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ORIGINAL ARTICLE

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Management of karst aquifers in Serbia for water supply

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Abstract Karst aquifers represent one of the main sources of water supply in Serbia. Wide distributions of karstic areas, abundant reserves, and excellent quality of karst groundwater have been the reasons for its extensive use in water supply systems throughout the country. In Serbia, 70 karstic sources have been tapped for centralized water supply, with the assessed minimal capacity exceeding 4.5 m^3/s. Most of the large cities of Eastern and Western Serbia currently use karst groundwater for water supply; however, due to unstable flow regime when only natural springflow is tapped, numerous problems arise during the recession period (summer–autumn). During the last two decades, after favorable conditions had been confirmed through hydrogeological survey and feasibility studies, several newly constructed systems for artificial control of karst aquifers (mostly in Eastern Serbia) resulted in significantly improved water supply.

Keywords Karst aquifer · Regime control · Water supply · Serbia

Introduction

Over 80% of Serbian population and industry use groundwater for water supply. The main aquifer systems are formed in alluvial deposits and highly karstified carbonate rocks. The latter has wide distribution in the Carpatho-Balkan mountain arch (Eastern Serbia) and in Dinaric mountain system (Western Serbia). The abundant reserves, excellent quality of water found in karst aquifers, as well as prevailing inexpensive gravity distribution systems have been the reasons for its mass exploitation throughout Serbia (Stevanović 1995). Their expansion particularly started after WW II. Until now, about 70 karstic sources with the total minimal capacity exceeding 4.5 m^3/s have been tapped and used for water supply of numerous large cities and industrial centers (Niš, Bor, Pirot, Paraćin, Ćuprija, Valjevo, Novi Pazar, Prijepolje, Pec, Priboj, etc.). This number does not include the tapped springs for villages, smaller settlements, and factories.

The main problem in water supply in Serbia is water shortage during the recession period (summer–autumn) caused by small discharge from karstic aquifers. That period coincides with highest consumer water demand. Despite the fact that the total dynamic reserves in karst often surpass by far the exploitation capacities, most of the constructed intake structures simply tap natural discharge of the springs and thus depend solely on natural flow regime (Fig. 1).

Applied methodology

Hydrogeological surveys and feasibility studies undertaken during the last two decades made it possible to identify favorable conditions for artificial control of karst aquifers in numerous locations. On the basis of these results, several systems were constructed mostly in the region of Eastern Serbia with a great success. The methodology applied regularly included the following:

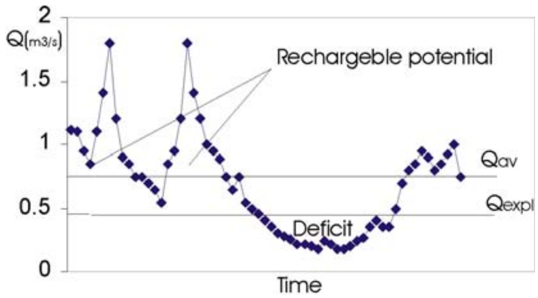

Fig. 1 Typical hydrogram of a karstic spring with potential exploitation capacity higher than natural minimal discharge

geological and hydrogeological mapping, remote sensing, geophysical survey (mainly geoelectrical methods such as resistivity or self potential), tracing tests, speleology, simultaneous hydrologic measurements, groundwater monitoring, exploratory drilling, wells testing, etc.

Understandably, not all of the existing karst sources can be regulated. In addition, any direct attempt at their control is bound to fail without a prior extensive research. The knowledge of karst aquifer characteristics is of key importance—in particular the discharge regime, position of karstification base and karstification intensity, including aquifer permeability. The artificial control requires deeper karstification and existence of geological groundwater reserves. Preferably, the spring should be of ascending type while contact of the karst and non-karst strata should represent a relative barrier only (i.e., made of permeable rocks to allow underground discharge). A control of karst aquifer should entail applying a series of artificial interventions within the aquifer, particularly in the discharge zone, with the aim of counterbalancing the regime, or rather equalizing the quantitative and qualitative groundwater features (Stevanović 1995). The appropriate type of water intake depends on specific circumstances but the application of large-diameter drilling wells has so far yielded the best results in Serbia. In the case of ascending vauclusian springs, it is also possible to install pumps into siphon channels. Pumping and drawdown may, when necessary, ensure additional inflow (Avias 1984; Stevanović et al. 1994; Soro et al. 1999). From the aforementioned it may be inferred that any water intake structure that aims at creating physical conditions necessary for exploiting the water reserves below discharge points, and thus leading to change in the natural regime, can be seen as an artificial intervention, the purpose of which is aquifer control. This is, therefore, an application which the standard intake structures do not permit.

Eventually, successful regulation of a karst aquifer has analogous effects with managing water resources of a surface reservoir. The aim is to take in the necessary water volume during a limited time period by counting on water replenishment during the next wet season (Fig. 2). Such an approach always requires sensitive analysis of available resources and sustainable water management measures (Jemcov and Stevanović 2004). In many cases, particularly in arid areas, mismanagement and uncontrolled groundwater pumping directly led to overexploitation.

The climatic and hydrogeological preconditions in Serbia and this part of South-Eastern Europe are favorable for creating a significant replenishment potential. The mean karst groundwater flow modulus is 5.6 l/s/km^2 for Carpatho-Balkanides (Stevanović and

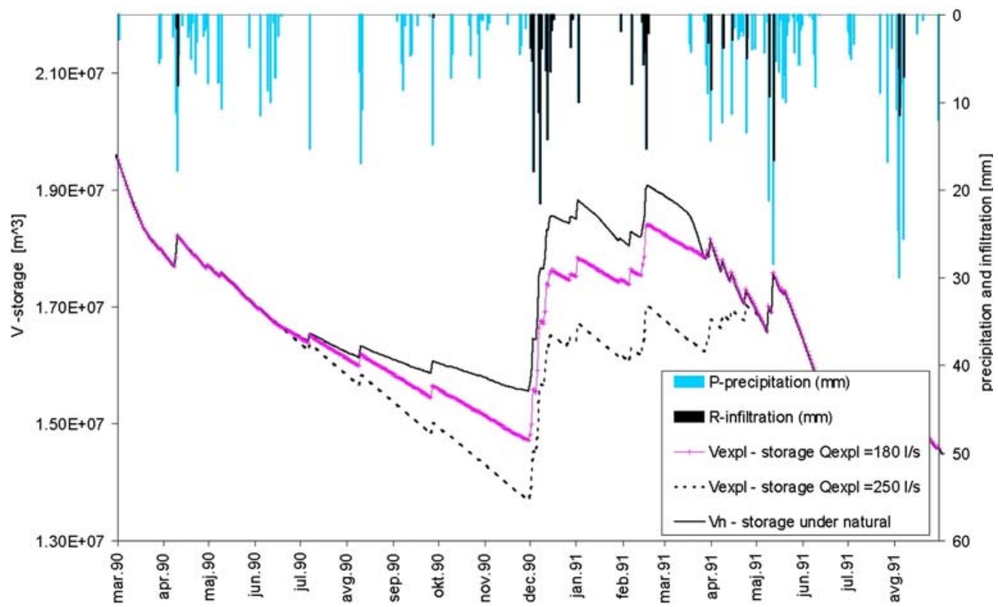

Fig. 2 Simulated exploitation rates of St. Petka spring

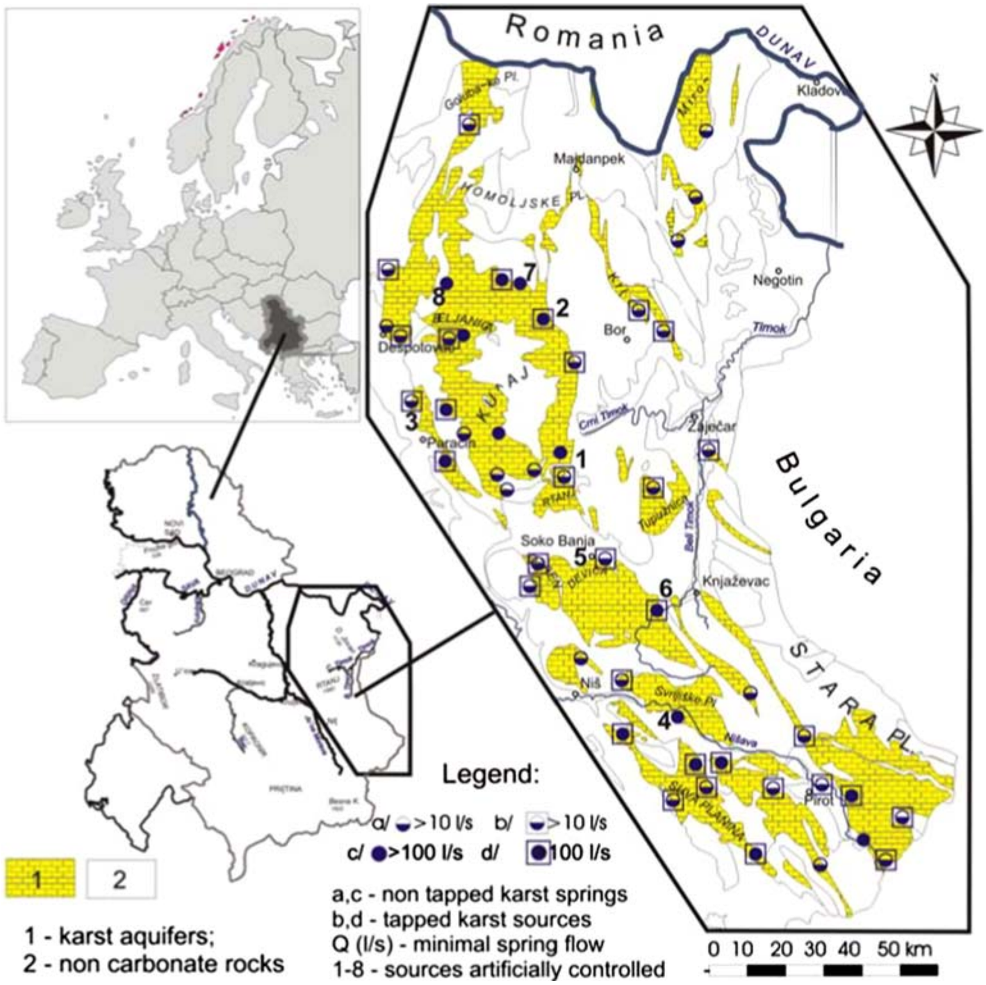

Fig. 3 Karstic aquifer of Carpatho-Balkanides (Eastern Serbia)—distribution and main sources

Filipović 1994), and 5.5–17.0 l/s/km^2 for certain regional aquifers in Serbian Dinarides. The difference between the total dynamic resources and summarized minimal springflow as an objectively exploitable part of water potential is 12.6 m^3/s and 14.6 m^3/s in Carpatho-Balkanides (Fig. 3) and Dinarides, respectively.

Eventually, overpumping could be applied wherever physically possible to ensure sufficient water volume in critical dry periods, when ‘‘loan’’ of geological reserves is presumed to be compensated soon after, i.e., within the same or the following hydrologic cycle.

Case examples

The last two decades have witnessed incessant dilemmas, even disputes, between Serbian water management experts, particularly hydro-technicians and hydrogeologists, concerning the future role of groundwater in water supply. The extreme claims that groundwater is scarce, exploitation systems unreliable, and the quality unstable, etc., have been reflected in earlier governmental schemes proposing almost complete substitution of groundwater by surface waters from large reservoirs. Lately, owing chiefly to the lack of funds and difficult economic situation, this ‘‘mega’’ concept has been mostly abandoned and a more rational option of building surface reservoirs where truly necessary (Central part of territory), and increasing the capacities of the existing and opening new groundwater-based sources is being increasingly embraced in practice.

The largest system for aquifer control is constructed as a ‘‘transitional solution’’ and part of the regional water system ‘‘Bogovina’’ (no. 1, Fig. 3) that should supply the towns of the Timok region (Bor, Zaječar, Negotin, and Boljevac). During 1991–1998, extensive hydrogeological investigations have been undertaken in south-east Kučaj. The greatest part of the catchment area of ca. 100 km^2 consists of karstified Lower Cretaceous limestone, through which drains the permanent ascending spring Mrljiš (Q = 80–1,000 l/s), a few smaller springs and underground discharge into the riverbed of the Crni Timok River, which represents the regional erosion level of the entire karst aquifer.

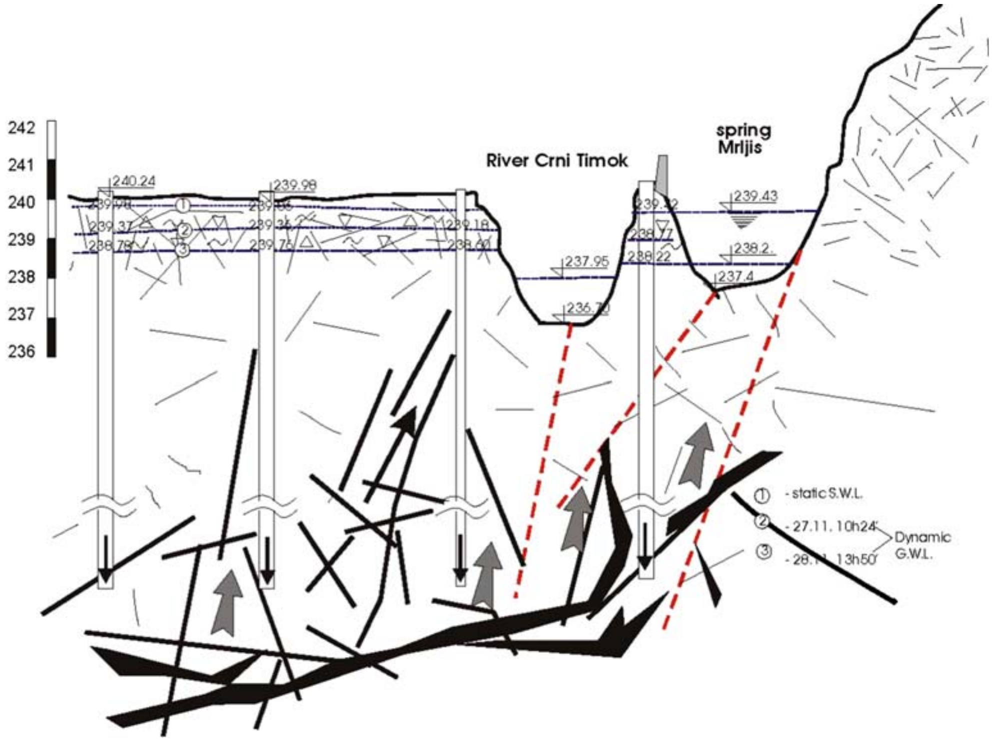

Fig. 4 Cross-section of Mrljis karst spring and drawdown of exploitation wells

During July 1992 (mean-low flow period) a pumping test lasting several days was performed at the Mrljiš spring. Prior to pumping, natural springflow had been 172 l/s, while through pumping discharge of 325 l/s was constantly maintained (Stevanović et al. 1994). The level at the discharging siphon of the spring was depressed by 2 m and in the nearest observation wells only by ca. 1 m. During this test, a tracing of the Crni Timok River was also conducted to investigate possible hydraulic connections of groundwater and surface water in the river, but throughout pumping no tracers were identified in the spring. This confirmed deep groundwater circulation, large reserves and drainage towards the riverbed, but not in the opposite direction. On the basis of these indications, geophysical survey and exploratory drilling have been conducted, and several favorable locations for the 100 m deep wells identified (Stevanović and Dragišić 1998).

Finally, four exploitation wells were constructed (Fig. 4). Several pumping tests verified their capacities ranking from 50 to 110 l/s (Stevanović and Dragišić 1997). An amount of 240–320 l/s was pumped out during the simultaneous test of all wells, producing a depression in the Mrljiš spring zone of less than 2 m (low flow water period). Optimal extraction rate of the source, as compared to the minimal springflow of Mrljiš, has increased almost fourfold. Following the request for sustainable water management, the monitoring system of the Crni Timok River has been established to prevent disturbance of the natural riverflow during the low flow period.

Similarly, hydrogeological research undertaken in the Zlot and Beljevina karstic valleys (no. 2, NE Kučaj) enabled to locate several highly productive wells which were between 80 and 120 m deep. Pumping these wells doubled the natural minimum flow of the springs tapped for the large industrial and mining center Bor (Stevanović et al. 1993).

The catchment area of the "Nemanja" karstic springs (no. 3) belongs to Ravanica limestones zone (the Velika Morava basin). Three springs that drain the same aquifer were tapped for the Ćuprija waterworks. Their small discharges within dry seasons, as well as increased water turbidity and bacteriological contamination after snow melting and intensive rainfalls, were the main problems in exploitation (Stevanović et al. 1998). Two recently drilled 80 m deep water wells ($Q \sim$ 15–25 l/s) provide an opportunity to pump more and better quality groundwater. All these findings have been confirmed through pumping tests and water balance analyses.

"Modro oko" in Krupac (no. 4) village is one of the five karstic springs tapped for the water supply of Niš, the second largest town of Serbia. It drains the southern part of Svljiške Planine Mountains ($>$ 100 km^2), and is characterized by high discharge variation $\sim$ 40–11,000 l/s. Aqua-speleological exploration of deep siphonal channels enabled the installation of high capacity pumps and performance of a longer pumping test. On the basis of the results, the pumping rate of 250 l/s is assumed to be adequate for continual extraction during periods of low flow regime. This amount of water, six times higher than extreme minimal natural springflow, should be easily replenished by a new recharge (Soro et al. 1999).

Sokobanja (no. 5) is one of the largest spas of Eastern Serbia. The problems of water shortage during summer season and mixing of thermal and fresh groundwater were the main limits for its further touristic expansion. A recently drilled deep well ($Q \sim 50$ l/s with insignificant drawdown), at the northern edge of Ozren karstic massif in the vicinity of Lepterija springs, offered a new perspective in the water supply and development.

The ascending spring Sinji Vir (no. 6) on the right bank of the Svrljiški Timok is tapped for the town of Knjaževac. The spring is distinguished by diffuse discharge through river sediments, which has been confirmed by the results of simultaneous measurements of the Timok riverflow. The investigations of the ''Geozavod''—Belgrade have defined the position of the main drainage zone, while a newly constructed intake is preventing mixing of water from the river and the aquifer/spring. This intervention has rendered possible water pumping and continual exploitation of around 200 l/s (doubled natural minimal yield).

Around 80 km South of Belgrade Nepričava system is operated to supply the Lazarevac mining center. A system of deep wells taps a water-bearing horizon in Triassic limestones underlying the alluvial and Neogene deposits at an average depth of 150 m (Mijatović 1994). Several wells have potential capacity exceeding 50 l/s, but regional drawdown occurred due to limited natural infiltration rate. An artificial recharge system has been suggested through water injection wells in the upstream part of the catchment.

Regional hydrogeological exploration has identified many other groundwater sources in Serbia with a good potential and opportunities for application of similar aquifer control measures. There are also very important data obtained by recent deep aqua-speleological exploration of some large discharging springs, e.g., Mlava—no. 7, Krupaja—no. 8 (Milanović 2004) (Fig. 5). In the case of vauclusian springs Mlava and Krupaja, which are over 70 m deep, still undiscovered channels offer a good perspective and possibility to apply an earlier proposed solution for tapping and regulating this rich karstic aquifer for water supply for Belgrade and surrounding municipalities (Stevanović et al. 1986).

Monitoring of the systems built until now generally does not provide indications of significant drawdown or overexploitation; further expansion is still possible. But all this has to come as result of a new research effort. Controlled exploitation must be linked with proper water management in general.

Conclusion

Karstic groundwater of Serbia, although much exploited, has not been sufficiently investigated and fully understood so far. This is often the reason for the diminishment of its value and potential. Furthermore, in karst aquifers, usually only naturally discharged water quantities are tapped. As a result, a significant decrease of springflow occurs in the recession period, which leads to a water shortage in current exploitation systems. Certain successfully constructed systems and the results obtained in controlling karst aquifers that include various source types and discharge conditions recommend these methods for wider application in local water management practice.

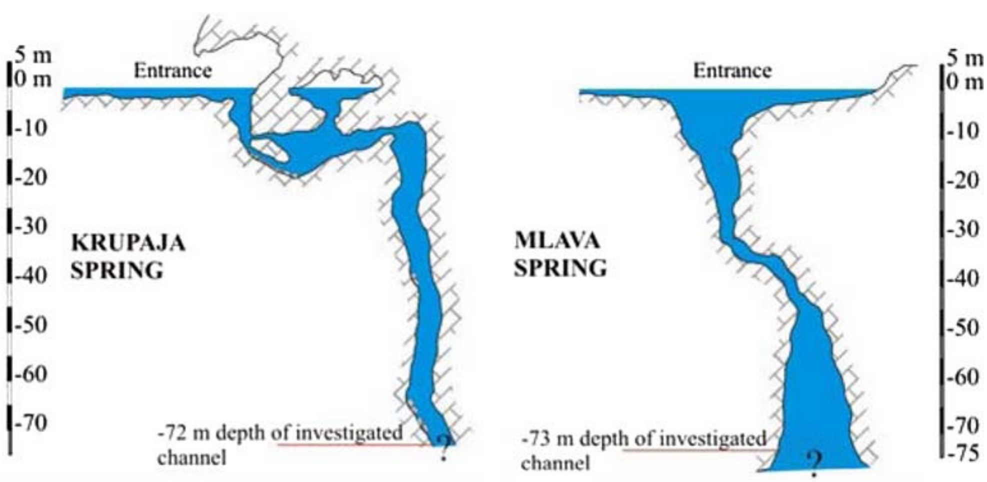

Fig. 5 Cross-sections of Krupaja and Mlava ascending springs (acc. to Milanovic diving explorations 2004)

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