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Use of hydrochemistry and isotopes for improving the knowledge of groundwater flow in a semiconfined aquifer system of the Eastern Slavonia (Croatia)

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A B S T R A C T

Knowledge of groundwater flow, and accordingly, groundwater residence time is immensely important for the sustainable management of groundwater resources. This requires a good conceptual model of the aquifer system. In this paper, a conceptual model based on the interpretations of hydrogeological and hydrochemical data, as well as measurements of environmental tracers (^{18}O, ^{2}H, ^{3}H) was formulated for a semiconfined aquifer system in Eastern Slavonia in Croatia. The aquifer system is composed of Quaternary gravel and sand and silty–clayey interlayers and is covered with low permeability deposits. Measurements of water levels and environmental tracers in the study area clarified the groundwater flow evolution from the recharge area to the discharge area. The content of stable isotopes confirmed that the groundwater originates from precipitation. The tritium content and geochemical processes (such as cation exchange, silicate weathering) suggested a relatively long residence time of groundwater in the part of the aquifer system that is further from the Sava River. The same is confirmed by the results of calculated particle tracking pathlines.

1. Introduction

For the sustainable management of groundwater resources, the knowledge of groundwater dynamic is very important. The concept of a “flow-system” was introduced by Tóth (1962, 1963). According to him, three types of flow systems may occur in a small basin: local, intermediate and regional. Their division is based on understanding a number of elements in an aquifer system such as hydrology, topography, geology and permeability. Based on these elements, a conceptual model of a groundwater system can be formed. A good conceptual model primarily depends on the quality of hydrogeological system qualification (Anderson and Woessner, 1992). Bredehoeft (2005) argues that in many instances construction and calibration of groundwater models lead to a reformulation of the first conceptualization. This iterative process can lead to the “best possible representation of the system” (Bredehoeft, 2003). Consequently, any investigation of a groundwater system that will contribute to the construction of a better conceptual model is valuable.

An investigation of the hydrochemical and isotope characteristics of water (Ben Moussa et al., 2014; Bestland and Stainer, 2013; Folch et al., 2011; Houcine et al., 2014; Huang and Pang, 2010; Koh et al., 2012; Kraiem et al., 2014; Liu et al., 2014; Lorite-Herrera et al., 2008; Marković et al., 2013; Röper et al., 2012) contributes to the understanding of groundwater flow systems. Different groundwater residence times cause the formation of groundwater whose chemical composition and age vary over the vertical and lateral extent of the aquifer. As groundwater flows through sediments of different mineralogical compositions and hydraulic properties, groundwater velocity, travel times and chemical composition vary accordingly. At the same time, the chemical composition of the water is changed. This may lead to the conclusion that these are “different” waters and that there is no hydraulic continuity within an aquifer system. However, the results of numerous studies have shown that this is not so (Atkinson et al., 2014; Boronina et al., 2005; Cartwright et al., 2010; Han et al., 2009).

In this paper, a conceptual model for a semiconfined aquifer system in Eastern Slavonia in Croatia was constructed on the basis of the measurement and interpretation of hydrogeological and hydrochemical data, as well as measurement of environmental tracers (^{18}O, ^{2}H, ^{3}H). Studies of the general hydrogeological characteristics of the wider area have been conducted by Mayer et al. (1981), Miletić and Urumović (1975), Miletić et al. (1986) and Urumović et al. (1978). The first conceptual model of the wider range of the study area was given by Miletić et al. (1993). Radiocarbon and tritium measurements have been conducted in Đakovo and Vinkovci, north from the study area (Grgić et al., 1991). The authors concluded that there is no significant hydraulic communication between recent meteoric water and groundwater in deep aquifer layers.

Because the research was conducted sporadically over several decades, the results of 30 years of research were presented by Pekaš and

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Brkić (2007). In those years, the works related to the development of the Sikirevci regional pumping site were already in progress, and further studies were continued. Meanwhile, the exploitation of groundwater started. In the future, this pumping site will be the main water supply for the eastern part of Croatia. Therefore, there is a real need to increase knowledge about the aquifer system. The purpose of the investigation of the hydrochemical characteristics and composition of the environmental tracers (^{18}O, ^{2}H and ^{3}H) in water is to improve the knowledge of the groundwater flow evolution in the semiconfined aquifer system, not only at the Sikirevci pumping site in Eastern Croatia but also at the other parts of the Pannonian basin.

2. Site description

The study area is situated in the Sava River valley in eastern Croatia (Fig. 1). It is a markedly lowland area, with altitudes of approximately 85–86 meters above sea level (m a.s.l.) with local depressions of approximately 83 m a.s.l. The Sava River flows into the southern part of this area. Along the Sava River lies the state border with Bosnia and Herzegovina.

The climate in this part of Croatia is moderate continental with mean annual temperatures from 11 to 12 °C. The mean annual rainfall in the period from 1960 to 1991 was 740 mm with a downward trend (Brkić et al., 2010). In the period from 2007 to 2013, the mean total annual rainfall was approximately 700 mm. There are two rainfall maximums during the year: the primary one occurs at the transition from autumn to winter, and the secondary one is at the end of spring and the beginning of summer.

The aquifer is of Quaternary age. It belongs to the alluvial fan of the Bosna River, which flows from the south (from Bosnia and Herzegovina), and on Croatian territory, it spreads between the Sava River to the south and the Vrpolje–Cerna line to the north. Looking from the Sava River toward the north, the alluvial fan becomes thinner and the content of fine sediments increases, which is in accordance with the theory of sedimentation of alluvial fans (Reading, 2009). By reducing the grain size and increasing the amount of fine-grained sediments, the hydraulic conductivity values of these deposits are also reduced.

Mineralogical and petrographic analyses of the boreholes located near the Gundinci village were conducted by Mutić (1993). The depth of the boreholes was 70 m. These analyses have shown that Holocene deposits reach from the surface to approximately 18 m of depth, and middle and upper Pleistocene deposits are found from 18 m to 70 m. Pleistocene deposits reflect the changes in climate during their deposition. The coarser gravelly sand layers were deposited during warm and humid interglacial periods with high water energy, while fine grained sands, silts and clays were deposited during cold glacial periods with low water energy. The mineralogical composition of sediments shows that these materials were mainly brought from the south from mountains in Bosnia and Hercegovina. Holocene deposits from 18 m to 10 m depth mainly consist of silt and sand with small amounts of gravel due to the stabilisation of climate. The youngest and uppermost deposits are fine grained and were brought by flooding of rivers and erosion of the loess plateau to the north. Due to the above mentioned variations in conditions during the deposition of sediments, the lithological structure of these deposits is very variable in both the horizontal and vertical directions.

The captured aquifer system on the Sikirevci pumping site is made of gravelly sands and sandy to sandy–clayey gravels, with silt and clay interlayers and lenses (Fig. 2). It is captured at intervals from 25 to 80 m of depth. The total thickness of the captured layers of the aquifer varies from 40 to 60 m. The average hydraulic conductivity of the aquifer is approximately 1.7×10^{-3} m/s in the area of the pumping site, and it is reduced to less than 10^{-3} m/s in the northern edge of the alluvial fan. The

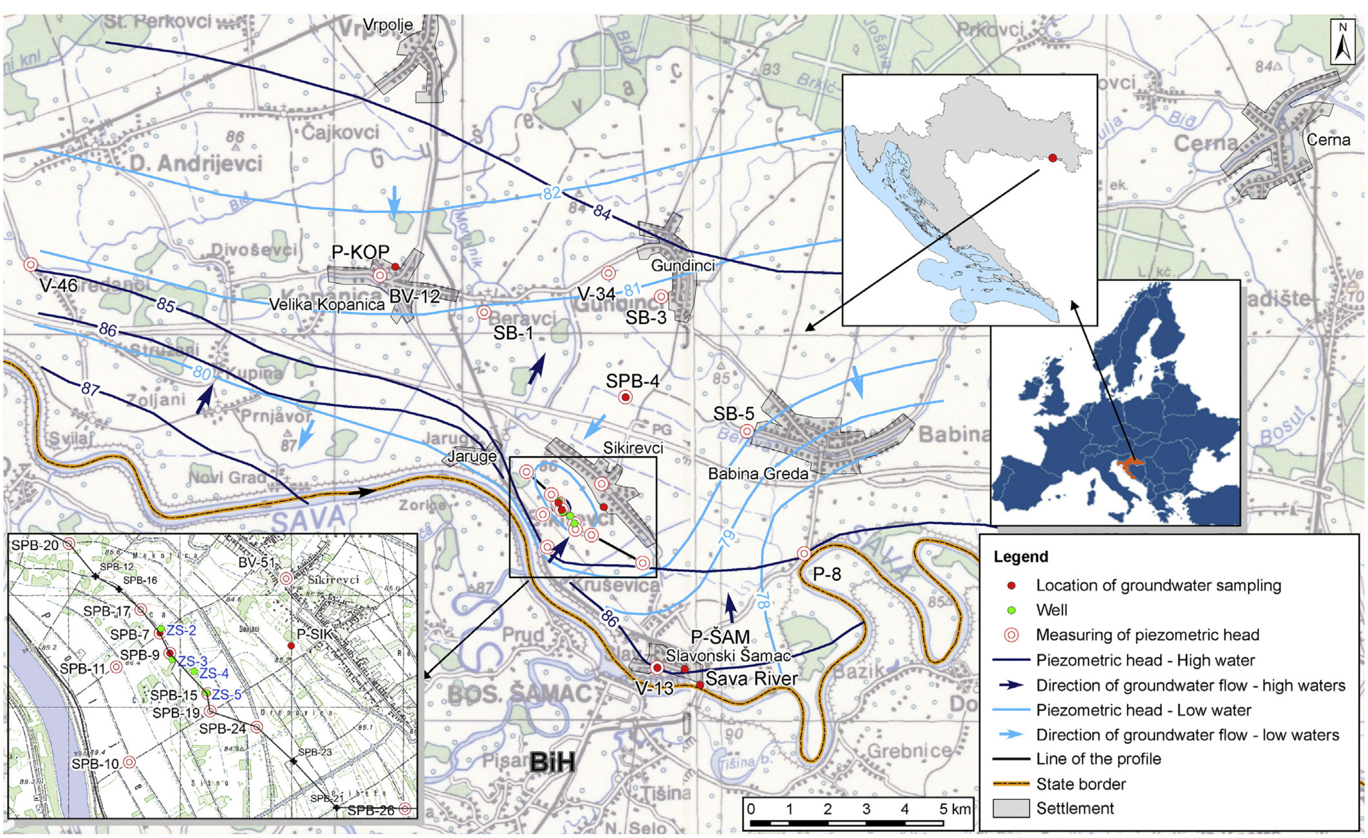

Fig. 1. Location map of the study area.