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GROUNDWATER RESOURCES FOR DRINKING WATER SUPPLY IN SERBIA´S SOUTHEAST PANNONIAN BASIN

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Abstract: Long-term monitoring of groundwater regimes has been conducted to study the impact of prolonged groundwater abstraction from an aquifer in northern Serbia (Bačka District). This aquifer within the Pannonian Basin represents the principal source of drinking water supply. In general, the quality of the groundwater used as the drinking water supply in this region is not satisfactory. The quality of raw water is analysed. Groundwater temperature is in range of 14 and 24 °C, while turbidity is between 0.3 and 9.3 NTU. The chemical parameters that have elevated concentrations include the ammonium ion (0.05 – 0.4 mg/L), iron (0.05 – 3 mg/L), arsenic (10 – 210 µg/L) and $KMnO_4$ demand (4 – 195 mg/L). The dissolved solid content of waters in some locations exceeds 1000 mg/L. A hydrodynamic model was used to study the effects of current groundwater abstractions. The scenarios that were assessed reflected reduced precipitation and different rates of groundwater abstraction. The outcomes presented in this paper, have contributed creating a clearer picture of the hydrogeological characteristics of this part of the Pannonian Basin and provided insight into the conditions for more robust management of this groundwater resource.

Key words: groundwater management, monitoring, groundwater quality, balance, database

1. INTRODUCTION

Groundwater is the only resource from which water is withdrawn to provide water supply for the population and industry in Bačka District (northern Serbia) (Polomčić et al., 2011). As such, this resource is of great importance to the development of industry and communities of Bačka. Long-term groundwater abstraction from groundwater bodies shared by Bačka and southern Hungary is compounded by declining groundwater levels in both countries and an utter lack of knowledge about the amounts of groundwater withdrawn by each country. The Water Managemant Master Plan of the Republic of Serbia identifies various concepts aimed at resolving the water supply problem in Bačka, such as the development of a regional water supply system (Đurić et al., 2007). Short-term orientation of water supply (5-10 years) is to develop micro-regional water systems (connecting several villages and municipalities in a unit, depending on the available sources) (PSSTD, 2009). However, in solving water supply problems in the Bačka District there are problems related to the groundwater quality where priority is given to settlements with elevated concentrations of arsenic in groundwater, which is of geological origin (Papić et al., 2012). In 2008, hydrogeological investigations were conducted within the scope of the project entitled Sustainable Development of Hungarian-Serbian Transboundary Aquifer (SUDEHSTRA), a cross-border cooperation project funded by the European Union (ERDF/INTERREG IIIA/Community Initiative), whose objective and tasks were fully in line with the targets of the EU Water Framework Directive (WFD, EC 2000/60) and the daughter Groundwater Directive (Stevanović et al., 2008, 2011). A recommendation after completing the project was to continue monitoring, and this has been done, and results of new research are presented in this paper. In 2010 and 2011, further investigations were undertaken in Bačka District (Serbia), which included the recording of groundwater abstractions, monitoring of groundwater level fluctuations, and sampling of water for chemical analyses. Data on the groundwater regime in Bačka were used to verify the appointed prediction of groundwater regime according to the SUDEHSTRA project, and provide an adequate basis for groundwater management in this part of the Southeast Pannonian Basin.

This paper has two complementary aims: (a) to determine the groundwater balance for aquifers used for water supply through utilization of a groundwater model, (b) to analyse groundwater quality used for public water supply in Serbia´s Southeast Pannonian Basin (Bačka region).

2. STUDY AREA

The study area encompasses a part of Serbia (Bačka District), up to the border with Hungary (Fig. 1A). The eastern and western boundaries of the study area are defined by the Tisa (Tisza) and Danube rivers. The southern border is defined by the channel Danube-Tisa-Danube (Fig. 1B). This channel represents a hydro-system with great economic significance for Serbia. It serves a multitude of purposes: drains the excess water during the humid season, provides the necessary quantities of water for irrigation in the dry season, supplies water to industry and some settlements around the main channel network, serves for navigation, fishing, etc. (Milanović et al., 2011). The surface of the study area is 5148 km^2.

The study area is within the Pannonian Basin, a vast lowland surrounded by mountain ranges, whose formation began in the Eocene, when strong tectonic movements led to the break-up and sinking of parts of the former mainland. After separating from the Tethys, the sunken region was occupied by a new sea, the Paratethys, which during the Neogene period played a dominant role in the formation of the geological makeup of the region between the Alps and the Carpathian Mountains (and further to the east) (Royden et al., 1983; Royden & Horváth, 1988).

2.1. Geological setting

The oldest rocks in the study area are Precambrian and Paleozoic formations that constitute the basement of younger sedimentary rocks. High temperatures and pressures have led to recrystallization, producing metamorphic rocks. The overlying rocks are Triassic and Cretaceous sediments, represented by carbonate, flysch, sand-clay and marl deposits (Čanović et al., 1988). During the Tertiary period, largely clay and sand sediments were deposited within the basin, whose thickness in the northeast is greater than 2500 m. The deeper reaches of this complex include considerable oil and gas deposits, while the youngest, Pliocene sediments are significant from a water supply perspective. Quaternary clay-sand and sand-gravel sediments, which are as thick as 200 m in Bačka, are the principal sources of water supply in this area (Kukin, 1969). A large part of the territory of Bačka District is covered with sediments, deposited as loess plateaus, and loess-like sediments (Ćalić et al., 2012).

2.2. Hydrogeological setting

With regard to the hydrogeological characteristics of the Pannonian Basin in Serbia, there are four distinct hydrogeological systems (Fig. 1C) between the youngest Quaternary deposits on the ground surface and the deepest geological formations which make up the floor of the basin (Milosavljević et al., 1997).

The first hydrogeological system is made up of deposits from the ground surface to the Upper Pontian floor. Up to a depth of about 200 m, this system features sand-clay deposits where groundwater relevant to water supply has been formed. The deeper systems contain thermal and mineral waters, whose temperatures are up to 80^{o}C, with a mineral content that was found to be as high as 50 g/L in the deepest reaches. The first hydrogeological complex comprises the so-called "first" aquifer, then the "second" aquifer (commonly referred to as the "Basic water-bearing complex" (BWC) because it is used for drinking water supply by the entire Province of Vojvodina (Josipović & Soro, 2012), and the "third" aquifer is in Pliocene sand deposits (Fig. 1D). The third aquifer is a major contributor to the water supply in other parts of Vojvodina, such that it was not studied in any detail within the scope of this research.

The first aquifer is recharged by infiltration of atmospheric precipitation and, in alluviums, by infiltration of surface water. Recharge on account of groundwater flow from the Lower Quaternary water-bearing complex (BWC) is also characteristic, particularly in areas where Lower Pleistocene sand deposits are in direct contact with Upper Pleistocene sediments. Under natural conditions, the aquifer is discharged through evapotranspiration as well as groundwater flow to surface streams, but artificial discharge through groundwater abstraction via water wells is also considerable (Dimkić et al., 2007).

Pleistocene sediments that make up the BWC extend beyond Serbia's borders, into other parts of the Pannonian Basin in Croatia, Hungary and Romania. The aquifer is confined, largely subartesian. Today, the piezometric head distribution is significantly affected by numerous groundwater abstractions. Infiltration of precipitation is a considerable source of recharge of the BWC in the loess found over a considerable portion of the ground surface in northern Serbia (according to SUDEHSTRA project infiltration of precipitation is 20–30%).

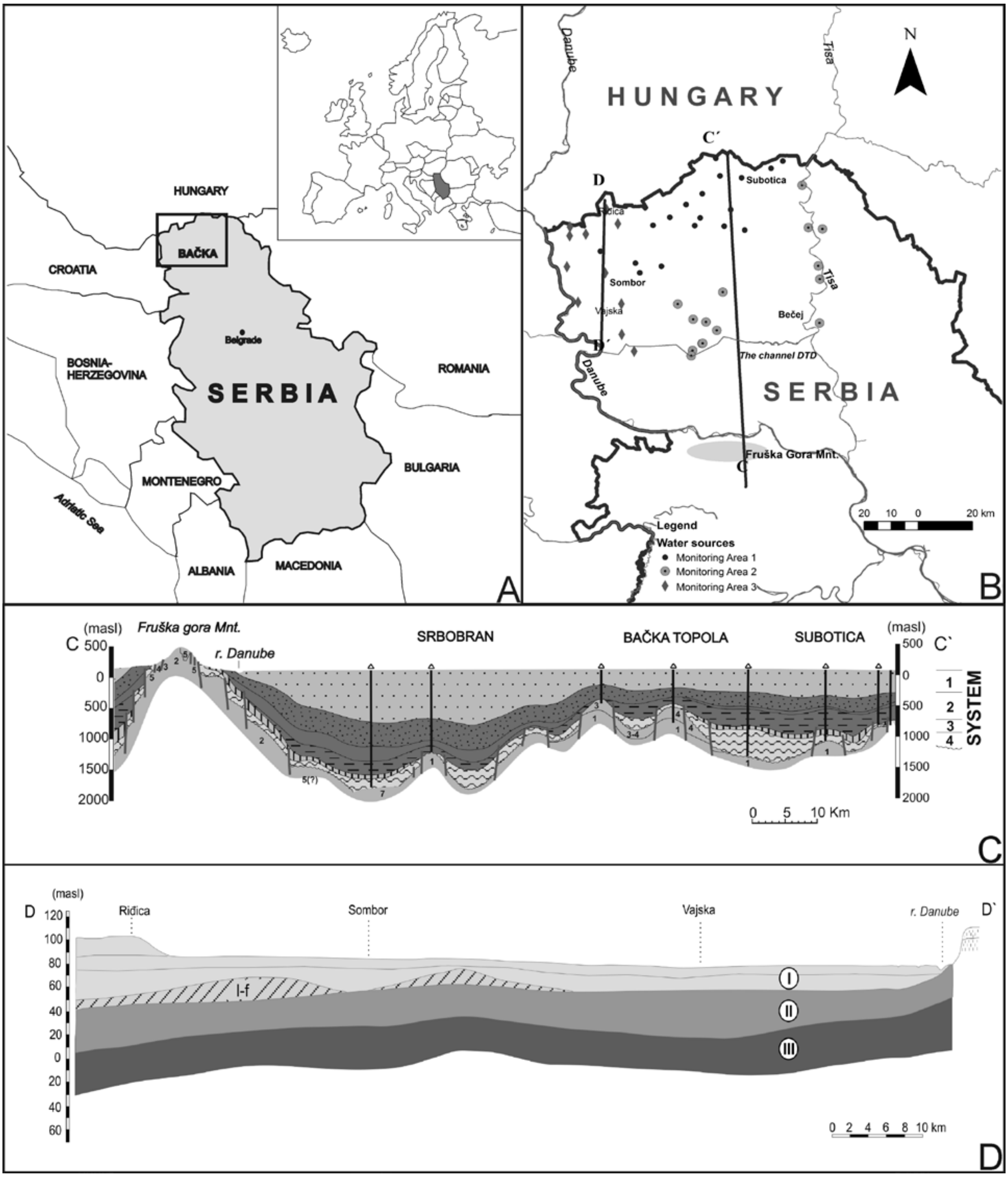

Figure 1. A) Geographic location of the study area B) Groundwater monitoring locations; sections C-C´ and D-D´. C) Regional hydrogeological section through the terrain with four distinct hydrogeological systems (Marinović, 1982, modified). D) Extent and inter-relationships of Tertiary and Quaternary aquifers relevant to drinking water supply: I (first aquifer) - Loess, alluvion, terraces and sand-gravel deposits ; II (second aquifer, called "Basic water-bearing complex" - BWC - Fluvial - lacustrine sand deposits; III (third aquifer) - Pliocene sand deposits; l-f: Low permeable fluvial-swamp deposits.

The aquifer is also recharged by groundwater flowing from distant areas, originating in the northwest from Mt. Mecsek in Hungary and in the northeast and east from the Carpathian Mountains and from Fruška Gora Mt. in the south (Polomčić et al., 2010). Another source of recharge is infiltration of water from the Danube and the Tisa when the stages of these two rivers are high. The BWC is predominantly discharged by groundwater abstractions that have resulted in lowered groundwater levels across the region, as a result of over-exploitation. A low average hydraulic gradient, of the order of 10^{-3}, causes a very small groundwater flow velocity (Polomčić et al., 2011).

3. METHODS

The methods used for determination of qualitative and quantitative characteristics of the transboundary aquifers within the SUDEHSTRA Project (2007-2008) included four levels of research: preparatory activities, data collection, network monitoring, development of a hydrodynamical model (Stevanović et al., 2008; Polomčić et al., 2010; Stevanović et al., 2011). One of the key outcomes of these efforts was the development of a hydrodynamic model, which was supplemented with new data on groundwater abstractions from aquifers in Bačka collected in 2010 and 2011 and presented in this paper. Only the first aquifer and BWC were considered. This allowed a more accurate assessment of the groundwater regime to be obtained; very important for the water supply of Bačka.

3.1. Monitoring, field sampling and analytical methods

The groundwater regime monitoring system was set up in such a way as to ensure that as much groundwater information as possible was gathered in the study area (Bačka). The selected wells were representative of the methods of abstraction in the entire area. Groundwater levels were measured at the exploitation wells at the 12 groundwater sources (Table 2, Fig. 5). To ensure reliable and frequent recording, divers were installed and the time interval was set at one hour.

In addition to collecting groundwater quantitative data, a large number of physicochemical analyses of the raw water sampled from various groundwater sources for drinking water supply were conducted using 150 groundwater samples. The well water sampling procedure was consistent with the relevant regulations (Official Gazette of the SFRY No. 33/87). During sampling, groundwater temperature, conductivity and pH were also measured, while the remaining parameters were determined by accredited labs in Serbia. The groundwater hardness was determined by complexometric titration, turbidity by the nephelometric method, dry residue by the gravimetric method, nitrate, nitrite and ammonium ions by the spectrophotometric method, and $KMnO_4$ demand by the volumetric method. Atomic absorption spectrometry was used to determine metals concentrations.

3.2. Database

In situ investigations were conducted in the study area for the purpose of developing a hydrodynamic model, comprised of data collection at the groundwater sources and surveying of the water supply providers. During the SUDEHSTRA project, a large number of data were collected to help identify the characteristics and operating modes of the groundwater sources. The many data were entered into a database designed for efficient processing. Different types of data were selected according to various criteria and used to develop the hydrodynamic model.

The database was created in MS Access and its structure is that of a relational database, comprising 14 spreadsheets, among which appropriate relationships were, established (Fig. 2). Based on common characteristics of the data, a total of nine forms were developed to integrate the data (Fig. 2).

In addition to providing insight into the general organization of the groundwater sources and water supply providers, the forms contained information about the hydrogeological characteristics of the source, the number and structural features of the groundwater abstraction facilities, the technology applied and the water quality at source, along with some information pertaining to groundwater protection at source. The data on groundwater regime monitoring and hydrodynamic characteristics of the groundwater sources were particularly important. For model purposes, queries and search tools were developed to allow for the extraction of data based on a large number of criteria (keys) and retrieval of answers from all forms.

Table 1. Hydrogeological layers which are presented in the model and initial values of hydraulic parameters (Kh-horizontal hydraulic conductivity, Kv - vertical hydraulic conductivity)

Layer number	Layer hydrogeological functions	Lithostratigraphic members	Kh (m/day)	Kv (m/day)	Porosity (-)
1	partially permeable layer	clayey sediments from the loess plateau in the center of the exploration area (Telečki plateau on the Serbian side)	4	0.004	0.1
2	first water bearing layers	alluvial sediments and Pliocene sands	2	0.004	0.2
3	impermeable layer	Plio-Quaternary clay	0.015	0.0002	0.1
4	second water bearing layer	Plio-Quaternary sands	10	0.4	0.2

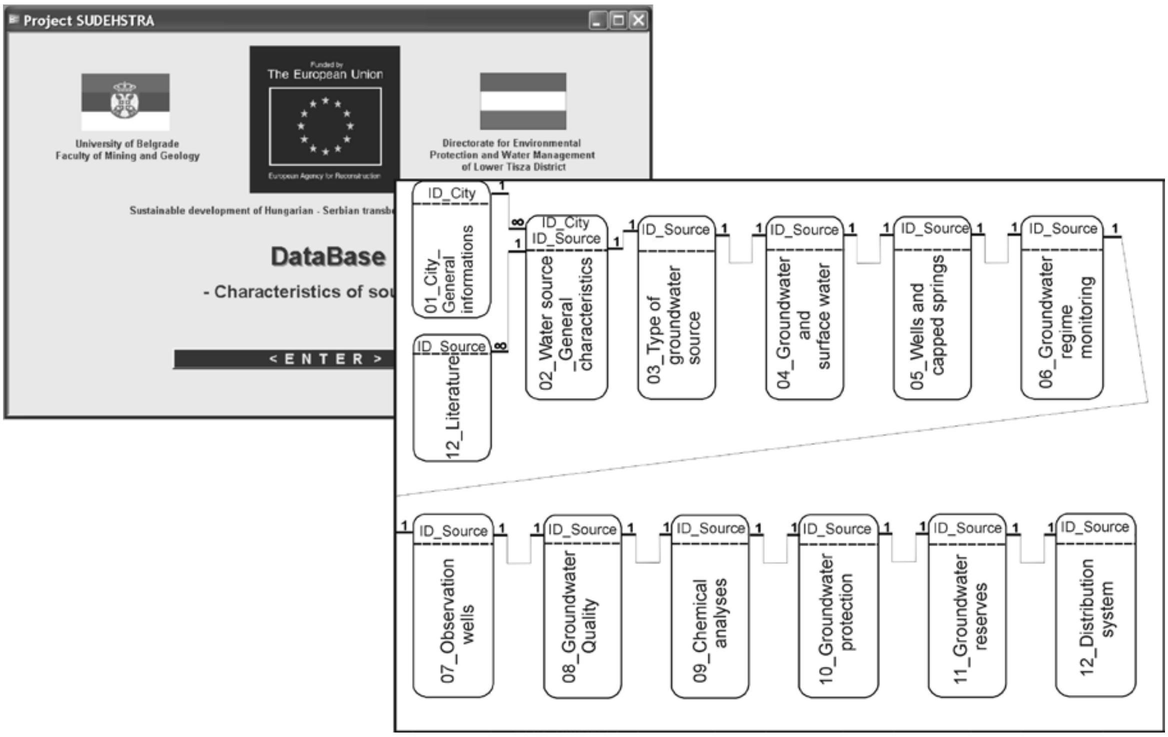

Figure 2. Database home page and spreadsheet relationships.

Two aspects of the database are noteworthy: the menus and command buttons are designed to be extremely user-friendly and the applicability of the database was broadened to include water supply organizations. This facilitates the standardization, archiving and availability of the data to relevant government institutions. Another important characteristic is that the database was developed in MS Access, such that its software compatibility allows for full integration with Serbia's leading geological information system (GeolISS), and the data are exportable to Modflow which was used in groundwater modeling. All new data, from 2010 and 2011, have been incorporated into the existing database.

3.3. Development and calibration of a hydrodynamic model

A multiple-layer hydrodynamic model was developed to assess and analyze current groundwater abstractions. Its inputs included the data collected from regional geological and hydrogeological investigations, previous exploratory and production boring, regional geophysical investigations, as well as hydrometeorological and hydrological data and groundwater abstraction records. The applied numerical model was MODFLOW-2000, a modular three-dimensional finite difference groundwater flow model developed by the US Geological Survey (Harbaugh et al., 2000). The software used was Groundwater Vistas 5.33b (Environmental Simulations International, Ltd.). The hydrodynamic model of the area of investigation consists of four layers observed in the vertical profile (Table 1). Each layer corresponds to a geologic layer in the vertical section of the field. These layers are separated and represented schematically on the basis of knowledge of the area and analysis of extensive field data. Part of southern Hungary (from the Serbian border to Kiskunfelegzhaza) was covered by the model during the SUDEHSTRA project (125km×145km) (István et al., 2008; Stevanović et al., 2008, Polomčić et al., 2010).

The flow field was modeled with a basic cell size of 1000 m × 1000 m, reduced to 125 m × 125 m within the zones of the groundwater sources (Fig. 3). Hydraulic parameters on the model are presented with hydraulic conductivity (horizontal and vertical) and porosity. Each of these hydraulic parameters was taken as a representative value in each discretization cell (Table 1). The following boundary conditions were specified in the model: recharge, evapotranspiration, general head boundary, boundary with defined flow, drainage and river boundary, and no-flow cells (Fig. 3) (Polomčić et al., 2010). Infiltration rate was imported on the basis of topographic and geological characteristics of the area. Maximum infiltration rate (100 mm/year) was considered on the loess plateau north from Bascalmas, while the lowest (20 mm/yr) was in the valley of the River Tisa. Evapotranspiration is a function of the depth of groundwater, and it was found that below a depth of 5 m this is practically nonexistent (E = 0).

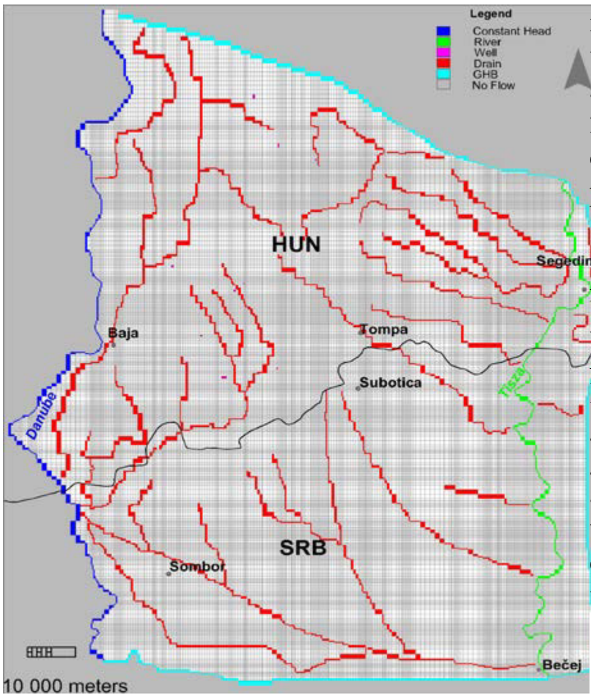

Figure 3. Modeled area and boundary conditions of the first model layer.

General head boundary was introduced in simulating the impact of a known source of subsurface recharge that is outside the analyzed field. In the northwest recharge area, simulated by this boundary condition is the region of Mecsek in Hungary. In the south area of recharge is Fruška Gora (Serbia), and the most distant recharge area is located to the east of the Carpathians (Romania and Hungary). This boundary condition is set up in every layer and represents the contour border of the area investigated. The exceptions are the first and second layer, where the Danube River represents the western border. Because of the significant effects of the Danube on the groundwater in the western part of the area, its impact was simulated through the constant head boundary condition. On the eastern side, the Tisa River and drainage channels were taken as a head-dependent flux boundary ("river boundary" for Tisa River and "drain boundary" for channels). Cells outside the contours of the area of investigation are defaulted to no-flow cells (Q=0), and are identical in every layer of the model. The model was calibrated for the stationary conditions of the groundwater regime using observed groundwater levels in each of the sources in the territory of both countries.

4. RESULTS AND DISCUSSION

4.1. Monitoring of groundwater abstraction

A hydrodynamic assessment of the groundwater regime of the aquifer in Bačka, which is used for drinking water supply, was conducted with the goal of assessing whether groundwater abstractions would be sustainable over the next 15-20 years under different abstraction rates and climate change conditions involving a 20% decrease in precipitation levels.

The main urban water supply issues in Bačka are associated with the groundwater abstraction regime. The large distribution of the intergranular aquifer and very slow water exchange prevent rapid renewal of this groundwater resource, such that long-term abstraction of substantial amounts of groundwater creates a deficit reflected in declining groundwater levels. The problem resulting from abstraction of greater amounts of groundwater than the available dynamic reserves of the BWC was created after the development of centralized drinking water supply systems in the 1960s.

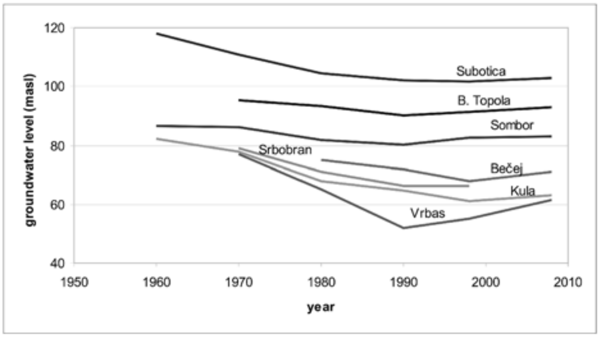

Figure 4. Groundwater levels in the study area.

The increasing rate of abstraction was not supported by appropriate groundwater regime monitoring, such that prolonged excessive abstractions have threatened the natural recharge capability of the aquifer, causing a regional decline in groundwater levels. The greatest drawdowns were recorded in the late 1980s, exceeding 20 m within the zones of some groundwater sources for urban water supply, and between 8 and 9 m in rural areas (Dimkić et al., 2007). Notable deceleration of the groundwater level decline is noted in the early 1990s (Fig. 4), which can be presumed to be because the war and economic crisis in the region led to a significant decrease in industrial water demand as large industrial facilities were shut down. Table 2 shows the current urban water demand in the study area (Bačka) and the aquifers from which groundwater is abstracted.

The model developed in the SUDEHSTRA Project (2007-2008) was supplemented with the new data (2010 - 2011) on abstractions and groundwater levels in Serbia; in Hungary, the rates of groundwater abstraction remained the same as before (Fig. 5).

Table 2. Average rates of groundwater abstraction for public and industry water supply in Bačka in 2010 and 2011.

	City / town	Exploited aquifer	Public water supply [l/s]	Industry water extraction [l/s]
1	Ada	II (BWC)	33	20
2	Apatin	I + II (BWC)	52	110
3	B. Topola	II (BWC)	22	30
4	Bečej	II (BWC)	96	80
5	Kanjiža	II (BWC)	25	40
6	Kula	I + II (BWC)	46	50
7	Mali Iđoš	II (BWC)	15	15
8	Senta	II (BWC)	50	55
9	Sombor	I + II (BWC)	145	165
10	Srbobran	I + II (BWC)	30	15
11	Subotica	II (BWC)	258	270
12	Vrbas	I + II (BWC)	65	100

The distributions of the groundwater levels of the first aquifer and the BWC generally coincide, suggesting their hydraulic contact and a common source of recharge: infiltration of precipitation within a spacious loess plateau in southern Hungary and the Teleč Plateau in Serbia - from Subotica in the north to Kula and Vrbas in the south (Fig. 5). Occasional differences in general groundwater levels are a result of the rates of abstraction from these aquifers. Relative to the first aquifer, the largest BWC drawdowns were recorded in Bačka (Fig. 5, Table 2).

4.2. Basic hydrochemistry

The chemical composition of the groundwater is the combined result of the composition of water that enters the groundwater reservoir and the reactions with minerals present in the rock that may modify the water composition. To facilitate insight into the qualitative characteristics of the groundwater used as drinking water supply in this part of Serbia, the study area was divided into the following zones: Monitoring Area 1 – MA1 (groundwater sources in the extended area of Subotica), Monitoring Area 2 – MA2 (groundwater sources in the vicinity of Bečej), and Monitoring Area 3 – MA3 (groundwater sources in the vicinity of Sombor) (Fig. 1B). Each of these locations represented an area that holds the largest groundwater sources in the given region.

The groundwaters in Bačka, as well as in the entire Pannonian Basin, are several thousand years old (6.000 – 22.000 years); water exchange is slow, such that groundwater is in perpetual interaction with the surrounding sediments (Josipović & Soro 2012; Vukoje, 2001). Hydrogen and oxygen isotopes indicated that most of the waters are of paleometeoric origin, infiltrated during a cold period. The waters are generally of the $NaHCO_3$ type. Na and HCO_3 were found to increase with depth and/or temperature (Varsányi et al., 1997). In the 500 m thick upper zone of the gravel and sandy aquifers used for drinking water supply in Hungary, the basin-type areas, the dissolved solid content of waters is less than 1g/L. In the recharge areas the calcium-hydrocarbonate type characteristically becomes an alkali-hydrocarbonate type in direction of the flow along the flow pass (Ministry for environment and water, 2006).

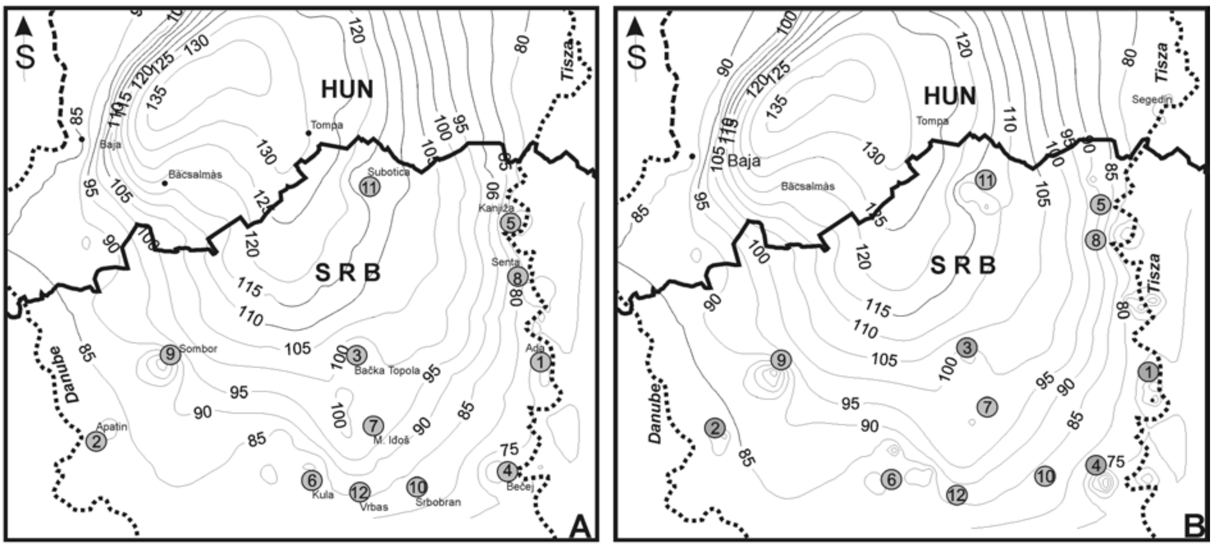

Figure 5. Piezometric head distribution based on the data observations in 2010 and 2011, of A) the first aquifer, and B) the BWC in Bačka and southern Hungary (Southeast Pannonian Basin). Legend: Numbers 1 to 12 indicate the groundwater sources identified in Table 2.

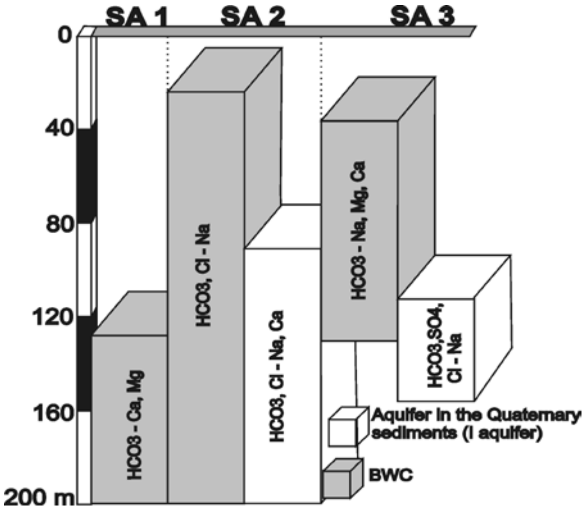

Figure 6. Depths of tapped intervals at which groundwater is withdrawn, settings of the abstraction wells and basic chemistry.

A hydrochemical scheme of changes in chemical composition with depth was developed. The basic cation-anion composition of the groundwater was found to vary with the depth of the tapped aquifer (Fig. 6). The basic chemistry is determined largely by the presence of hydrocarbonates, up to 98% equivalent in the Quaternary strata of MA1 and MA2. The deeper aquifer in MA2 and MA3 is characterized by elevated concentrations of chlorides of up to 50% equivalent at some locations, and extremely low chloride concentrations in the Quaternary strata in MA1. The sodium ion was found to dominate all the water-bearing complex, except the Quaternary deposits in MA1 where the cation composition primarily featured calcium and magnesium (Fig. 6) (Mandić & Papić, 2005).

4.3. Groundwater quality

Groundwater abstracted for the public water supply in Bačka region has poor quality, but it is possible to apply treatment technologies to achieve regulated drinking water standards. Among the non-compliant parameters, those that stood out included: temperature, turbidity, ammonium ion (NH_4^+), iron, arsenic and $KMnO_4$ demand (Table 3).

With regard to the physical parameters, groundwater temperatures were found to be in the 14-24^{o}C range, which is much higher than the optimal 12^{o}C for drinking water. Water coloration and turbidity also failed to meet drinking water standards. $KMnO_4$ demand is a measure of the content of organic substances. Some organic substances found in groundwater do not degrade to mineral forms (nitrates, ammonia, carbon dioxide), but retain rather stable organic structures known as humic acid and salts. Humic substances are the most frequent organic substances found in the Pannonian Basin groundwater, which give this groundwater a characteristic yellow color. With regard to the BWC, the lowest $KMnO_4$ demand within the study area was recorded in MA1.

Among the nitrogen triad (ammonium, nitrites and nitrates), the presence of the ammonium ion was found to have the most significant impact on groundwater quality. Nitrites and nitrates occurred sporadically, as a result of the transitional oxidation-reduction environment of the aquifer. Ammonium ion concentrations in virtually the entire study area, at all sampled wells, exceeded the MPC (Maximum Permissible Concentration) prescribed by drinking water standards (0.1 mg/L) (Official Gazette of the FRY No. 42/98) (Table 3). The main process responsible for the high ammonium concentrations is likely to be mineralization from sediments rich in organic matter. Mildly elevated nitrate concentrations were recorded in MA1 and MA2, while extremely low nitrite concentrations were indicative of a reducing environment.

Iron concentrations ranging from 0.4 mg/L to 1 mg/L were recorded at MA1, where the second aquifer is tapped. To the south, east and west, iron concentrations in the first aquifer declined to 0.05 –3 mg/L. The iron concentrations in the deeper aquifer formed in Pliocene sands were considerably lower, compared with those of the Quaternary strata of the shallower aquifer.

Table 3. Parallel representation of average physicochemical parameters in the extended areas of MA1, MA2 and MA3

Parameter	Monitoring area 1	Monitoring area 2	Monitoring area 3	MPC (Official Gazette of the FRY No. 42/98)
Temperature (^{o}C)	17	14-24	13.8-21.5	Optimal 12
Conductivity (µS/cm)	456-600	340-1319	Not measured	2500
pH	*ca.* 7.7	7.6-8.3	6.96-8.4	6.8-8.5
Turbidity (NTU)	1.7-9.3	0.3-12.3	Not measured	1
TDS (mg/L)	*ca.* 370	315-831	390-1414	1000
$KMnO_4$ demand (mg/L)	4-9	5.6-104	4.8-195	12
Fe (mg/L)	0.4-1	0.05-1.45	0.14-3	0.3
NH_4^+ (mg/L)	0.398-0.173	0.05-2.63	0.02-3.2	0.1
As (µg/L)	20-173	<10-100	10-210	10

Arsenic concentrations are a major concern for drinking water supply as a number of harmful effects of arsenic on human health have been identified throughout the world, such as skin changes; cardiovascular, respiratory and neurological effects; and skin and various other cancers (Petrusevski et al., 2007). For this reason it is necessary to determine the concentration of this element and extremely important to identify the source and mobility of arsenic in the groundwater.

The mobility of arsenic in groundwater depends on highly-complex geochemical processes in a particular setting (Kim et al., 2009). A condition that favors arsenic migration is a reduction environment where desorption and dissolution take place. Low Eh values (<50 mV), the absence of dissolved oxygen, elevated Fe, Mn, NH_4^+ concentrations, high alkalinity, the presence of organic substances and low sulfate concentrations (<5 mg/L) are the general hydrochemical characteristics of groundwaters that feature elevated arsenic concentrations (Smedley & Kinninburgh, 2002). These are the very features that characterized the groundwater in the study area. The largest city in the study area is Subotica (MA1) (population 140,000); it is the only city with a water treatment plant. The area covered by Subotica obtains its drinking water supply from 13 groundwater sources. Based on the analyses, the average concentration of arsenic at these groundwater sources was 110 μg/L. The presence of the ammonium ion and absence of nitrates in the groundwater suggested a reducing medium, which generally creates favorable conditions for arsenic migration in groundwater. The iron concentration in the groundwater used for drinking water supply in Subotica varied from 0.04 to 0.96 mg/L (Papić et al., 2012). The iron concentration in the groundwater used for drinking water supply in Subotica varied from 0.04 to 0.96 mg/L (Papić et al., 2012).

Table 3 shows As concentrations in groundwaters used for drinking water supply in Vojvodina. At nearly all MA1 locations, arsenic concentrations exceeded the MPC, while in MA3 they were found to be as high as 210 μg/L. MA2 featured arsenic concentrations from 10 to 100 μg/L. Other countries that share the Pannonian Basin also have drinking water supply concerns due to elevated arsenic concentrations in groundwater. In Croatia, the areas of Osijek in the Baranja region and Vukovar in the Srijem region are particularly threatened, with arsenic concentrations in the groundwater used for drinking water supply measuring as high as 491 μg/L. Groundwater is tapped from Middle - Upper Pleistocene sediments (Ujević et al., 2010). In Romania and Hungary, about half a million people who live in the Pannonian Basin use groundwater with arsenic concentrations exceeding the MPC, while arsenic concentrations in the groundwater withdrawn for drinking water supply are up to 240 μg/L (Rowland et al., 2010).

4.4. Groundwater balance of the first aquifer and BWC in the Southeast Pannonian Basin

Water extraction from the first aquifer and BWC extends beyond Serbia's borders into other parts of the Southeast Pannonian Basin. The groundwater balance of a groundwater system can be determined by calculating the inputs and outputs of water, and the storage changes of the groundwater system. For the area included in the model, the major inputs of water are the infiltration of the precipitation and groundwater inflow, while the major outputs from a groundwater system are evapotranspiration, groundwater pumping, groundwater discharge in rivers (Danube and Tisa) and drainage channels. The groundwater balance was assessed based on the groundwater abstraction rate recorded in Bačka in 2010 and 2011, and in southern Hungary in 2008.

All data related to groundwater balance on the Hungarian side of the Pannonian Basin used in this paper are defined in the SUDEHSTRA Project (Stevanović et al., 2011). Table 4 is a numerical representation of the current groundwater balance elements of the first aquifer and the BWC in the Southeast Pannonian Basin.

The groundwater balance assessments of the first aquifer and the BWC indicated that precipitation and evapotranspiration play significant roles in the study area. The difference between these parameters represents the amount of water infiltrated into the water-bearing complex (directly into the first aquifer, and indirectly into the BWC – from the first aquifer through a semi-pervious interbed), amounting to 5637 l/s. Most of the infiltrated water is withdrawn by production wells (4547 l/s); drainage channels take up 1037 l/s and surface streams 1077 l/s.

The high precipitation infiltration rate is driven by the geomorphological and geological features of the surface sediments. A relatively large loess plateau on the surface of the study area, characterized by a strong precipitation infiltration capability, determines the general direction of groundwater flow, from the central loess plateau to the fringes of the Bačka region (Polomčić et al., 2010). Under current groundwater withdrawal conditions, the considered aquifer is drained via production wells and into the Danube and Tisa rivers and drainage channels.

Prognostic calculations focused on two basic scenarios: climate change reflected in decreasing precipitation and different rates of abstraction in Serbia and Hungary (four variants). In the first two scenarios (Variants A and B), the current rate of abstraction was considered, but with precipitation reduced by 10 and 20%, respectively, while in Variants C and D the rate of abstraction was increased and precipitation reduced by 20%. The resulting groundwater balance is shown in table 4.

Compared with the current groundwater balance of the aquifer, reflecting the current rates of groundwater abstraction (Table 4), in Variants A and B, due to reduced precipitation and the current rate of abstraction, evapotranspiration declines as a result of declining groundwater levels by 2060-4155 l/s (Table 4). This causes a redistribution of the drainage of the aquifer into surface streams. Less groundwater is drained into the drainage channels and the Danube River, on aggregate between 424 l/s (Variant B) and 840 l/s (Variant A). However, due to a decline in groundwater levels (Variant A), groundwater will likely be recharged on account of infiltration from the Tisa River.

Variant C is extreme, in terms of both the assumed climate change impact and the rates of abstraction. This variant involves the greatest decline in groundwater levels in the study area, compared with the present state. Consequently, evapotranspiration is reduced (by 4213 l/s), as are the amounts of water drained into the Danube (488 l/s) and the drainage channels (377 l/s). On the other hand, this variant involves the highest rate of infiltration from the Tisa River (139 l/s) (Table 4).
Variant D retained the elevated rate of groundwater abstraction in Hungary, but this rate was reduced in Serbia by 15% relative to the current rate. With regard to the redistribution of groundwater in these circumstances, the water balance in Variant D is similar to that in Variant C.

Characteristic of the analyzed scenarios and variants of climate change and rates of groundwater abstraction is a groundwater balance deficit compared to the current balance of BWC (Table 4). The highest deficit of 1331 l/s occurs in Variant C, which is the most extreme case in terms of climate change and groundwater abstraction rate. The calculated reductions of recharge of the tapped aquifers and different rates of abstraction in Serbia and Hungary allowed further declines in groundwater levels relative to the present state to be predicted.

Additional drawdowns in each of the analyzed variants for three groundwater sources that feature the highest rates of abstraction in Bačka are shown in figure 7. The climate change impact forecast involving reduced precipitation infiltration by 10% and 20% relative to long-term averages suggests a significant decline in groundwater levels in Serbia, ranging from 14.4 to 18.2 m in the areas of Subotica, Sombor and Bečej. Additional drawdowns in excess of 10 m occur in Kula and Bečej, as well as in the extended area of Szeged, Hungary. In the entire study area, both aquifers would experience an additional drawdown of 0.5 – 1 m. In Variant C, relative to Variant A, the groundwater source in Subotica shows a larger drawdown as a result of a higher rate of groundwater abstraction from the aquifer in Hungary. With increasing distance from the state border, the impact of the increased rate of abstraction in Hungary would decrease.

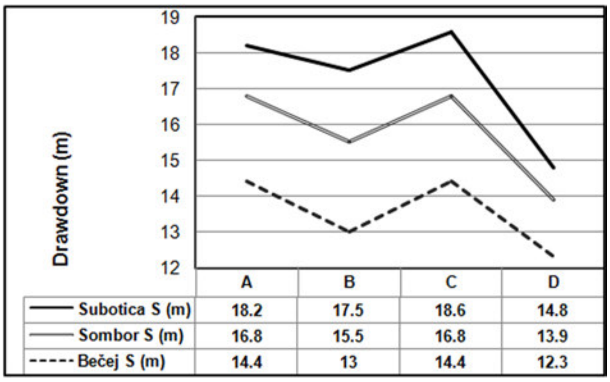

Figure 7. Additional drawdowns at selected groundwater sources in Bačka.

Table 4. Current groundwater balance and groundwater balance forecasts for the first aquifer and the BWC in the Southeast Pannonian Basin

Variant	Infiltration of the precipitation	Groundwater inflow	Evapo-transpiration	Wells	Danube River	Tisa River	Drainage channel	Water budget difference	Groundwater deficit
	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)
2011	28160	4025	-22523	-4547	-1019	-58	-1037	3001	0
A	22528	3361	-18368	-4547	-556	127	-660	1886	1115
B	25344	3448	-20463	-4547	-810	35	-822	2185	816
C	22528	2981	-18310	-4697	-531	139	-620	1670	1331
D	22528	3582	-18518	-4365	-625	46	-671	1977	1024

(2011 – reference year, A - Current exploitation, Infiltration of precipitation 80%, B - Current exploitation, Infiltration of precipitation 90%, C - Infiltration of precipitation 80%, Expl. SRB 100%, Expl. HUN 110%, D - Infiltration of precipitation 80%, Expl. SRB 85%, Expl. HUN 110%, mark "–" groundwater outflow from the model).

At select groundwater sources the drawdowns would remain virtually the same (Sombor and Bečej) as in Variant A. Groundwater abstraction in Hungary would have virtually no impact on groundwater levels south of Bačka Topola (water source 3, Table 2) in Serbia. A reduced rate of groundwater abstraction in Bačka, at decreased precipitation infiltration rates (Variant D), results in a smaller drawdown than in Variant C. Under these conditions, the greatest difference between additional drawdowns relative to Variant C would occur in Subotica, as a result of the reduced yield of the largest of the three analyzed groundwater sources.

5. CONCLUSIONS

Drinking water supply in the southeastern part of the Pannonian Basin is provided by groundwater abstractions from the first aquifer and the basic water-bearing complex (BWC) in Quaternary sediments. These sediments, up to a depth of about 200 m, are characterized by sand and gravel deposits that contain significant amounts of water for drinking water supply. The basic groundwater chemistry is dominated by hydrocarbonate, while the cation composition varies with the depth from which groundwater is withdrawn. The reduction conditions that prevail in the geoenvironment result in elevated concentrations of iron, manganese, the ammonium ion and organic substances. However, high arsenic concentrations are among the principal water quality issues, as concentrations of this element at some groundwater sources exceed the drinking water standard several times.

Groundwater balance assessments of the first aquifer and the basic water-bearing complex (BWC) indicated that precipitation plays a significant role in the study area. Relative to the groundwater balance under current abstraction conditions, the first two analyzed variants showed that reduced precipitation, at current abstraction rates, is likely to lead to reduced evapotranspiration as a result of a decline in groundwater levels by 2.06 – 4.21 m^3/s. In these cases, there will be additional permanent drawdowns from 0.5 to 1 m of both aquifers over the entire study area, and from 14.4 to 18.2 m at the most productive groundwater sources.

When the worst-case climate change scenario, compounded by increased rates of abstraction (in Hungary), was analyzed, the largest decline in groundwater levels was found to occur in the state border area. In essence, any increase in abstraction rates in Hungary would be expected to result in a further decline in groundwater levels of the tapped aquifers all the way to Bačka Topola in Serbia.

One of the characteristics of the groundwater abstractions from this aquifer is over-exploitation, with more groundwater being withdrawn than can naturally be renewed. Compared to the current balance of groundwater in the BWC, all the analyzed scenarios indicated a larger deficit of groundwater (max. 1331 l/s).

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REFERENCES

Ćalić, J., Gaudenyi, T., Milošević, M., Štrbac, D. & Milivojević, M. 2012. *Geomorphometrical method for delineation of plains - case study of the South-Eastern (Serbian) segment of the Pannonian Plain*; Carpathian Journal of Earth and Environmental Sciences, May 2012, Vol. 7, No. 2, 239 – 248.

Čanović, M., Kemenci, R. & Pantić, N., 1988. *The Mesozoic of the Pannonian basin in Vojvodina (Yugoslavia).* Matica Srpska, Novi Sad, pp. 112-114 [in Serbian].

Dimkić M., Stevanović Z. & Đurić D., 2007. *Utilization, Protection and Status of Groundwater in Serbia*. Regional IWA Conference on Groundwater in the Danube river basin and other large river basins, Jaroslav Černi Institute for Development of Water Resources, Belgrade, pp 83-102.

Đurić D., Josipović J., Jevtić G., Slimak, T., & Pušić, M., 2007. *Groundwater Management in Vojvodina*, Proceedings Regional IWA Conference on Groundwater Management in the Danube River basin and large river basin, IWA, 185-192.

Harbaugh, A.W., Banta, E.R., Hill, M.C. & McDonald, M.G., 2000. *MODFLOW-2000*. The U.S. Geological Survey Modular Ground-Water Model, User Guide to Modularization Concepts and the Ground-Water Flow Process, U.S. Geological Survey Open-File Report 00-92, Reston, VA, USA, pp 121.

István, V., Kovács, B., Stevanović. Z. & Polomčić, D., 2008. *Hydrodynamic modelling of the transboundary Hungarian-Serbian aquifer.* Proceedings of XIIth Congress of Hungarian Geomathematics and The 1st Congress of Croatian and Hungarian Geomathematics. Applications of geostatistics, GIS and remote sensing in the fields of geosciences and environmental protection, 29-31 May 2008. Book of Abstracts. Mórahalom, Hungary.

Josipović, J., & Soro, A., 2012. *Groundwater of Vojvodina.* Monograph. Jaroslav Černi Institute for the Development of Water Resources, Belgrade, pp. 37. [in Serbian].

Kim, Y.T., Yoon, H.O., Yoon, C. & Woo, N.C., 2009. *Arsenic species in ecosystems affected by arsenic-*

rich spring water near an abandoned mine in Korea. Environ. Pollut. 157(12):3495-501.

Kukin, A., 1969. *Geological conditions of artesian water occurrence in Backa and their physical and chemical properties,* Proc. Nat. Sci 37, Matica Srpska, Novi Sad, pp. 55-58. [in Serbian].

Mandić, M. & Papić, P., 2005. *A Contribution to the Understanding of the Qualitative Properties of Groundwater in Vojvodina.* In: Proceedings 14th Conference of Geologists of Serbia and Montenegro, Novi Sad pp. 385-390 [in Serbian]

Marinović, Đ., 1982. *The general geological and hydrogeological conditions in the province of Vojvodina.* In: Proceedings VII Yugoslav Symposium of hydrogeology and engineering geology, III/3, Novi Sad. [in Serbian].

Milanović, A., Milijašević, D. & Brankov, J., 2011. *Assessment of polluting effects and surface water quality using water pollution index: a case study of hydro – system Danube – Tisa – Danube*, Serbia; Carpathian Journal of Earth and Environmental Sciences, September 2011, Vol. 6, No. 2, p. 269 – 277.

Milosavljević, S., Vasiljević, M. & Vilovski, S., 1997. *Hydrogeological studies in Vojvodina (Research drinking, industrial and mineral water).* In: Monograph 100 years of hydrogeology in Yugoslavia, Faculty of Mining and Geology, Belgrade, pp.117-146 [in Serbian].

Ministry for environment and water, 2006. *Groundwaters in Hungary II* (compiled by the Water Management Directorate of VITUKI Environmental Protection and Water Management Research Institute on behalf of the Ministry for Environment and Water), Budapest, pp. 26-27.

Papić, P., Ćuk, M., Todorović, M., Stojković, J., Hajdin, B., Atanacković, N. & Polomčić, D., 2012. *Arsenic in tap waters of the south Pannonian basin (Serbia) and arsenic risk assessment*, Pol. J. Environ. Stud. Vol. 21, No 6, 1783-1790.

Petrusevski, B., Sharma, S.K., Schippers, J.C. & Shordt, K., 2007. *Arsenic in drinking water.* Delft: IRC International Water and Sanitation Centre, Vol. 17, pp. 1-57.

Polomčić, D., Stevanović, Z., Dokmanović, P., Papić, P., Ristić-Vakanjac, V., Hajdin, B., Milanović, S. & Bajić, D., (2011) Groundwater supply in Serbia – Situation and Perspectives. In: Polomčić D. and Ristić-Vakanjac V. (ed) 40 years of the Department of Hydrogeology. Faculty of Mining and Geology. Belgrade, Serbia, pp 45 - 78. [in Serbian].

Polomčić, D., Stevanović, Z., Milanović, S., Sorajić, S., Hajdin, B. & Kljajić, Ž., 2010. Sustainable development of the Hungarian – Serbian transboundary aquifer. Vodoprivreda 246-248 pp. 223-235 Belgrade.

Provincial secretariat of science and technology development (PSSTD), 2009. Water Supply and Water Protection Strategy for the Autonomous Province of Vojvodina. University of Novi Sad, Faculty of Science and Mathematics, pp. 52-70 [in Serbian]**.**

Regulation of Hygienic Correctness of Drinking Water. *Official Gazette of the SFRY No. 42/98.*

Regulation of sampling and laboratory methods for the analysis of drinking water. *Official Gazette of the SFRY No. 33/87.*

Rowland, H., Omoregie, E., Millot, R., Millot, R., Jimenez, C., Mertens, J., Baciu, C., Hug, S. & Berg, M., 2010. *Geochemistry and arsenic behaviour in groundwater resources of the Pannonian Basin (Hungary and Romania).* Applied Geochemistry 26: 1–17.

Royden, L.H., & Horváth, F., 1988. *The Pannonian Basin – a Study of Basin Evolution*. American Association of Petroleum Geologists - Memoir Series. 45, 1-16.

Royden, L.H., Horváth, F. & Rumpler, J., 1983. *Evolution of the Pannonian Basin System 1. Tectonics.* Tectonics vol. 2, issue 1, pp. 63-90.

Smedley, P.L. & Kinninburgh, D.G., 2002. *A review of the source, behaviour and distribution of arsenic in natural waters.* Applied Geochemistry 17: 517-568.

Stevanović, Z., Kozák, P., Lazić, M., Szanyi, J., Polomčić, D., Kovács, B., Török, J., Milanović, S. & Hajdin, B., 2008. *Towards sustainable management of transboundary Hungarian – Serbian aquifer*. IV International Symposium on Transboundary Waters Management, CD 4 pages, Ses. 1(2), Thessaloniki.

Stevanović, Z., Kozák, P., Lazić, M., Szanyi, J., Polomčić, D., Kovács, B., Török, J., Milanović, S., Hajdin, B. & Papić, P., 2011. *Towards Sustainable Management of Transboundary Hungarian-Serbian Aquifer*. Chapter in the International Monography Transboundary Water Resources Management: A Multidisciplinary Approach, 1 Ed. (eds. Ganoulis J., Aureli A. and Fried J.). Wiley-VCH Verlag, 143-149.

Ujević, M., Duić, Ž., Casiot, C., Sipos, L., Santo, V., Dadić, Ž. & Halamić, J., 2010. *Occurrence and geochemistry of arsenic in the groundwater of Eastern Croatia*. Applied Geochemistry 25:1017–1029.

Varsányi, I., Matray, J.M. & Kovács, L. Ó., 1997. *Geochemistry of formation waters in the Pannonian Basin (southeast Hungary),* Chemical Geology Volume 140, Issues 1–2:89–106. PII:S0009-2541 97 00045-4.

Vukoje, M.S., 2001. *Water Supply in Zrenjanin* (in Serbia). Yugoslav Association of Water Supply and Sewerage, vol. 52, pp. 87-90 [in Serbian].

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