broda korištenjem hidroloških i hidrogeoloških analiza, kros-korelacijske analize te stabilnih izotopa vode (δ^2H i δ^{18}O). Rezultati su pokazali da je reakcija vodonosnika brža pri visokim vodostajima u odnosu na niske vodostaje, dok je izotopni sastav svih promatranih voda pokazao da rijeka Sava predstavlja glavni izvor napajanje promatranog vodonosnika. Dodatno, pokazalo se da kod dugog trajanja niskih vodostaja utjecaj rijeke Save nije toliko dominantan. Nadalje, rezultati su također pokazali da je potrebno više hidroloških i hidrogeoloških istraživanja na širem području istraživanja, kako bi se dobili što detaljniji i precizniji rezultati. Ovo je također važno zbog postojanja prekograničnih vodnih resursa u velikom dijelu sliva rijeke Save te ako se želi postići održivo upravljanje vodnim resursima.

Ključne riječi: rijeka Sava; podzemna voda; kros-korelacijska analiza; stabilni izotopi vode; grad Slavonski Brod

Author`s contribution

Zoran Kovač (1) (associate professor) participated in data processing and laboratory analyses, results interpretation and wrote most of the manuscript. **Borna-Ivan Balaž (2)** (univ. spec. oecoing., mag. ing. geol.) participated in field sampling, laboratory analyses and editing of the manuscript. **Ferid Skopljak (3)** (full professor) participated in data interpretation and editing of the manuscript. **Lucijan Perić (4)** (univ. bacc. ing. geol.) participated in data processing and editing of the manuscript.