Геолошки анали Балканскога полуострва Annales Géologiques de la Péninsule Balkanique	76	85–91	Београд, децембар 2015 Belgrade, December 2015

DOI: 10.2298/GABP1576085P

Impact of river bank filtration on alluvial groundwater quality: a case study of the Velika Morava River in central Serbia

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Abstract. Alluvial aquifers are preferred sites for drinking water production. Riverbed sediments and saturated alluvial sediments have great potential for groundwater purification which is essential for preserving the stability of the groundwater quality. Conducted research in the area of groundwater source Brzan in central Serbia showed that intergranular aquifer has potential not only to purify polluted surface water but also to enrich water quality. Main aquifer recharge is infiltration of surface water from the Velika Morava River. The quality of surface water is very variable, especially for some components such as turbidity, conductivity, $KMnO_4$ consumption, and iron, chloride and nitrates content. On the other hand, the quality of groundwater is characterised with minimal oscillation particularly regarding mentioned components. Based on numerous results on surface and groundwater quality we can conclude that water from the groundwater source Brzan is with good quality and can be used for drinking consumption with minimal treatment despite the fact that aquifer is in strong hydraulic connection with the Velika Morava River. Improvement of water quality is result manly of water filtration through river bad sediments and aquifer body.

Key words: River bank filtration, Alluvium, Groundwater recharge, Groundwater quality, the Velika Morava River.

Апстракт. Алувијалне издани се у свету најчешће користе за водоснабдевање становништва. Самопречишћавање подземних вода у алувијалним седиментима речног корита и обале има велики значај у очувању стабилности квалитета подземних вода које се добијају из ових средина. Спроведена хидрогеолошка истраживања на изворишту Брзан у централној Србији су показала способност интергрануларне издани да речну воду не само пречисти него јој и побољша квалитет. Прихрањивање овог изворишта се врши на рачун инфилтрације речне воде из Велике Мораве. Док су површинске воде променљивог квалитета, посебно у погледу мутноће, проводљивости, утрошка $KMnO_4$, садржаја јона гвожђа, хлорида и нитрата, квалитет подземних вода акумулираних у интергрануларној издани је са минималним осцилацијама поготово у садржају поменутих компоненти. Извориште Брзан се одликује подземним водама доброг квалитета које се уз минималан третман дистрибуирају крајњим потрошачима, упркос томе што се налази под јаким хидрауличким утицајем Велике Мораве захваљујући изузетној способности издани да побољша квалитет подземне воде.

Кључне речи: филтрација кроз обалске и седименте речног корита, алувијални седименти, прихрањивање подземних вода, квалитет подземних вода, Велика Морава.

Introduction

In many countries worldwide, alluvial aquifers which are hydraulically connected to watercourses are preferred sites for drinking water production. These aquifers are relatively easy to exploit, generally highly productive and located close to the consumers. However, because of their location, their shallowness and their close relationship with the water course, these aquifers are particularly sensitive to pollutants (Doussan *et al*. 1997).

River bank filtration (RBF) is a simple technology for surface water treatment which has been widely applied along major rivers throughout Europe for

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many decades. For example, 30–60 % of the population in Germany, Hungary and Serbia consume drinking water which originates from RBF (STAUDER *et al*. 2012). One example is the city of Berlin (Germany) where the public water supply strongly depends on bank filtration and groundwater precipitation recharge. Nearly 70% of the 220 million m^3/year of exploited water rely on the recharge processes (56% from bank filtration and 14% from precipitation recharge). Surface water is not directly tapped for water supply of city of Berlin, even though there are several proximate rivers and lakes (GRÜNHEID *et al*. 2005). This approach has been increasingly being applied in USA and Asia recently (RAY *et al*. 2002; JHA *et al.* 2009; CHANG *et al*. 2011).

period of deterioration of the river water quality will not harm the quality of alluvial aquifer (SONTHEIMER 1991; MÄLZER *et al*. 2002; RAY 2004).

Effects of the RBF are well explained on the example of groundwater recharge of Velika Morava alluvial aquifer. The groundwater source "Morava-Brzan" is located on the left bank of the broad alluvial plain of the Velika Morava River (Fig. 1), upstream of the confluence with the Lepenica River at one of the meanders that the Velika Morava River creates right after leaving the Bagrdan gorge. The water supply system is based on tapping groundwater from the alluvial deposits of the Velika Morava River. It was built in 1970's and immediately incorporated in Kragujevac city water supply system (PETROVIĆ & ŽIVANOVIĆ 2014). A total

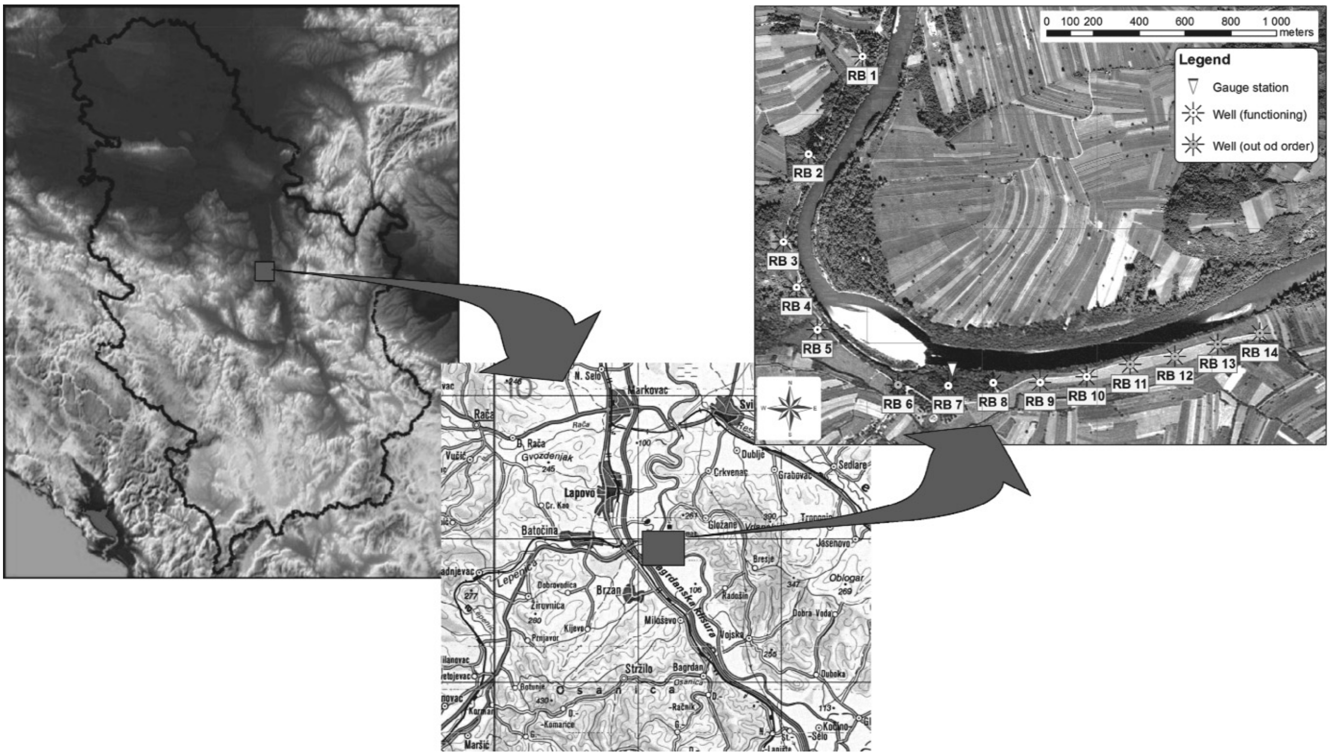

Fig. 1. Geographical location of the groundwater source "Morava-Brzan" and positions of the wells within.

River bank filtration is based on the natural biological and sorptive cleaning powers of the sediment and on the high efficiency in removing diffuse pollutants (e.g. organics and pathogenic microorganism) from waste water discharge (HISCOCK & GRISCHEK 2002; GRÜNHEID *et al*. 2005; DIMKIC *et al*. 2007). Moreover, RBF serves as an efficient barrier against many substances which can be accidentally discharged into a river for a short period ("shock load"). Other important issue is that water tapped from an RBF-well is a mixture of drained river water and present groundwater which flows much longer (weeks, months, years). A shock load usually lasts for 1–3 days and can result in shutting down the river water treatment plant until the pollution passes. On the other hand, such brief

number of 14 radial wells (RB-1 up to RB-14) were built on the concave bank of the river in the period from 1970 to 1976 (STOJADINOVIĆ 1997). Although wells were designed and built with the intent to deliver more than 400 l/s in total, during the period of investigation and in the earlier period of the system operating they rarely reached a total capacity greater than 150 l/s (PETROVIĆ & ŽIVANOVIĆ 2014). One of the reasons for such low level of exploitability of the water supply system is that 5 wells are idle for more than 15 years.

The Velika Morava Valley is open to the north and is under influence of the continental climate. Summers are hot and dry, winters are cold with precipitation in the form of snow and rarely rain. The hilly and mountainous terrains of the catchment area of the Velika Morava River made of low permeable rocks with small retardation capacity causing significant river flow variations in correlation to the amount of rain.

The composition of the plain, from hydrogeological point of view, can be divided into 3 major layers (Fig. 2): a. clayey overlaying sediments with thickness of 4–6 m (alluvial deposits); b. aquifer layer with thickness of 5–10 m (mean 6 m), mainly composed of gravel and sand (alluvial deposits); and c. bottom low permeable layer (aquitard) at a depth of 13–16 m below ground surface. The low permeable layer consists of Neogene clay sediments in the middle area of the groundwater source, and of Palaeozoic schists in the upstream and downstream part of the groundwater source (Fig. 3).

in this period. River levels were measured at staff gauge located in the area of the groundwater source. The measurements were conducted on daily bases. Groundwater level at all wells and piezometers (34 measuring points) were manually measured on a weekly basis. One well (RB-9) and one piezometer (P-11N) were selected for installing data loggers (Schlumberger Mini-Diver) for continuous water level measurements.

Influence of climate parameters was analysed using climate data from nearby state meteorological station Bagrdan-Vojska. Rainfall and temperature data were obtained for each day during the research period.

Water quality of the Velika Morava River and groundwater from the alluvial aquifer was monitored by conducting series of chemical analyses that included following parameters: water temperature, turbidity,

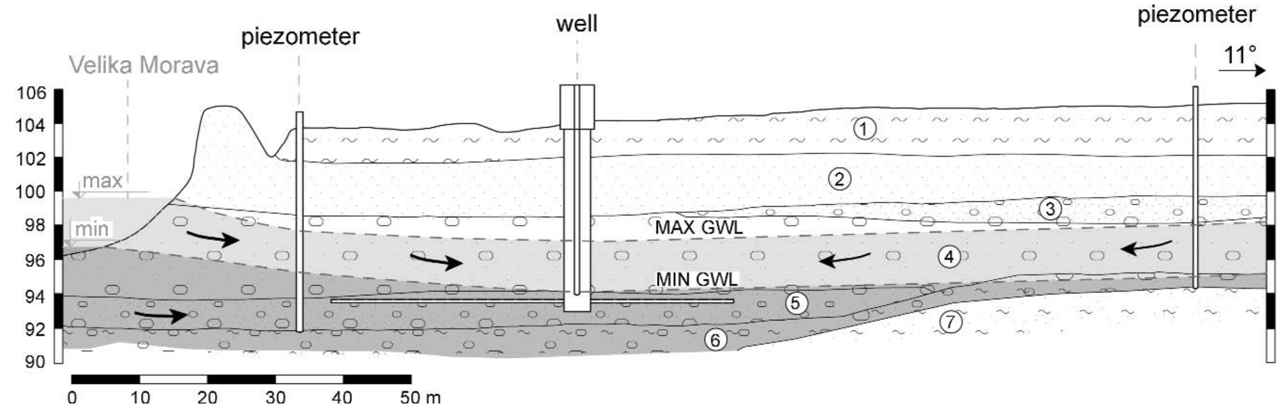

Fig. 2. Hydrogeological profile across the “Morava-Brzan” groundwater source. Legend: **1,** clay – overlaying alluvial sediments; **2,** sand – alluvial sediments; **3,** sandy gravel – alluvial flood facies; **4,** gravel – alluvial facies of river bed; **5,** sandy gravel – alluvial lower facies of river bed; **6,** gravel and sand with clay – alluvial facies of river bed; **7,** silty-sandy clay – Neogene sediments.

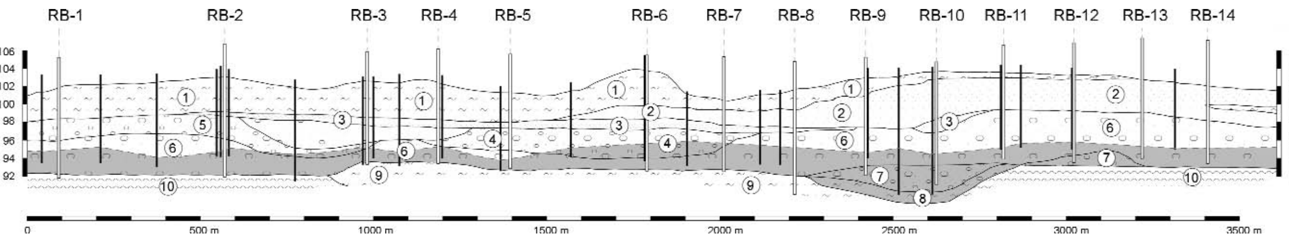

Fig. 3. Hydrogeological profile along the “Morava-Brzan” groundwater source. Legend: **1,** clay – overlaying alluvial sediments; **2,** sand – alluvial sediments; **3,** sandy gravel – alluvial flood facies; **4,** gravel – alluvial facies of river bed; **5,** sandy gravel – alluvial flood facies; **6,** gravel – alluvial facies of river bed; **7,** sandy gravel – alluvial lower facies of river bed; **8,** gravel and sand with clay – alluvial facies of river bed; **9,** silty-sandy clay – Neogene sediments; **10,** Palaeozoic shale.

Methods

Groundwater regime of alluvial aquifer and surface water regime of the Velika Morava River were monitored in the period Nov. 2011 – Jan. 2013. Changes of groundwater and surface water levels were observed

colour, pH, specific conductivity, hardness, dissolved cations (Na^+ , K^+ , Mg^{2+} , Ca^{2+}, Fe^{2+}or Fe^{3+}, Mn^{2+}, Al^{3+}, etc.) and anions (Cl^-, F^-, I^-, Br^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, NO_3^-, NO_2^-), metals that act like cations mostly (Cu, Zn, Pb, Co, Ni, Cr, As, Se, Mo, etc.), nonmetals (HS^-, F^-, B, P, silica as SiO_2 etc.), consumption of $KMnO_4$, dissolved gases (oxygen, carbon-dioxide, hydrogen sulphide, ammonia), phenolic compounds, anionic detergents, residual chlorine, mineral oil, polycyclic aromatic hydrocarbons, cyanide, etc. Water samples were also microbiologically analysed to detect and count aromatic hydrocarbons the total coliform and E. coli as well as faecal streptococci, aerobic mesophilic bacteria, Proteus spec., etc.

Groundwater and Velika Morava River water samples were analysed periodically, once per month by representatives of Water Supply System of Kragujevac city. Water sampling and analyses were also conducted by representatives of Institute of Public Health in Kragujevac city periodically, once in two months during the research period. Parameter list for these analyses was reduced and only main parameters of water quality and health indicators were monitored. Institute of Chemistry, Technology and Metallurgy of the University of Belgrade conducted analysis of water samples from "Morava-Brzan" groundwater source, for each season (spring, summer, autumn, winter), in order to get a full picture of groundwater quality during seasonal changes. Obtained results were used to analyse quantitative and qualitative regime of alluvial aquifer as well as the Velika Morava River.

Results and conclusions

Hydraulic connection of alluvial aquifer and the Velika Morava River has been proven by observation of water stage of the river and groundwater level during the period of research (Fig. 4). The regime of quantity of groundwater showed large fluctuations and it is especially influenced by seasonal changes as well as periodical storm rain events. The synthesis of the collected data from the water supply system: the capacity of wells, groundwater levels (GWL), correlations of GWL and the precipitation and the impact of the Velika Morava River on the GWL helps us to conclude that quantity of water in aquifer the most depends of water stage of the river. However, we cannot exclude influence of precipitation during low water stage (especially storm events) and influence of quantity of groundwater that infiltrates from surrounding aquifers.

A comparative analysis of total monthly precipitation and fluctuations of groundwater levels in wells at the "Morava-Brzan" could not find any direct functional dependency between rainfall and groundwater levels. The amount and timing of rainfall have no direct effect on the capacity of the water supply system. As a result, the amount of tapped water is about 100 l/s even during the summer and autumn months, when smallest amounts of precipitation occur. On the other hand, diagram at figure 5 shows strong correlation between the river stage and observed groundwater level. Therefore we can conclude that the groundwater level depends, on three factors: the pumping capacity of the source and the flow of the Velika Morava River and to some point on amount of rainfall (Petrović & Živanović 2014).

In accordance with the foregoing, it can be noticed that the regime of groundwater depend on direct contact with the Velika Morava River all the time, and coming under greater influence of rainfall in part of the periods when the river does not have enough water to recharge aquifer. Then the GWL increases only in short intervals, after storm rainfall events (daily rainfall of 20 mm or more). Capacity of wells, and thus the whole water supply system, directly and significantly affects the condition of GWL only in the period when the water level in the Velika Morava River stagnates and precipitation is decreased or absent, as in the case of the end of July 2012 to mid-October 2012 (Fig. 4).

Based on data obtained from the water quality analysis, we can conclude that the groundwater in the alluvium of the Velika Morava River tapped by the water supply system "Morava-Brzan" has a good and constant quality. Unlike groundwater quality, quality of water in the Velika Morava River varies greatly during the year (Petrović & Živanović 2014). The water in the Velika Morava River is characterized by fluctuations in the physical and chemical composition, under the influence of the condition of river and rainfall. Noticeable changes beside the obvious parameters (turbidity and water temperature) suffered electrical conductivity, consumption of $KMnO_4$, total iron concentration, concentration of chloride and nitrate ions.

Values of electrical conductivity of groundwater are inversely dependent of the flow of the Velika Morava River and amount of precipitation. Values of electrical conductivity of river water are two times lower than those recorded in the groundwater (Fig. 5). Based on the changes of this parameter, with a certain probability, we can conclude that the water exchange is quick and happens in few days or weeks, depending on the season. During the periods of intense infiltration the conductivity decreases which is especially noticeable in late spring, when a wave of high water level of the river passes due to melting of snow and heavy spring rains in the upper reaches and tributaries component of the Velika Morava River. Values of electrical conductivity of the groundwater at that time decrease more than 200 μS/cm in comparison to the "low water" periods when we can see a twofold increase in the quantity of dissolved substances in groundwater, due to its long stay in contact with the particles of aquifer.

Consumption of $KMnO_4$ can only be considered as a conditional criterion of amount of organic matter in the water. The content of organic matter in the groundwater reached equilibrium and there is no significant impact of the external factors. On the other side same parameter in the river water varies depending on the flow with lowest values during the winter

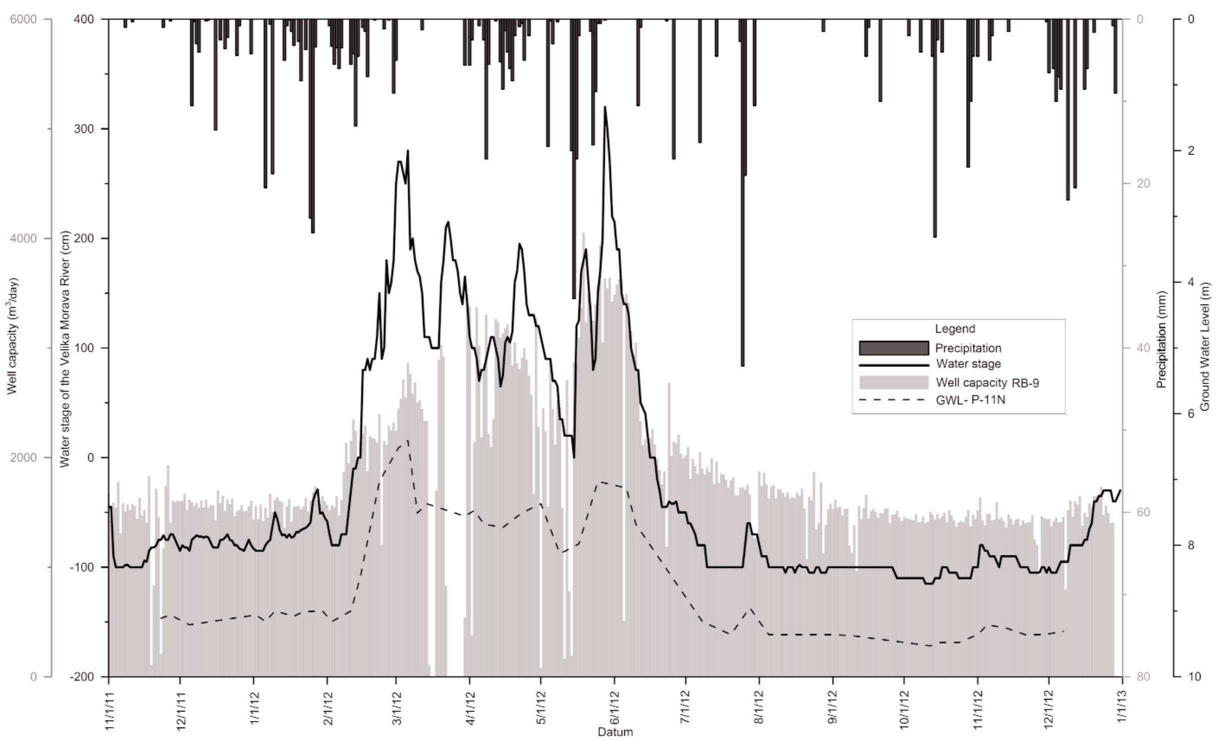

Fig. 4. Diagram of precipitation, water stage of the river, capacity of RB-9 well and GWL in piezometer P-11N.

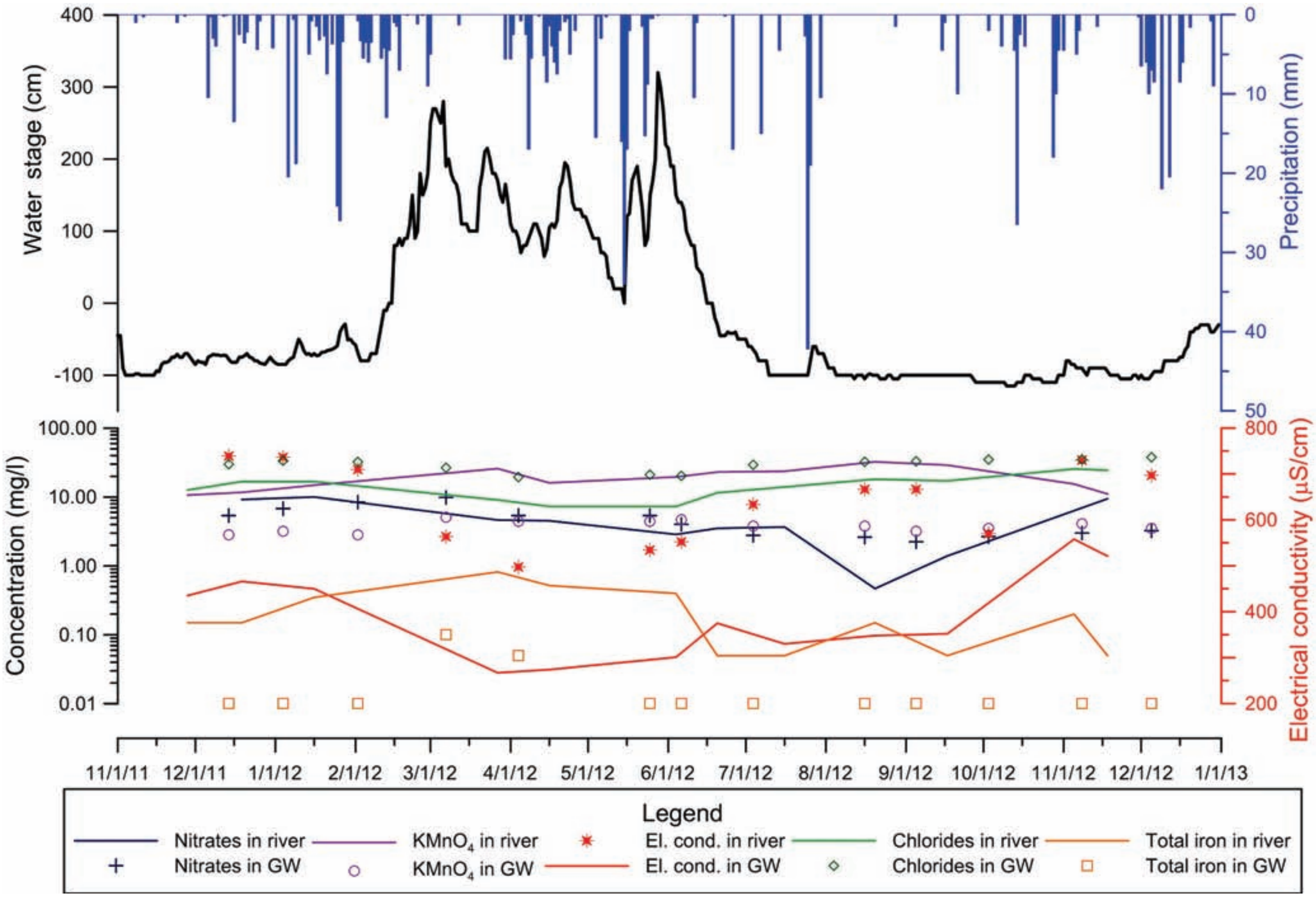

Fig. 5. Diagram of chemical parameters of groundwater and water from the Velika Morava River, compared to precipitation and water stage.

when river water level reaches the minimum value (Fig. 5).

One can notice two “peaks” of recorded concentrations of total iron, the first at a time of high water and the second at time of low water levels of the Velika Morava River (Fig. 5). However, none of them exceeding the maximum permissible concentration for groundwater (GAZETTE SRY 1998). Here we point out the existence of a great “mechanism of purification” of water that was formed within the aquifer (STAUDER *et al.* 2012). The increase in the concentration of iron in groundwater during high water is due to increased infiltration of river water into the aquifer, which in this period contains higher concentrations of ferrous ions from the upper reaches of the constituents. On the other hand, the concentration of Fe^{2+} ions in a period of low water has increased due to the general decrease in the amount of water in the aquifer and the river, and slower movement through the intergranular aquifer and longer time of contact with the particles containing ferrous ions.

The concentration of chloride ions in the analysed samples of groundwater is inversely proportional to the water level and the amount of precipitation, and in surface water it is half the concentration of ions in groundwater, observed during the same period (Fig. 5). This difference is due to the dissolution of mineral matter from the environment (sandy-gravel sediments, with a significant presence of dust and clay fractions), in which groundwater reside.

Concentration of nitrate ions in groundwater shows a certain dependence on the amount of infiltrated water (Fig. 5). There is certain causality, but also the period of delay in response to increase of the amount of rainfall and water levels in the river, in the period February–March, when the concentration of NO_3^- ions decreases due to the increase in the amount of infiltrating water. However, when it comes to the stabilization of flow of the Velika Morava River and the amount of rainfall, decreasing trend of nitrate concentration is maintained until September, when again there is an increase in the concentration of nitrate. The nitrate concentration in groundwater and surface water, which are analysed, do not exceed permissible levels. This data also imply the existence of good protection of overlaying layer of aquifer and excellent autopurification mechanisms of river, because despite the expressed agricultural activities in the Velika Morava River area and in the upstream areas of the catchment of the river and its tributaries, there is no significant burden of water by nitrates.

Stability of regime of groundwater quality in the observed aquifer formed in the alluvium of the Velika Morava River indicates excellent rejuvenating properties of the environment and it is of great importance for use of this resource for municipal water supply. We must emphasize the fact that despite the huge hydraulic impact that river has, the environment was able to create specific conditions for the creation and maintaining of a groundwater quality, which remains beyond the reach of lower-quality of surface water.

Acknowledgments

The authors would like to thank VLADAN RADULOVIĆ (Serbia) for his editorial support, IULIAN POPA (Romania) and JÁNOS SZANYI (Hungary) for reviewing the paper. This research was supported by the Ministry of Education, Science and Technological Development (as a part of the Projects No. 176022 and No. 43004) and Ministry of Environment, Mining and Spatial Planning (grant to B.Z.P and V.J.Ž).

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Резиме

Утицај филтрације кроз седименте речне обале и корита на квалитет алувијалних подземних вода: пример реке Велике Мораве у централној Србији

Алувијалне издани се у свету најчешће користе за водоснабдевање становништва, али су истовремено и јако изложене потенцијалном загађењу. Самопречишћавање подземних вода у изданској зони има велики значај у очувању стабилности квалитета подземних вода које се добијају из збијене издани формиране у алувијалним седиментима. Спроведена хидрогеолошка истраживања на изворишту „Морава-Брзан" у централној Србији (сл. 1) су показала способност интергрануларне издани да речну воду не само пречисти него јој и побољша квалитет. Извориште је лоцирано на левој обали реке Велике Мораве, неколико километара узводно од уливања реке Лепенице. Настало је 70-тих година XX века, када је израђено 14 бунара са хоризонталним дреновима. Континентална клима подручја заједно са геолошким условима унутар слива Велике Мораве изазива велике промене водостаја током године. Са хидрогеолошког аспекта, речну долину у области истраживања можемо поделити у 3 велика слоја (сл. 2 и 3): 1. глиновити седименти „кровине" дебљине 4–6 метара; 2. шљунковити и песковити седименти збијене издани дебљине 5–10 метара; и 3. „подина" издани, на дубини 13–16 метара, састављена од слабо пропусних и непропусних неогених седимената у средишњем делу изворишта и непропусних палеозојских шкриљаца у узводном и низводном делу изворишта. Истраживања на подручју изворишта спроведена су од новембра 2011. године до јануара 2013. године. Извршена су осматрања нивоа подземних вода (НПВ), водостаја реке и количина падавина. Прихрањивање овог изворишта се врши на рачун инфилтрације речне воде из Велике Мораве, делимично из суседних издани и инфилтрацијом падавина (пре свега током лета, када је водостај реке низак) (сл. 4). Можемо да закључимо да је НПВ збијене издани формиране у алувијалним седиментима Велике Мораве под значајним утицајем водостаја реке, али да у периодима ниског водостаја долази под утицај инфилтрираних падавина и утицај НПВ суседних издани. У наведеном периоду вршен је мониторинг квалитета изданских вода и речне воде, лабораторије ЈКП „Водовод и канализација" и Института за јавног здравља, оба из Крагујевца, су пратили параметре санитарне исправности на месечном тј. двомесечном нивоу, док су стручњаци Института за хемију, технологију и металургију (ИХТМ) израдили комплетне анализе у оквиру сваког годишњег доба. Површинске воде су изузетно промењивог квалитета (Сл. 5), посебно у погледу мутноће и електричне проводљивости, али и утрошка $KMnO_4$, садржаја јона гвожђа (Fe^{2+}), хлорида (Cl^-) и нитрата (NO_3^-), а квалитет подземних вода акумулираних у интергрануларној издани је са минималним осцилацијама концентрација поменутих компоненти. Уколико посматрамо вредности електричне проводљивости у реци и у издани можемо закључити да је водозамена брза и одиграва се у оквиру неколико дана (евентуално недеља), и зависи само од годишњег доба. Што се тиче промена осталих наведених параметара морамо нагласити да су варијације током посматраног периода у речној води лако уочљиве. Промене концентрација издвојених параметара у подземној води постоје али су под контролом средине у којој је издан формирана, стога су варијације мале, и никада не прелазе максимално дозвољене концентрације прописане правилником. Стабилност режима квалитета подземних вода изворишта „Морава-Брзан", упркос томе што се извориште налази под јаким хидрауличким утицајем Велике Мораве одржава се захваљујући изузетној способности издани да „пречисти и побољша" квалитет инфилтриране воде. Самопречишћавајућа својства издани омогућавају да се подземна вода само уз минималан третман (филтрирање и хлорисање) дистрибуира крајњим потрошачима.