Solutions for groundwater management in areas affected by high arsenic content: Vojvodina case study

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ABSTRACT

Drinking water supply in Vojvodina (Serbian part of the Pannonian Basin) depends entirely on groundwater resources, whose use in the past has led to problems reflected in insufficient water quantities and poor natural water quality. Quality parameters such as NOM, ammonia, methane, and boron, along with naturally high arsenic levels (in some parts in excess of 150 μg/l) in the groundwater, have become a serious health threat to the local population (DKMT, 2006). Increasing pressure on groundwater resources has already resulted in over-exploitation ("mining") of the aquifer, with the current rate of water extraction exceeding its sustainable yield. In order to provide sufficient quantities of high-quality drinking water, the opening of new renewable groundwater sources in the Danube alluvium is proposed. Field investigations and hydrodynamic analyses (NPV46B, 2006) have shown that sufficient quantities of groundwater can be provided from the Danube alluvium (Apatin-Bezdan and Kovin-Dubovac areas), and that the natural water quality is such that the application of basic treatment methods (aeration, retention, filtration and disinfection) will produce high-quality drinking water.

Key words: arsenic, alluvium, depletion, drinking water, Vojvodina

1. INTRODUCTION

Within the territory of Vojvodina (Serbia), public water supply predominantly relies on groundwater abstraction from the so-called "main" aquifer, in the southern part of the Neogene Pannonian Basin shared with Hungary, Romania and Croatia. Over-exploitation of groundwater in the past and insufficient groundwater recharge have resulted in aquifer depletion and lowering of groundwater levels, with every prospect that this trend will continue. Along with insufficient groundwater quantity, poor groundwater quality has become a growing problem for Vojvodina's 339 water supply systems. Quality parameters such as natural organic matter, ammonia, methane, and boron, along with naturally high arsenic levels (in some parts in excess of 150 μg/l) in groundwater, have resulted in a serious health threat to the local population (DKMT, 2006).

High concentrations of arsenic in groundwater are a common problem in all neighboring countries as well. In eastern Croatia, nearly 200.000 people drink water with arsenic concentrations ranging from 10 to 610 μg/l on a daily basis (Habuda-Stanic *et al.*, 2007). In Hungary and Romania, in the Maros Alluvial Fan and the Körös Basin, high arsenic concentrations trace to arsenic-bearing minerals, which erode and are transported to the basin not only from the Transylvanian Mountains (SUMANAS, 2008), but also from the catchment areas of the Danube, the Dráva and the Zagyva rivers (Csalagovits, 1999). Additionally, other chemical components such as iron, manganese, ammonia, organic material and methane trace to water-rock interactions involving subsurface flow over more than 10.000 years, according to environmental isotope studies (Deseo and Deak, 2007).

Numerous investigations have shown that long-term exposure to low arsenic concentrations in drinking water is a health hazard (WHO, 2001; UNICEF, 2006). Therefore, ensuring drinking water quality with regard to arsenic, consistent with WHO recommendations and the Drinking Water Directive 98/83/EC (As <10 μg/l), is a major challenge for the water supply industry in these countries. The Water Management Master Plan of the Republic of Serbia calls for the water supply problem of Vojvodina to be solved by forming regional water supply systems based on groundwater sources in the Danube and Sava alluvions, or by using existing local groundwater sources. For water supply in Banat and Backa, two zones have been identified as suitable locations for sources of considerable capacities: along an upstream stretch of the Danube (Apatin-Bezdan) and along a downstream stretch of the Danube (Kovin-Dubovac).

2. GROUNDWATER USE AND ARSENIC PROBLEM IN VOJVODINA

Over 2 million inhabitants and industry in Vojvodina use groundwater for their water supply, tapped from the aquifers formed at different depths, from 20 to more than 200 m. There are a large number of aquifers in water-bearing media of younger chrono-stratigraphic units – Quaternary and Pliocene, of which the most important for public water supply are:

- the "first" aquifers from the surface, in alluvial plains,
- the main aquifers formed within the basic water-bearing complex (so-called Main Water-bearing Complex, BWC), and
- the aquifers formed in Pliocene water-bearing media.

Nearly 70% of the groundwater abstracted in Vojvodina originates from deep, regional aquifers. The over-exploitation problem has been present in Bačka and Banat since the early 1980's, when the rate of abstraction for public and industrial water supply exceeded natural recharge of the BWC. The impact of over-exploitation is primarily seen in declining groundwater levels in the wider areas of groundwater sources (resulting in increasing abstraction costs), declining yield, and in some cases local land subsidence. Extreme drawdowns have been recorded in the wider zones of water sources; lowering of piezometric head over the past 3 decades is seen in northern Bačka and northern Banat (between 20 and 30 metres). A forecast of the effects of future groundwater abstraction at the current rate (roughly 4,5 m^3/s) or higher, showed that that there will be a further decline in groundwater levels, in some areas by several dozen meters (Jaroslav Cerni, 2000).

The quality of groundwater in Bačka, Banat and Srem is characterized by distinctive inequality, ranging from acceptable water quality to water that requires a high level of treatment. Groundwater chemistry in central Bačka is characterized by elevated concentrations of organic substances, arsenic, iron and manganese, while in the catchment area of the Tisa and in western Bačka (Odžaci), $KMnO_4$ demand is greater than 20 mg/l, and even as high as 100 mg/l (the prescribed limit value is 8 mg/l). Other characteristics of this groundwater include permanently elevated iron concentrations, sometimes as high as 3 mg/l, and the absence of manganese, nitrite and nitrate. Based on recorded values, there are several areas with extremely high arsenic concentrations (> 50 μg/l): northern, western and southern Backa, and northern and central Banat (Fig.1)(Table 1).

A relatively narrow zone between the towns of Zrenjanin and Žitište (central Banat), is characterized by highly-mineralized groundwater (in excess of 1200 mg/l), and high concentrations of iron (generally 0,4 but also above 2 mg/l), arsenic (up to 200 μg/l), and the ammonium ion (over 2 mg/l), as well as significantly high NOM levels in groundwater (with $KMnO_4$ demand occasionally exceeding 200 mg/l). Over the past decade, major efforts were made (especially in the Town of Zrenjanin) to find a suitable technology for the treatment of this groundwater; 9 pilot plants were installed and tested but the results were not satisfactory. A highly complex technology (aeration, flocculation/sedimentation, ozonation, multilayer filtration and disinfection, and in some cases reverse osmosis) is required to treat this groundwater (Stauder, 2007).

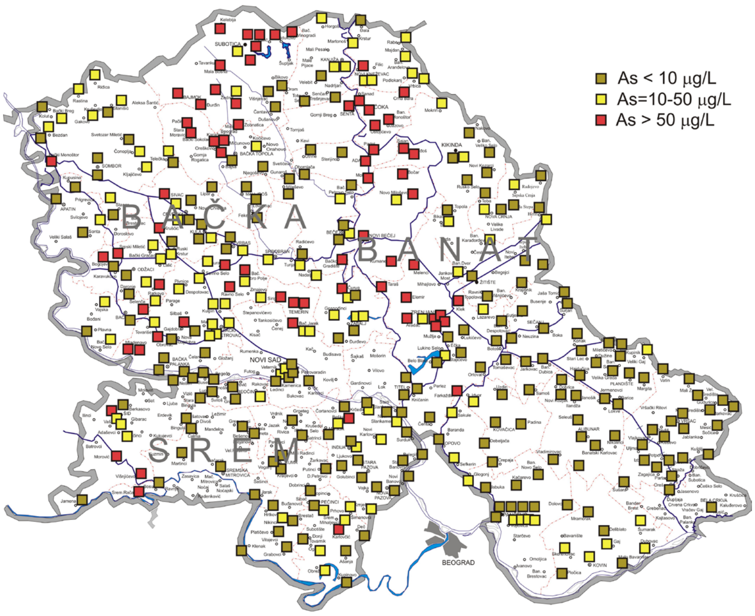

Fig. 1 Arsenic concentrations in public water supply wells in Vojvodina (based on Monitoring Report, 2009)

According to recent data, there are only a few areas in Vojvodina where background arsenic levels in groundwater are below the health limit. Also, there is no general rule that applies to the distribution of arsenic in different aquifers; while in western Backa and southern Backa the highest arsenic concentrations were recorded in groundwater generally tapped from between 100 and 200 meters (from BWC), in southern Banat only 5% of the groundwater samples collected from wells deeper than 70 metres exhibited As> 10 µg/l (Fig. 2). At the same time, arsenic levels occasionally vary to a large extent within in the same aquifer at small distances (i.e. the distance between 2 well fields, Sibnica and Gradska Suma, is less than 1000 meters).

Table. 1: Arsenic content in public water supply wells in Vojvodina (based on Monitoring Report, 2009)

DISTRICT	TOWN	DEPTH (m)	WATER-BEARING FORMATION	CONTENT As (µg/l)		
				MIN.	MEAN	MAX.
WEST BACKA	APATIN	<60	"First" aquifer	0,5	4,0	6,4
	RATKOVO	148-240	Pliocene	22,5	183,3	344,1
	RUSKI KRSTUR	200	Pliocene	38	47,1	55,9
	SOMBOR	65-70	"First" aquifer + BWC	4,2	5,4	6,6
		-	Pliocene	1,8	14,9	25,9
SOUTH BACKA	NOVI SAD	< 30	"First" aquifer	1,8	8,6	37,0
	BAČKI JARAK	130 - 185	Pliocene	28,8	63,6	107
	SIRIG	135	Pliocene	214	221	231
	OBROVAC	280-320	Pliocene	77	102	148
	TEMERIN	120 - 160	Pliocene	16	48,8	62,0
SOUTH BANAT	VRŠAC	80 - 95	BWC	< 0,5	0,7	0,94
	PANČEVO	36 - 54	BWC	1,1	13,7	45,4
	KOVIN	65 - 70	BWC	21,7	25,6	32
SREM	RUMA	50 - 54	"First" aquifer	2,5	3,0	3,7
		144 - 150	Pliocene	1,6	3,5	6,7
	ŠIMANOVCI	85	BWC	11	13,7	17
	OBREŽ	66 - 68	Pliocene	37	41	46
	KARLOVČIĆ	80 - 120	Pliocene	45	60	76

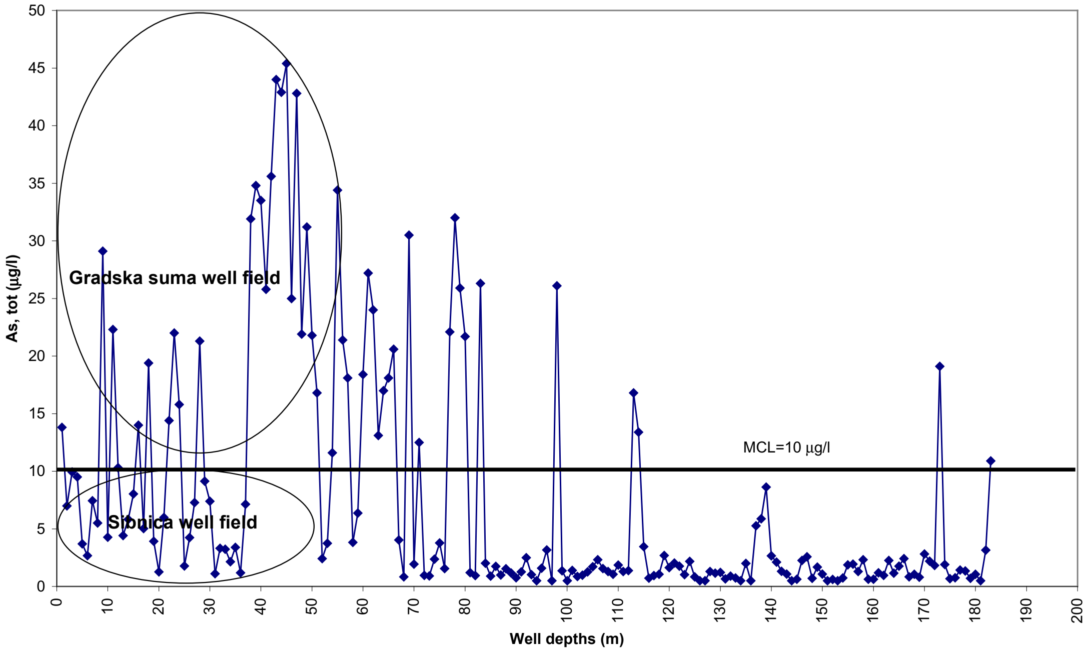

Fig. 2 Arsenic concentrations in public water supply wells in South Banat (Monitoring Report, 2009)

3. SUSTAINABLE GROUNDWATER MANAGEMENT SOLUTIONS AND IMPROVEMENT OF PUBLIC WATER SUPPLY

The inadequate natural quality of the water withdrawn from the main aquifer (As, NOM, NH_4, B...), as well as over-exploitation, prompted a search for sustainable groundwater management solutions. Sound groundwater management involves not only sustainable abstraction (the quantity aspect), but also the preservation of water quality. It is a decision-making process which encompasses all issues pertaining to groundwater abstraction and land use, including regulations and restrictions governing the establishment of wellhead protection areas, or the designation of areas in which aquifers are subject to special protection of groundwater quantity and quality (Dimkic *et al.*, 2008). Water supply issues in different parts in Vojvodina have led to the establishment of various solution selection criteria, the major three being:

1. *the availability of adequate quantities* of groundwater to meet the current and future drinking water demand, or to meet such demand with no adverse impacts (dramatic drawdown, deterioration of water quality, etc.)
2. *natural groundwater quality* that enables relatively simple (and economically-viable) water treatment processes to raise water quality to drinking standards, and
3. *feasibility of developing safeguard zones* around existing and future water sources for water-supply, while at the same time not significantly encroaching on other nearby facilities/activities.

Based on these criteria, two general water-supply solutions were proposed: the development of regional water sources in alluvial deposits of the Danube River (so-called regional or centralized water supply scheme), or the development or expansion of local water sources, along with complex treatment technologies (so called decentralized water supply scheme). According to Water Management Master Plan, water supply issues in the Province of Vojvodina need to be resolved through the formation of regional water supply systems, relying on groundwater sources in the Danube alluvium. Two zones have been identified as the best locations for large-capacity sources: an upstream stretch of the Danube (between towns Apatin and Bezdan) and a downstream stretch of the Danube (between towns Kovin and Dubovac). Toward this goal, activities to date included dedicated field investigations of potential locations for new regional sources of water supply, as well as the preparation of related feasibility studies of regional water supply systems for western Bačka and Banat.

A regional source for central and northern Banat (an area with some 600.000 inhabitants), would be formed in the alluvial plain of the Danube, between Kovin and Dubovac (Fig. 3). With regard to the geological structure, the most common are Pleistocene and Holocene gravels and sands, with a hydraulic conductivity of the water-bearing medium in the range from $1x10^{-4}$ to $1.2x10^{-3}$ m/s (NPV46B, 2006). The studied area is under the influence of backwaters caused by the construction of the Iron Gate Dam and is actively protected by a system of drainage canals and pumping stations that control groundwater levels. The formation of a groundwater source will have a positive effect in that it will relieve the stress currently imposed on drainage system capacity in the riparian area. A forecast of the influence of future groundwater abstraction on this area shows that up to 2400 l/s can be tapped from the riparian belt, 100 m from an existing embankment, with drawdowns of about 6 m. This water quantity is enough to meet the water demand of 13 municipalities in central and northern Banat through the year 2050. The water is of the calcium-carbonate type, moderately hard, with low pH fluctuations in the range of neutral reactions. Low values of sodium and potassium cations and chloride anions have been registered. Organic content ($KMnO_4$ demand) was detected at only two piezometers. In general, iron and manganese concentrations are elevated, while a somewhat high arsenic concentration (0.18 μg/l on average) was detected at only three locations.

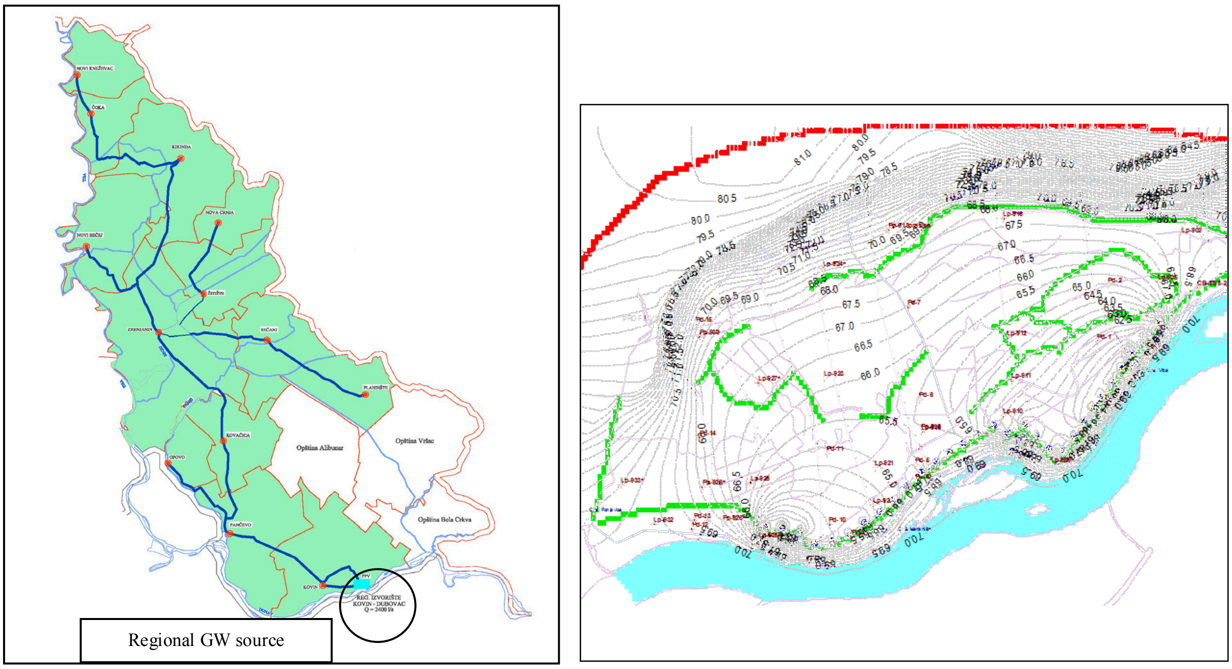

Fig. 3 Proposed regional water supply system for Banat
a) disposition of regional system and b) prognostic model calculations in the area of regional GW source

Feasibility analysis of Banat water supply system showed:

- Centralized water supply system is the more expensive solution compared to de-centralized one (investment costs 340 Mio € compared to 270 Mio €)
- Price of water production is higher in the case of de-centralized system (0,88 € compared to 0,57 €), mostly because of higher level of water treatment needed in case of local waterworks

In general, centralized water supply scheme is more expensive solution in the first 15 to 20 years of operation but after that period financially and by its structure, is very convenient and should be the goal for the future.

4. CONCLUSIONS

The conclusion of the feasibility analysis is that despite the high capital expenditure needed to resolve drinking water issues in Vojvodina by constructing regional systems, such an approach is deemed to be feasible and its benefits outweigh costs. By introducing new, alternative water sources and regional (or semi-regional) water supply systems, harmful health impacts of arsenic-bearing groundwater will be avoided, which is an important benefit of this solution. It would not only be a benefit to human health but also to the development of local communities. In addition to providing sufficient quantities of drinking water of good quality, these systems would ensure efficient use of slowly-renewable groundwater resources. Investigations and hydrodynamic analyses have shown that sufficient quantities of groundwater can be withdrawn from the Danube alluvium in the Apatin-Bezdan and Kovin-Dubovac areas, the quality of which is such that the application of basic treatment methods (aeration, retention, filtration and disinfection) will produce drinking water of good quality.

In addition to providing sufficient quantities of good-quality drinking water, these systems would allow for efficient utilization of groundwater resources from slowly-renewable aquifers. Such an approach to the threatened quantitative groundwater status is in accordance with the principles promoted by the WFD, especially with regard to transboundary water resources, shared with neighboring countries.

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