Local groundwater supply systems for remote settlements, current state and prospects for utilization: case studies from Serbia

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ABSTRACT

Water supply for remote rural settlements is a big issue in the Republic of Serbia. Most local supply systems are developed and maintained by the local community and are in a poor condition. Based on a national strategy, this issue should be resolved with the construction of regional systems using artificial reservoirs. In this paper, case studies from three areas in Serbia are shown in order to offer the alternative to regional water supply with the development of autonomous groundwater supply systems in remote settlements, especially in cases when water supply from surface water inevitably leads to the deterioration in quality and quantity of resources. The research conducted included monitoring of regime parameters and conducting multiple chemical analyses in order to determine the stability of resources, both in the qualitative and quantitative sense, as well as other important factors for development of supply systems. It can be concluded that, if properly and continuously monitored and developed by public waterworks companies, those autonomous groundwater systems would be able to provide the required amount of quality resources for the water supply of remote settlements where necessary.

Key words | aquifer, autonomous water supply, reservoirs, Serbia, water quality

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INTRODUCTION

Currently, about four million people, which is about 55% of the entire population of Serbia, live in 3,904 rural settlements (Pantić & Živanović Miljković 2010). Based on the water management master plan of the Republic of Serbia (Jovičić *et al.* 2001), roughly 23.9 m^3/s of water is used for domestic water supply. From that amount, some 75% is abstracted from groundwater resources (Dimkić *et al.* 2011). Although Serbia has relatively large groundwater reserves, they are not evenly distributed across the country. The biggest aquifers are located in thick intergranular sediments of Neogene and Quaternary age. Based on hydrogeological research conducted in the past, the available groundwater potential of aquifers in Neogene and Quaternary subartesian aquifers is 9.41 m^3/s (Polomčić *et al.* 2012). The national strategy for the water supply of the Republic of Serbia from 1977 suggested that the water supply should be provided with regional systems through the construction of 29 reservoirs (Dokmanović & Nikić 2015). These systems should provide an integrated water management and a centralized water supply in the territory of Serbia. Up to now, only some of those reservoirs have been completed and included in the water supply.

For years, there was a problem of water supply for smaller, remote settlements. Most of those local supply systems were constructed and maintained by the local community and were in really bad condition. Based on the law on public utilities (National Assembly 2011), jurisdiction over local water supply systems was awarded to public waterworks companies. Unfortunately, the transition of the jurisdiction did not go smoothly because public companies

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are, in most cases, reluctant to take over, mostly because additional investments in old and neglected systems are required. In this paper, the current state of local groundwater supply systems in three municipalities are shown (Figure 1).

The municipality of Ruma is located in Vojvodina, Srem region. It is located between Fruška Gora mountain in the north and Sava river in the south. There are 17 settlements in this municipality, of which, 16 have a rural character. The entire population is estimated at 60,000, of which, about 50% lives in rural settlements. There are two regional water supply systems that provide water for the population of Ruma and surrounding settlements, while five remote settlements have local systems (Dobrinci, Grabovci, M. Radinci, Nikinci, and Putinci). All water sources are under the jurisdiction of a public communal company. The entire water supply comes from groundwater.

The municipality of Novi Kneževac is located in northeastern Vojvodina, Banat region. It is located between state borders with Hungary in the north, Romania in the east and the River Tisa to the west. There are nine settlements in this municipality, of which, eight have a rural character. The entire population is estimated at 11,300, of which about 40% lives in rural settlements. Six rural settlements in this municipality possess autonomous water supply systems (B. Aranđelovo, Podlokanj, Majdan, Filić, Sr. Krstur, and Djala). All settlements are under the jurisdiction of a public communal company and use groundwater as resource.

The municipality of Aleksinac is located in central Serbia, with the mountains Ozren, Devica, and Bukovik to the north, Small and Big Jastrebac to the south, with the River Morava flowing through the center of Aleksinac valley. This municipality has 72 settlements in total, of which, 67 have a rural character. The entire population is estimated at about 55,000, of which, about 65% lives in rural settlements. Water supply for 20 settlements and about 35,000 inhabitants is provided from a centralized system, Bovan Lake with the water treatment plant Bresje. Some settlements have autonomous water supply systems and use tapped springs or wells, while a large number of remote settlements have no water supply infrastructure and are forced to rely on individual water supplies. The plan is to join 12 more settlements to the water supply network in the next two years, and local groundwater systems will be abandoned.

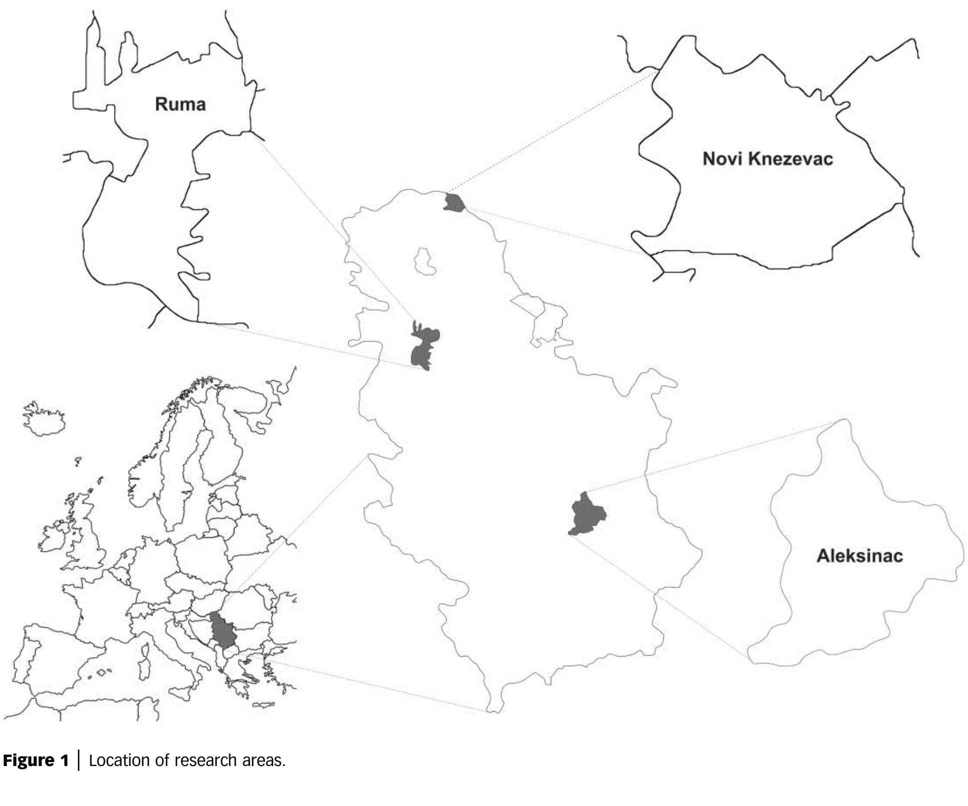

Figure 1 | Location of research areas.

AIM AND HYPOTHESIS

The aim of this research was to provide an alternative to centralized water supply from artificial reservoirs/lakes, especially in cases when water needs to be transported to remote settlements. One of the reasons is the high cost of pipeline construction as well as the cost of water treatment. Also, a centralized water supply represents a significantly higher load on the exploited system which inevitably leads to deterioration in quality and quantity of resources.

Eutrophication is the general term used to describe the suite of symptoms that a lake exhibits in response to fertilization with nutrients (Schindler *et al.* 2008). It causes harmful algal blooms, kills fish, increasing anoxia in deeper parts of lakes due to the decay of plant material, and many other related problems. It is largely caused by increasing inputs of phosphorus and nitrogen, which are abundant in human sewage, in the excrement of livestock, and in synthetic fertilizers applied by agriculture (Schindler 2012).

Several authors have investigated the quality of water from lakes and reservoirs in Serbia and its implications for water supply. The dense bloom of cyanobacteria *Planktothrix rubescens* occurred in the Vrutci Reservoir (Western Serbia), which has been excluded from the water supply system of the city of Užice (population 78,000) to date. Resilience and remediation strategies rely on modified operation, restrictions in nutrient loadings, and on the upgrade of the water treatment process (Kostić *et al.* 2006). Several investigations of Gruža Reservoir (Central Serbia), intended for the water supply of the city of Kragujevac (population 150,000) have been performed. The effects of anthropogenic influences on the trophic status were investigated in 2007 and all factors showed accelerated 'aging' as a consequence of direct anthropogenic influence (Ostojić *et al.* 2007). Results from 2014 to 2015 showed a high risk level to public health according to the World Health Organization (Čađo *et al.* 2016). During 2008–2009, an investigation into the ecological condition and water quality of Lake Ćelije (Central Serbia), which is being used for water supply of the city of Kruševac (population 58,700), was carried out. It was concluded that water quality was in accordance with the limit values for the reservoir used in the water supply, but with a eutrophication tendency and deterioration of water quality due to increasing pollution of the lake (Milenković Anđelković *et al.* 2010). Barje Reservoir (Southern Serbia) is being used for the water supply of the city of Leskovac (population 60,000). Research conducted in 2010, 15 years after filling and zero test, showed that the water quality is still at a satisfactory level, but with indications of the start of the process of eutrophication (Cibulić *et al.* 2013).

Based on previous research, water from Bovan Lake, which is being used for the water supply of Aleksinac municipality has the same problems. An increasing level of cyanobacterial bloom was recorded (Sedmak & Svircev 2011). Cyanobacteria, also known as blue-green algae, are a diverse group of photosynthetic prokaryotes of the the Kingdom Eubacteria. In eutrophic waters and under specific environmental conditions, they can form blooms. Large cyanobacterial bloom events are sometimes referred to as 'harmful algal blooms' if linked with negative environmental, health, or economic impacts. These adverse effects include reduction in aquatic ecosystem biodiversity, impairment of drinking water treatment processes and potable water supply, and not least, health hazards due to the production of potent toxins (*cyanotoxins*) (Svirčev *et al.* 2014). Based on continual monitoring provided from 2010 to 2014 (Jovanić *et al.* 2014), it can be concluded that during summer, because of higher water temperatures, lack of oxygen and intensification of mineralization of organic matter, the volume of ammonia increases. Concentrations of nitrates increase during spring and late summer as a consequence of anthropogenic activities. Also, increased numbers of coliform bacteria (*Escherichia coli*) and bacteria of fecal origin (*Streptococcus faecalis*) were documented, especially during the summer season.

Another problem is aggradation, which causes a decrease in the useful volume of the lake and can lead to deterioration in water quality. Based on measurements done from 1978 to 2010, it was concluded that the lake volume decreased by 6.77 million m^3 in that period (Mihajlović *et al.* 2011).

Bearing in mind the evident deterioration of water quality in Bovan Lake, as well as examples from other Serbian reservoirs that are being used for water supply, it can be assumed that additional pressure on that resource in the form of connecting new settlements can create new problems in the water supply. Therefore, the main hypothesis is that, for settlements which already have autonomous water supply systems, a better solution can be investment in existing systems. The possibilities for development and management of local supply systems will be shown in examples from the municipalities of Ruma and Novi Kneževac.

RESEARCH AREAS AND METHODOLOGY

The municipality of Ruma, in terms of hydrogeological setting, presents with shallow unconfined aquifers in alluvial sediments of Sava River and its tributaries, and confined aquifers with artesian and sub-artesian pressure of sandy and gravelly sediments of Tertiary and Quaternary age. Sediments of Miocene and Pliocene age are present with sand, gravel, clay, marl, sandstone, conglomerate, and varieties. Packets of those sediments are characterized with frequent successions, thus, there are layers of aquifers and aquitards. Artesian aquifers of Quaternary and Plio-Quaternary age are represented with sand and gravel of different granulation. Aquifers have good filtration characteristics, with filtration coefficient of the order 10^{-3} m/s in sand and 10^{-2} m/s in gravel. These layers are considered to be most productive in terms of water supply. All screen intervals are located in those layers. Recharge of these aquifers comes from hydraulic connectivity with alluvial sediments and direct infiltration of precipitation in areas where these sediments come to the surface (Nešković 2014).

The municipality of Novi Kneževac presents with intergranular aquifers within two hydrogeological complexes which are clearly separated with a clayey layer. The first hydrogeological complex is composed of Quaternary sediments up to 80 m from ground level. Depending on location, its characteristics change from unconfined to confined, sub-artesian. The second hydrogeological complex is distributed in the interval from 90 to 240 m. Based on location, it is possible for one or several sandy layers to be allocated to where a confined, artesian aquifer has been formed. All screen intervals are located in this interval. Based on conducted pumping tests, filtration coefficient of the aquifer was determined and it varies from 1.5×10^{-4} to 6.6×10^{-4} m/s (Mitrović *et al.* 2014).

The municipality of Aleksinac presents with two intergranular aquifers. The first aquifer is unconfined and developed within alluvial, proluvial, and terrace sediments of Quaternary and Pliocene age. This aquifer has hydraulic connection with the Južna Morava River. The second, artesian complex is developed within sediments of Neogene age. These sediments have a diverse lithological composition as a consequence of frequent changes in sedimentation conditions. The largest distribution has sandy-clayey sediments where the clay fraction is predominant, while sand and gravel are rare. Similar to every basinal structure, forming of specific coastal sedimentation is characteristic. Alteration of layers of sand, gravel, clay and marl is evident, considering that the amount of coarse grained material is greater in the peripheral parts of the basin. Based on drilling results in this area, four artesian horizons were determined between 100 and 200 m and their average filtration coefficient determined as 1.1×10^{-3}. Recharge of these aquifers mostly comes from infiltration of precipitation in peripheral areas of the basin, while only a small part comes from infiltration of surface water (Špadijer & Živanovic 2005).

For the purpose of this research, a total of 17 sampling points was observed, five in the municipality of Ruma, six in the municipality of Aleksinac, and six in the municipality of Novi Kneževac (two wells in Sr. Krstur and Djala were considered as one sampling point). Locations of sampling points are shown in Figure 2, while technical characteristics, flow and groundwater level (GWL) are shown in Table 1.

Wells in Dobrinci, Grabovci, Nikinci, and Putinci are located on the outskirts of settlements, while the well for Mali Radinci is located next to the road, Ruma–Stara Pazova. All wells are equipped with well pumps, flow meters, and have established sanitary protection zones. All of them are included in a water supply network.

Wells in Sr. Krstur, Majdan, and Djala are located on the outskirts of settlements, while wells in B. Aranđelovo, Podlokanj, and Filić are located in the center of settlements. Some of these wells are in a really bad condition, without any wellhead protection, which allows for unauthorized access to the well site. Some flow meters are out of order

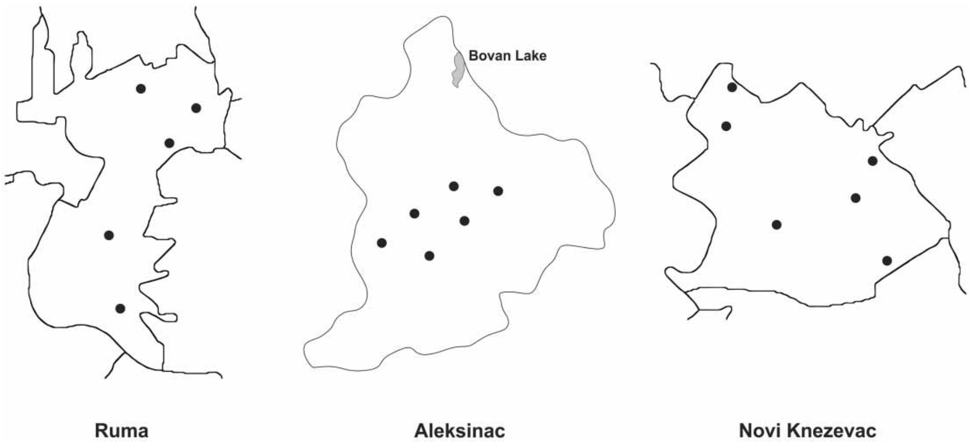

Figure 2 | Location of sampling points.

Table 1 | Summary table of technical characteristics, flow and GWL for sampling points

Location	Year of drilling	Depth (m)	Screen interval (m)	Q (l/s)	GWL (m)
Ruma					
Dobrinci	1981	73	55–67	7.9	8.92
Grabovci	1985	76.6	52–73	7.2	10.26
M. Radinci	2007	72	52–64	9.3	47.95
Nikinci	2006	101	90–95	3.4	13.69
Putinci	1999	95	70–80, 86–90	3.9	19.12
Novi Kneževac					
Sr. Krstur B-1	1978	No data	178–204	4.2	4.40
Sr. Krstur B-2	1986	182	148–178	5	+0.0
Majdan	1989	192	162–190	1.1	1.75
B. Aranđelovo	1975	189.5	153–187	0.7	3.17
Podlokanj B-1	1973	174	132.5–173	0.8	6.34
Djala B-1	1968	177	137–164	2.1	3.32
Djala B-2	1986	190	138.5–170.25	2.5	+0.0
Filic	1998	131	109–128	0.6	7.22
Aleksinac					
Glogovica	No data	150	No data	0.2	+0.0
Aleksinac	2005	350	114–131, 182–201, 256–265, 302–309[a]	0.5	No data
Zitkovac	No data	100	No data	0.4	+0.0
Krusje	No data	190	No data	No data	No data
D. Suhotno	No data	200	85–95	0.9[a]	+0.0
G. Adrovac	No data	276	130–137, 158–166, 183–197	1.3	18.1
Location	**Year of filling**	**Depth (m)**	**Useful volume (m^3)**	**Q (l/s)**	
Bovan Lake	1984	Up to 50	41,000,000	Up to 300	

[a]Estimate.

and for part of the wells there is no technical documentation. All wells are used for the water supply of settlements.

The well in Glogovica is situated on arable land next to the old highway. It has no proper cover. The well was abandoned, and due to artesian pressure water drains to the nearby road. The well that is on the road between Aleksinac and Žitkovac has sub-artesian pressure and is equipped with a pump. The well in Žitkovac is arranged as a public fountain and water is used for drinking. A sub-artesian well is located in Krušje on private property. Both wells in D. Suhotno and G. Adrovac are used for water supply in those settlements and are regularly maintained. Water from Bovan Lake was sampled at two points: raw water before treatment and treated water before the distribution network.

Sampling in Ruma and Novi Knezevac areas was conducted on a quarterly basis with a total of six samples in Dobrinci and Grabovci and five samples in M. Radinci, Nikinci, and Putinci. Every well in Novi Knezevac was sampled four times. In Aleksinac area, samples were taken on one occasion on every well. All wells, except in Glogovica, were equipped with a pump which was used for water extraction. There were no data about the depth of the pumps. Bearing in mind that the well in Glogovica had artesian pressure, a sample was taken from the surface. Samples from Bovan Lake were taken from the pipeline in the water plant.

During sampling, air and water temperature, pH value, and electrical conductivity were measured. Concentrations of NH_4^+, NO_3^-, NO_2^-, SO_4^{2-}, and PO_4^{3-} were determined by colorimetric method. Mg_2^{2+}, Ca_2^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and consumption of $KMnO_4$ were determined by volumetric method. Fe^{2+} and Mn^{2+} were determined with atomic absorption spectrometry (AAS). Concentrations of Na^+ and K^+ were calculated. Microbiological composition was determined by seeding on nutrient medium (Papic 1984).

RESULTS AND INTERPRETATION

Because all sampling points in Ruma and Novi Kneževac areas are under the jurisdiction of local public waterworks companies and part of the water supply network, by legislation, they should be under permanent monitoring. In Ruma, research on local groundwater sources was provided in order to determine sanitary protection zones (Krmpotić 2012a, 2012b, 2012c, 2013a, 2013b) while in Novi Kneževac, research was done in order to define groundwater reserves (Krmpotic & Tadic 2015). For the most part, the research was based on regime observations. In Ruma, GWL and well capacities have been monitored since 2006, while in Novi Kneževac, monitoring was established in late 2013. Measurements were carried out on a weekly basis for most of the wells. Based on available data obtained through monitoring, linear trends were calculated in order to see the effects of long-term groundwater exploitation (Figure 3).

As can be seen in Figure 3(a), there is a regional trend of increasing depth to GWL over time in the Ruma area. In the course of nine years, GWL dropped from 1.2 m (M. Radinci) to 4.2 m (Putinci). The only location without an evident drop was the well in Nikinci settlement. Proof that this decrease is not a consequence of an increase in exploitation can be seen in Figure 3(b). In three settlements exploitation stayed virtually the same throughout the course of time, while in Putinci and M. Radinci it even decreased. This brings us to a conclusion about the general trend of overexploitation in the area that the aquifer cannot recover to a full extent. Another possibility is that GWL decreases because of the well aging process, bearing in mind that some wells have been exploited for over 30 years (Smith & Comeskey 2010).

As can be seen in Figure 3(c) and 3(d), monitoring of GWL and exploitation in the Novi Kneževac area lasted for a little bit longer than a year, therefore, the data do not have large statistical significance. It should be noted that the trend for exploitation in Djala was composed of two wells, due to the two wells working in succession, when one is active the second one 'rests' and vice versa. That is actually the only positive trend in terms of exploitation. For all other wells, a negative trend is observed. In terms of GWL, it can be seen that all monitored wells have either a steady or positive trend in groundwater recovery. Wells B-2 in Djala and B-1 in Sr. Krstur have steady artesian pressure, while wells B-1 in Djala and Majdan show fast recovery trend.

In the Aleksinac area, there was no continuous monitoring for any well, although three of them (Zitkovac, D. Suhotno, and G. Adrovac) are used for water supply. Groundwater flow and levels were measured only once

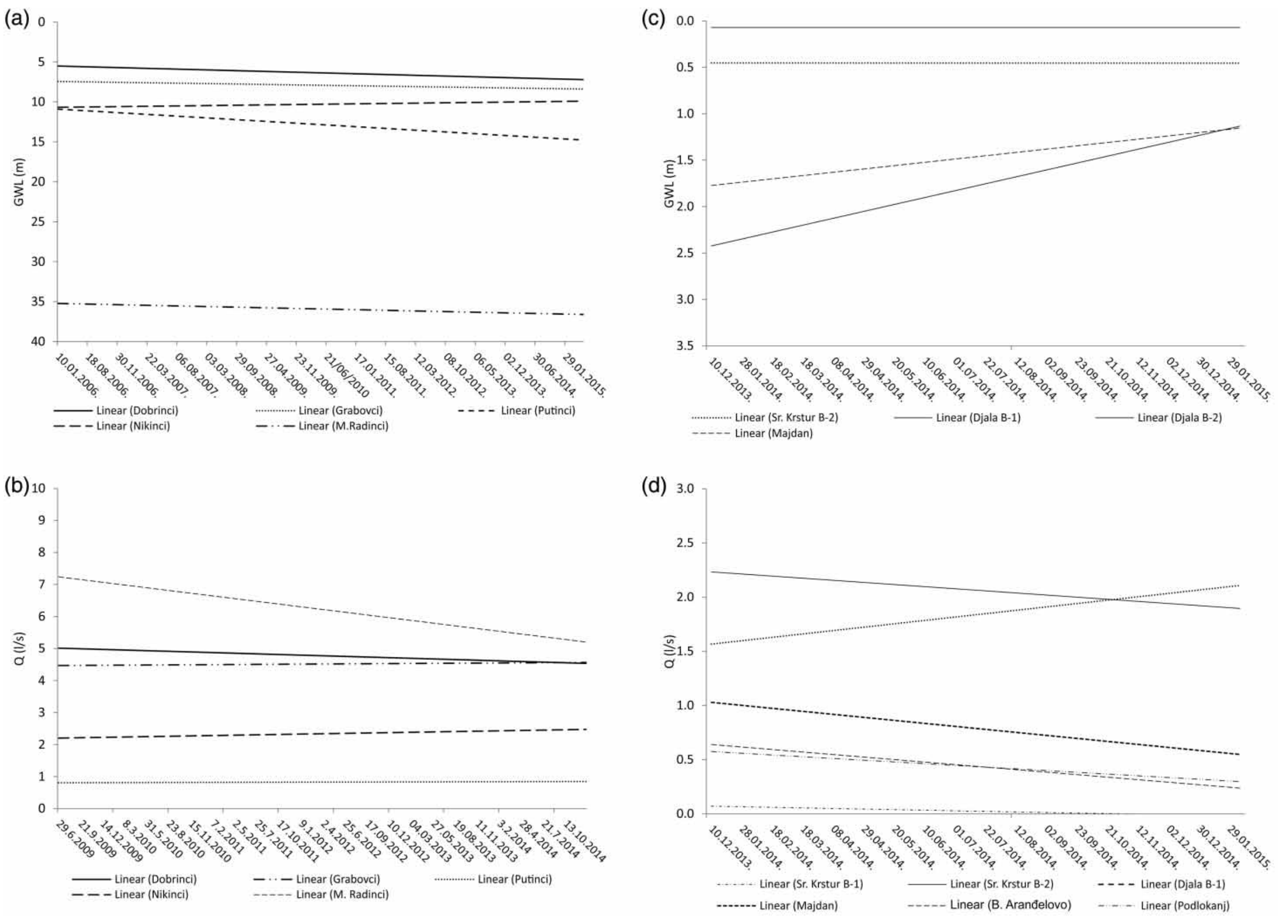

Figure 3 | Linear trend analysis of long-term exploitation in Ruma and Novi Kneževac areas.

and for those wells where there were technical capabilities. Based on observations, in the natural regime, most of those wells are with artesian pressure.

Hydrochemical analyses were carried out and interpreted in order to define the suitability of the groundwater resource for water supply (Brančić & Nešković 2016). Based on analyses of electrical conductivity and pH value, all groundwater samples were divided into four groups (Figure 4).

The first group comprises samples from the N. Kneževac area with conductivity between 410 and 891 μS/cm and pH between 7.1 and 7.6. The second group is composed of samples from the Ruma area with conductivity between 560 and 720 μS/cm and pH between 7.1 and 7.7. The third group comprises mineralized waters in Glogovica, Aleksinac, and Žitkovac with conductivity between 1,306 and 2,170 μS/cm and pH between 8.54 and 8.64. The fourth group is composed of low-mineralized waters in Krušje, G. Adrovac, and D. Suhotno with conductivity between 492 and 609 μS/cm and pH in the range 7.59–8.15. Raw water from Bovan Lake is low-mineralized with neutral pH. Based on regulations for hygienic quality of drinking water in Serbia (National Assembly 1999), pH of water which can be used for water supply must be in the range of 6.8–8.5 while conductivity has to be below 1,000 μS/cm. Samples of the third group have an alkaline pH and conductivity that transcends maximum allowed concentrations (MAC). Alkalinity of water in this area can be linked to intrusion of basanite ($CaSO_4 \cdot 0.5 (H_2O)$) within ultramafic rocks that occurred in the middle Miocene age. This caused metamorphosis of sediments from the lower Miocene and increased alkalinity

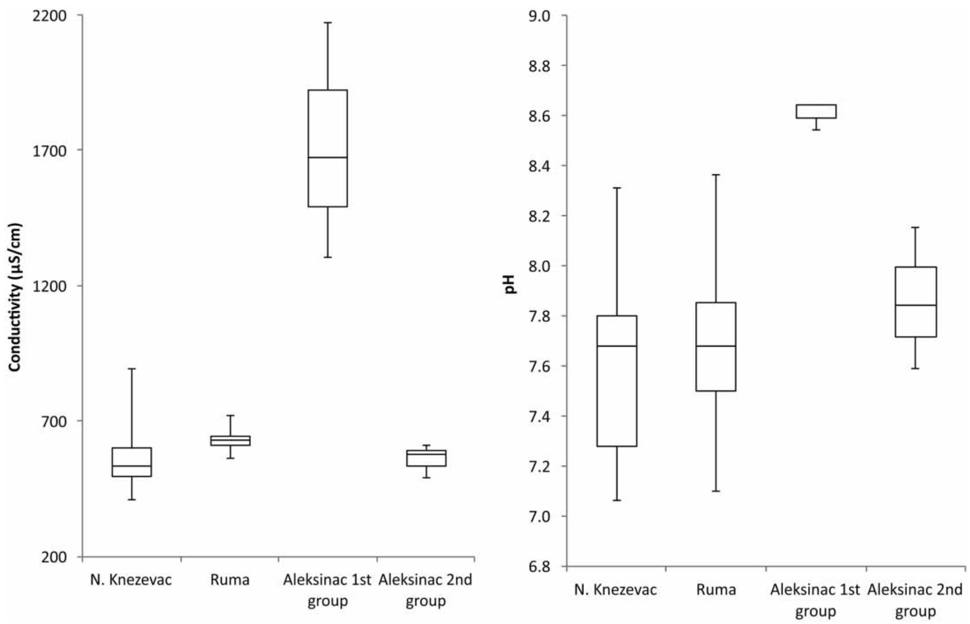

Figure 4 | Box and whisker plots of pH values and electrical conductivity of sampled water.

in groundwater. The large range of electric conductivity in the samples of the third group can be explained by differences in the depth of the wells subjected to sampling. Samples from the fourth group have neutral pH value and conductivity below MAC and, as such, are suitable for water supply.

In terms of chemical composition, all groundwaters are of hydrocarbon class. Samples from Aleksinac belong to the sodium group while samples from N. Kneževac and Ruma areas are dominantly of the calcium and magnesium group. Ionic groundwater compositions are shown in a Piper diagram (Figure 5).

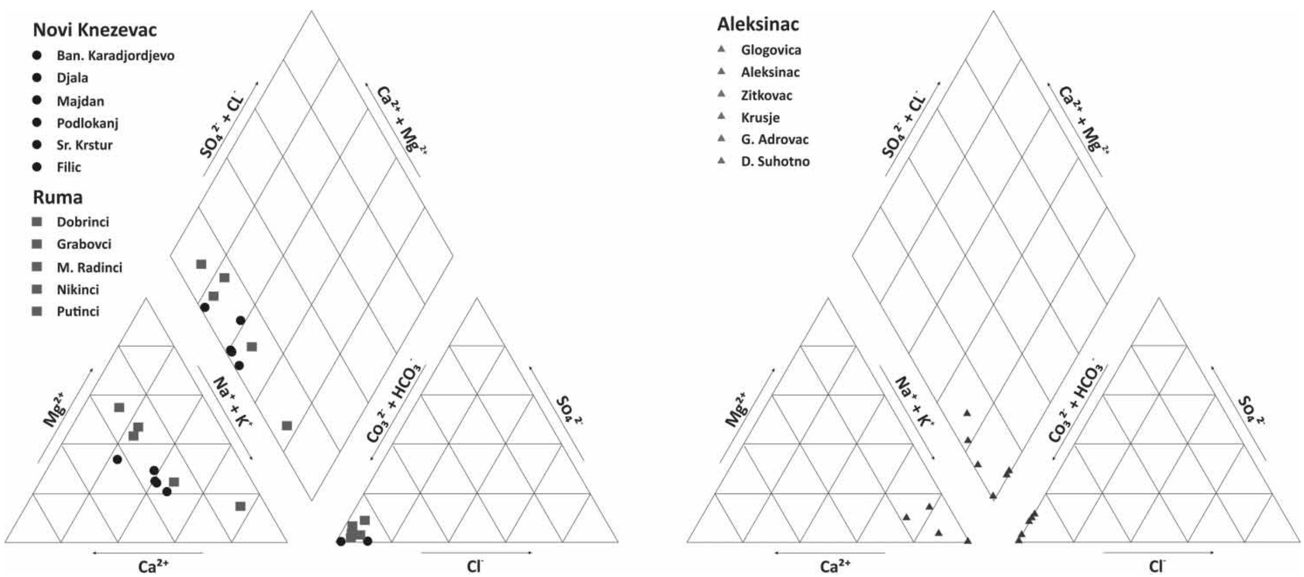

Figure 5 | Piper diagram of sampled groundwater in N. Kneževac and Ruma areas (left) and Piper diagram of sampled groundwater in Aleksinac area (right).

Concentrations of elements that are indicators of pollution were monitored for all sampling points (Figure 6). Based on regulations for the hygienic quality of drinking water in Serbia, the MAC for turbidity is 1.0 NTU, for NH_4^+ is 0.1 mg/l, for NO_3^- is 50.0 mg/l, and for consumption of $KMnO_4$ is 8.0 mg/l.

It can be said that ample variations were observed in most of the sampling points in both Ruma and Novi Kneževac areas. Turbidity was slightly elevated in three samples from Mali Radinci and in one sample in Nikinci. Really high values of 4.8 and 12 NTU were observed in Putinci. In the Novi Kneževac area, there was only one sample with elevated value (Filic). Elevated values for the concentration of NH_4^+ were observed at almost all sampling points, most of the time in succession, while the biggest values were recorded in Putinci (2.7 mg/l) and Djala (7 mg/l). Elevated values of NO_3^- were observed only in Dobrinci (15–18 mg/l) but those values did not exceed the MAC. Values of $KMnO_4$ consumption that are above the MAC were observed in one sample from B. Krstur (8.2 mg/l) and one from M. Radinci (10 mg/l). Owing to this, all wells in Ruma and Novi Kneževac areas undergo water chlorination before delivery of water to consumers.

In the Aleksinac area, only in the sample from Glogovica were elevated values for turbidity and concentrations of NH_4^+ recorded. That is most likely because of abundant rainfall in the week before sampling and the fact that this sampling point has no proper cover, hence there is direct contact with the terrain and exposure to atmospheric conditions. For other sampling points, concentrations of elements that are indicators of pollution do not exceed the MAC for drinking water. Given the depth of wells and tapped horizons, it is assumed that groundwater has no direct contact with the surface and that recharge is done at greater depths, hence the possibility of contamination is minimized. It is also assumed that because of this, groundwater would have a stable chemical composition throughout the year. However, it is important to point out that these assumptions were based on sampling performed only on one occasion, and they need to be confirmed with more analysis or using predictive models (Heidarzadeh 2017).

In order to quantify differences in the quality of groundwater and water from Bovan Lake, a comparative analysis was done. In Figure 6, values for raw water from Bovan Lake are presented as dots. Concentrations of NH_4^+ and NO_3^- are within the standards for drinking water, while turbidity and consumption of $KMnO_4$ are above the MAC. Therefore, in order for water to be suitable for drinking, treatment of raw water is mandatory.

Microbiological analysis showed that the raw water from Bovan Lake has over 161 colonies of coliform bacteria *Enterobacter* and *Citrobacter*. Fecal coliform bacteria *E. coli* was also detected. In order to achieve microbiological quality, raw water is treated with chlorine. None of the groundwater samples had bacteria and samples were microbiologically valid.

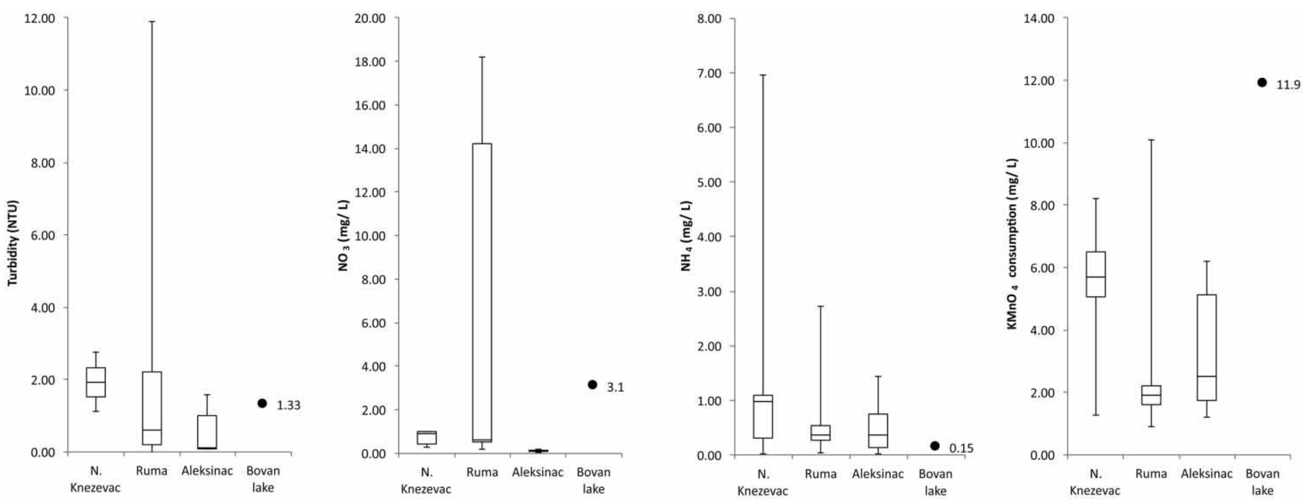

Figure 6 | Box and whisker plots of turbidity, and concentrations of NO_3^-, NH_4^-, and $KMnO_4$ consumption of sampled water.

In order to provide a broader view of results, comparison of national and EU legislation regarding potable water was provided. Bearing in mind Council directive 98/83/EC on the quality of water intended for human consumption (OJ 1998), it can be seen that Serbian legislation is stricter in terms of pH value (6.8–8.5 in Serbia; 6.5–9.5 in the EU), conductivity (<1,000 μS/cm in Serbia; <2,500 μS/cm in the EU), NH_4^+ (0.1 mg/l in Serbia; 0.5 mg/l in the EU), and turbidity (1.0 NTU in Serbia; acceptable for consumers in the EU). European legislation is stricter only in terms of consumption of $KMnO_4$ (8.0 mg/l in Serbia; 5.0 mg/l in the EU).

Although water quality is an important parameter that needs to be processed within the planning of the water supply for a municipality, there are other factors that need to be taken into account as well, such as demand, availability, and sustainability of resource. As already stated, about 35,000 inhabitants have a centralized water supply, while about 20,000 inhabitants in 52 rural settlements use an autonomous water supply. The average settlement has a population between 300 and 400. Based on data from the statistical yearbook for the period 2011–2013, average daily consumption of water is 122 liters per person (Vukmirović 2014). If that average is extrapolated and presented as l/s, it can be said that one rural settlement in Aleksinac municipality has a demand between 0.42 and 0.56 l/s of water for personal consumption, excluding cattle and irrigation. As can be seen in Table 1, most wells have a flow between 0.2 and 0.9 l/s with positive artesian pressure, while in G. Adrovac 1.3 l/s is abstracted with depression of 18.1 m. Bearing in mind that some of these wells are in use for a number of years, it can be assumed that in terms of availability and sustainability, these resources meet the demand of local communities. On the other hand, some settlements that use tapped gravitational springs for their water supply have issues with lack of the resource during summer when the demand is highest.

Reliability, resiliency, and vulnerability of one water supply system should be taken into account when developing one regional supply system. Reliability is defined as the probability of the system being in a satisfactory state, resiliency describes the capacity of a system to return to a satisfactory state from a state of failure, while vulnerability describes a severity of potential failure. Several methodological tools for risk assessment, management, and sustainable use of the water supply system are available (Jinno *et al.* 1995; Hamchaoui *et al.* 2015). Without going to deep into the methodology, it is clear that Bovan Lake is susceptible to pollution from the surface and that in some cases, pollution can lead to exclusion of the water source from the system for an indefinite period of time. On the other hand, deep aquifers with a thick layer of impermeable rock above are virtually invulnerable from the surface and the only danger can be a second borehole/well in the approximate vicinity. Reliability of autonomous groundwater systems can be compromised because of well aging after years of exploitation, which leads to a decrease in yield and an increase of depression.

Infrastructure and demography also have important roles in the development of water supply systems. Currently, a pipeline in Aleksinac municipality connects 20 settlements with a total of 260 km of primary and secondary networks. Based on plans for expansion, by the end of the year 2018, 12 more settlements should be connected to this regional system (Figure 7).

As can be seen from Figure 7, a large area of the municipality in conjunction with locations of the villages demands more than 130 km of pipeline, additional reservoirs, chlorination and pumping stations, just for the primary network. In order to provide some insights, comparative cost analysis for development of a regional system and development of local water supply systems is done. Analysis takes into account only those 12 settlements that are part of the expansion plan up to 2018.

In order to connect these settlements to the existing network, it is necessary to construct five new pipelines, in total length of at least 30 km, two new reservoirs with a capacity of 500 m^3, and three pumping stations because of the terrain in the northern and north-western part of the municipality. Estimation is made on the basis of the current price of materials and labor costs, and both labor and materials are included in the unit price. The cost of chlorination stations, secondary network, and water meters was not included in this estimation, bearing in mind that those costs would be the same both in the case of a centralized or autonomous water supply. The possible error is in the range of 5–10% (Table 2).

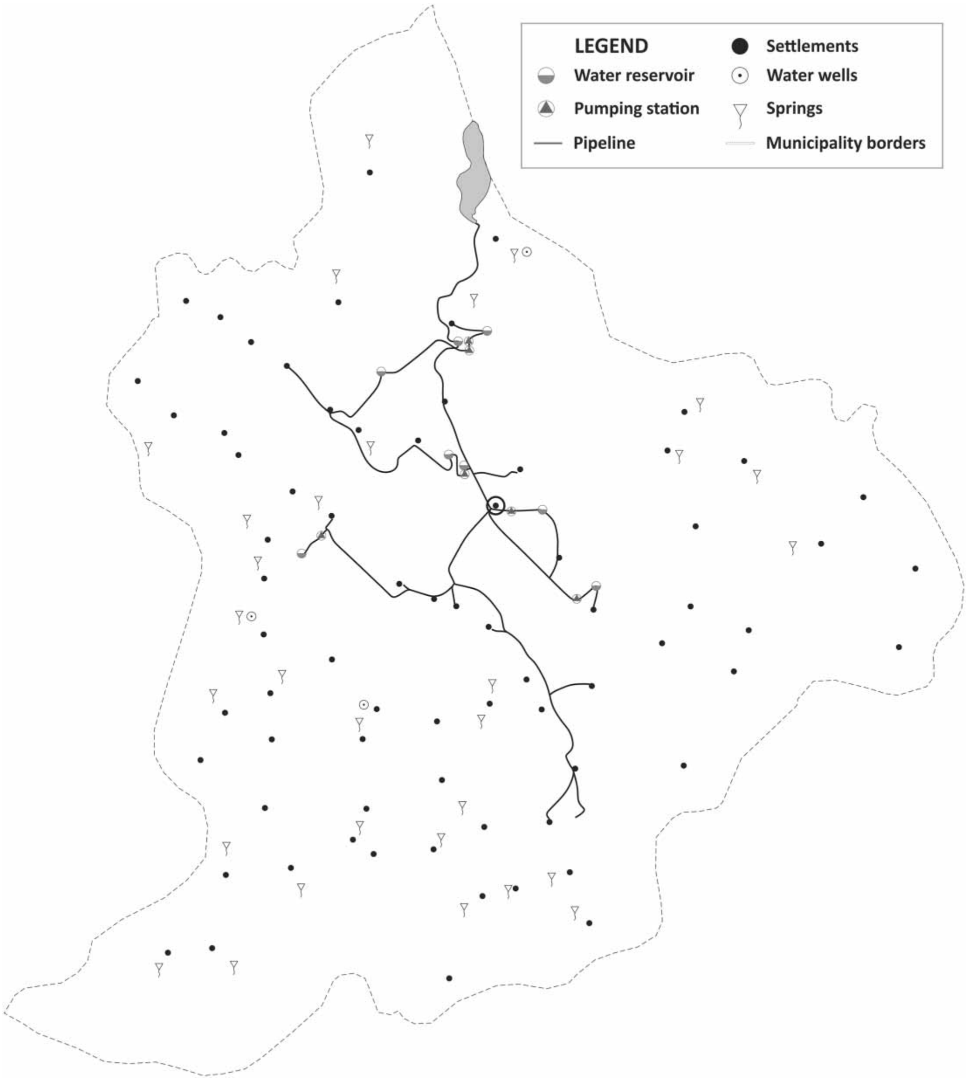

Figure 7 | Distribution of existing water supply network and plans for expansion with locations of settlements in the municipality of Aleksinac.

Currently, there are five active spring catchments in the area that is part of the expansion plan. The estimated costs for complete reconstruction of those catchments and drilling and development of wells in the settlements that have no other water source is given in Table 3. This estimation was done based on the assumption that wells should be up to 200 deep with 50 m of screen and have a yield less than 5 l/s, while catchments were dimensioned up to 10 l/s.

Based on this estimation, both investment and yearly costs for a centralized water supply are more than six times higher than the cost of complete reconstruction of the current and development of a new autonomous water supply system. Also, construction, connecting, and putting this system into use requires significantly more time then drilling and developing of one well or reconstruction of a spring catchment. As already stated, demand for water is estimated to be 0.42 and 0.56 l/s per rural settlement. Bearing in mind the small distances between settlements in the north-western part of the municipality, there is a possibility of a water supply for several settlements from one spring catchment or well battery. That would further reduce the cost of investment. However, in order for this possibility to be considered, additional field research is needed.

Table 2 | Estimated investment and yearly cost of pipeline, reservoirs, and pumping stations for 12 settlements in Aleksinac municipality

Pipeline				
Outer diameter (mm)	**Length (km)**	**Unit price (EUR/m)**	**Investment cost (EUR)**	**Yearly cost[a] (EUR/Year)**
400	8	169	1,352,000	60,840
315	5	108	540,000	24,300
225	10.5	87	913,500	41,105
200	6.5	78	507,000	22,815
Reservoirs				
Capacity (m^3)	**Number**	**Unit price (EUR/m^3)**	**Investment cost (EUR)**	**Yearly cost[b] (EUR/Year)**
500	2	340	340,000	8,500
Pumping stations				
Power (kW)	**Number**	**Unit price (EUR/kW)**	**Investment cost (EUR)**	**Yearly cost[c] (EUR/Year)**
10	2	1,800	36,000	3,600
6	1	2,000	12,000	1,200
Total			**Investment cost (EUR)**	**Yearly cost (EUR/Year)**
			3,700,500	162,360

[a]Amortization 2%; maintenance 1.5%, other costs 1%.
[b]Amortization 2%; maintenance 0.5%.
[c]Amortization 8%; maintenance 2%.

Table 3 | Estimated investment and yearly cost for drilling and development of wells and complete reconstruction of spring catchments in Aleksinac municipality

Works	**Investment cost (EUR)**	**Yearly cost[a] (EUR/Year)**
Well		
Well drilling and development (200 m well with steel casing and 50 m of screen)	31,000	1,250
Pumping equipment with 4 in. pump – delivery up to 7 l/s and head up to 60 m	9,150	460
Well house/shaft	4,300	300
Electro installations	10,450	730
Reservoir (30 m^3)	16,500	420
Total for 7 wells	499,800	22,120
Spring catchment		
Catchment construction	9,050	400
Pipeline and electro installation	1,500	110
Reservoir (10 m^3)	7,000	175
Total for 5 spring catchments	87,750	3,425

[a]Amortization 2–4%; maintenance 1–2%, other costs 1%.

A centralized supply system cannot be achieved without good infrastructure. Considering trends in migration from rural to urban areas, and the fact that some villages are 'slowly dying', the question is if those investments are cost-effective. However, most of the settlements have systems that are still under the jurisdiction of local communities, although, by legislation, all local water supply systems in Serbia were awarded to public waterworks companies. Public companies are still reluctant to take over, primarily because of the systems' condition and the need for additional investments. Also, a significant problem is that local communities are not interested in paying for water because the systems were built from voluntary contributions and, therefore, the water resource is 'their property'.

Despite all the problems, a good and stable water supply can be provided only by consolidated water management, regardless of the source. Transfer of jurisdiction over water sources from local communities to public waterworks companies has to be done to the full extent, especially bearing in mind the accession of Serbia to the European Union.

Management of small systems should not be any different to management of regional supply systems, in terms of duties, such as permanent monitoring, risk assessment and reporting (EC 2014). Examples from both Ruma and N. Knezevac municipalities show us that service, stability of water supply, and overall quality increased after water management was entrusted to a public waterworks company.

Consolidated water management is also a prerequisite for the conjunctive use of surface and groundwater where conditions for that exist. Conjunctive use relies on the principle that by using surface water when it is plentiful, groundwater can be available for abstraction in drought years when surface supplies are short. That way, groundwater can serve to mitigate fluctuations in the water supply, therefore representing a sort of buffer (Tsur & Graham-Tomasi 1991). Although the supply network from Bovan Lake is expanding, as in the case of D. Suhotno, it would be beneficial not to abandon or liquidate the existing objects, but to include them into the water supply.

CONCLUSIONS

About 55% of the entire population of Serbia lives in rural settlements, but for years, there was a problem of water supply of smaller, remote settlements. Most of those systems were developed and maintained by local communities and were in a bad condition. In this paper, the current state of local groundwater systems in the municipalities of Ruma, Novi Kneževac, and Aleksinac has been revealed.

The aim of the research was to provide an alternative to centralized water supply from artificial reservoirs/lakes, especially in cases when water needs to be transported to remote settlements. The first obstacle in a centralized supply is the large cost of the infrastructure and the second obstacle is the increased deterioration of water quality from lakes due to extensive use and natural resource vulnerability. Based on previous research, several reservoirs used for water supply of several municipalities have problems with deterioration of water quality, eutrophication and aggradation which causes a decrease in useful volume of the lake.

For the purposes of this research, a total of 18 sampling points were observed in three municipalities, 17 wells with artesian and sub-artesian pressure plus raw water from Bovan Lake. Sampling points in Ruma and Novi Kneževac areas are already a part of water supply systems while three sampling points in the Aleksinac area are being used for water supply. Others are public fountains, wells on private property, or abandoned.

Based on research, the aquifer in Ruma area shows a constant drop in GWL although in the last couple of years there has been no additional pressure on the system in terms of increased groundwater abstraction. On the other hand, in the Novi Kneževac area, it can be said that for all monitored wells either a steady or positive trend in groundwater recovery was observed. In the Aleksinac area, based on observations, in the natural regime, most of the wells are with artesian pressure.

Hydrochemical analyses showed that all sampling points from Ruma and Novi Kneževac areas belong to the same aquifer systems, respectively. On the other hand, samples from the Aleksinac area were divided into two groups. Samples from the first group are mineralized with alkaline pH, while samples from the second group are low-mineralized with neutral pH. In terms of basic hydrochemical composition, all sampling points have a stable regime. Increased values of parameters such as turbidity, $KMnO_4$ consumption, or nitrogen compounds in samples from Ruma and Novi Kneževac led to the fact that it is necessary to perform chlorination of groundwater before delivery to consumers. On the other hand, in Aleksinac area, only the sample from Glogovica had elevated values for turbidity and NH_4^+ concentration. All other samples were below the MAC for water supply. Raw water from Bovan Lake cannot be used for water supply without prior treatment due to microbiological contamination, as well as increased turbidity and consumption of $KMnO_4$. On the other hand, the groundwater of the second group is not burdened with pollutants and can be used for water supply without any prior treatment. Based on regulations for hygienic quality of drinking water in Serbia, groundwater of the first group cannot be used for drinking due to elevated conductivity and alkaline pH. On the other hand, if we were to compare the results with EU legislation which is more liberal, groundwater from this group would also be suitable for human consumption. However, in order to prove the stability of chemical composition, long-term monitoring is necessary.

Although water quality is an important parameter that needs to be processed within the planning of the water supply for a municipality, there are other factors that need to be taken into account as well, like availability, reliability, sustainability, vulnerability, infrastructure, etc. Centralized systems that use surface water can meet the demand easily but are more vulnerable and susceptible to pollution while groundwater resources have limited yield but greater reliability in terms of water quality.

During 2016, G. Adrovac was connected to the central water supply network, although this settlement has a local autonomous groundwater supply system. D. Suhotno also uses an autonomous system, while Krušje still has no supply system. Settlements that have mineralized water are supplied with water from a central distribution system. Due to lack of infrastructure, especially pipeline, and bearing in mind the much higher cost of those works in comparison to developing an autonomous water supply system, additional research of groundwater in this area can be cost-effective. Case studies from both Ruma and Novi Kneževac areas show us that the use of groundwater as an alternative to centralized water supply is reasonable, especially in situations where groundwater resource is already available on site and is of good quality.

It would be beneficial to start with conjunctive use of surface and groundwater where conditions for that exist. The first step would be transfer of jurisdiction over local water supply systems to public waterworks companies, because that would provide the possibility for integral planning of the whole system. After that, locations that have sufficient volume and satisfactory quality of resource from an autonomous supply system could use it while infrastructure is developed in those areas that have issues with supply. The type of resource that is to be used should be planned based on the many mentioned factors for each particular case.

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REFERENCES

Brančić, A. & Nešković, D. 2016 Groundwater of artesian aquifers as alternative for water supply of remote settlements in municipality of Aleksinac (Central Serbia). In: *2nd EWaS International Conference*, 1–4 June 2016, Chania, Crete, Greece.

Čađo, S., Đurković, A., Novaković, B., Denić, Lj., Dopuđa Glišić, T., Stojanović, Z. & Veljković, N. 2016 Fitoplankton akumulacionog jezera Gruža. In: *(Phytoplankton of the Gruža Reservoir) 45th International Conference of Water Use and Protection 'Voda 2016'*, Zlatibor, Serbia, pp. 251–258.

Cibulić, V. V., Stamenković, J. L., Luković, M. J., Staletović, M. N. & Ranđelović, L. J. 2013 Kvalitet vode u akumulaciji 'Barje' petnaest godina nakon formiranja i nultog ispitivanja (Water quality in 'Barje' reservoir fifteen years after filling and zero test). *Vodoprivreda* **45** (261–263), 111–122.

Dimkić, M., Stevanović, Z. & Djurić, D. 2011 Progress and improvement of the status of groundwater in Serbia. In: *Proceedings of IWA Specialist Groundwater Conference*, Belgrade, Serbia, Invited Paper, pp. 81–101.

Dokmanović, B. & Nikić, Z. N. 2015 Analiza (ne)održivosti aktuelne strategije vodosnabdevanja u Srbiji (Analysis of (un)sustainability of the current water supply strategy in Serbia). *Tehnika* **70** (3), 433–441.

EC 2014 *Framework for Action for the Management of Small Drinking Water Supplies, European Union*. doi: 10.2779/937641.

Hamchaoui, S., Boudoukha, A. & Benzerra, A. 2015 Drinking water supply service management and sustainable development challenges: case study of Bejaia, Algeria. *Journal of Water Supply: Research and Technology – AQUA* **64** (8), 937–946.

Heidarzadeh, N. 2017 A practical low-cost model for prediction of the groundwater quality using artificial neural networks. *Journal of Water Supply: Research and Technology – AQUA* **66** (2), 86–95. doi: 10.2166/aqua.2017.035.

Jinno, K., Zongxue, X., Kaw Amura, A. & Tajiri, K. 1995 Risk assessment of a water supply system during drought. *Water Resources Development* **11** (2), 185–204.

Jovanić, P., Stanisavljević, S., Radovanović, S., Vojinović, Z., Radivojević, V., Zlatković, S., Živić, J., Živić, P., Onjia, A. & Savi, C. 2014 *Analiza kvaliteta vode rezervoara Bovan (Analysis of quality of water in Bovan reservoir)*. Institute for Multidisciplinary Studies, Belgrade, Serbia.

Jovičić, M., Soro, A., Božinović, M., Djukić, M., Milovanović, M., Popović, M., Zdravković, D. & Milovanović, D. 2001 *Vodoprivredna osnova Republike Srbije* (*Water management master plan of the Republic of Serbia*). Institute for the Development of Water Resources Jaroslav Černi, Belgrade, Serbia.

Kostić, D., Marjanović, P., Marjanović, M., Blagojević, A., Trbojević, I., Predojević, D., Subakov Simić, G., Vulić, D., Obradović, V. & Keller, J. 2006 Drivers of phytoplankton blooms in the Vrutci Reservoir during 2014–2015 and implications for water supply and management. *Water Research and Management* **6** (3), 3–12.

Krmpotić, M. 2012a *Elaborat o zonama sanitarne zaštite izvorišta 'Dobrinci' (vodovod Ruma) (Elaborate about defining sanitary protection zones of water source 'Dobrinci' (waterworks company Ruma))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Krmpotić, M. 2012b *Elaborat o zonama sanitarne zaštite izvorišta 'Grabovci' (vodovod Ruma) (Elaborate about defining sanitary protection zones of water source 'Grabovci' (waterworks company Ruma))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Krmpotić, M. 2012c *Elaborat o zonama sanitarne zaštite izvorišta 'Mali Radinci' (vodovod Ruma) (Elaborate about defining sanitary protection zones of water source 'Mali Radinci' (waterworks company Ruma))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Krmpotić, M. 2013a *Elaborat o zonama sanitarne zaštite izvorišta 'NIkinci' (vodovod Ruma) (Elaborate about defining sanitary protection zones of water source 'Nikinci' (waterworks company Ruma))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Krmpotić, M. 2013b *Elaborat o zonama sanitarne zaštite izvorišta 'Putinci' (vodovod Ruma) (Elaborate about defining sanitary protection zones of water source 'Putinci' (waterworks company Ruma))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Krmpotic, M. & Tadic, D. 2015 *Elaborat o rezervama podzemnih voda na izvorištima u opštini Novi Kneževac kojima upravlja jkp '7. oktobar' (opština Novi Kneževac) (Elaborate about groundwater reserves on sources in municipality of Novi Kneževac under jurisdiction of public waterworks company '7. Oktobar' (municipality of Novi Kneževac))*. HidroGeoEko Inženjering d.o.o., Belgrade, Serbia.

Mihajlović, D., Ilić, B. & Stojanović, D. 2011 Optimalna upotreba obnovljivih resursa u funkciji zaštite životne sredine (Optimal use of renewable resources in function of environment protection). In: *Proceedings of First Symposium of Natural Resources Management*, pp. 53–63.

Milenković Anđelković, A., Nikolić, D. & Anđelković, M. 2010 Investigation ecological condition and water quality of lake Ćelije. *Euroinvent* **1** (1), 88–93.

Mitrović, V., Krmpotić, M., Nešković, D., Grujić, A., Tadić, D. & Poljak, D. 2014 Water supply of municipality of Novi Kneževac with groundwater – current state and recommendations. In: *35th International Professional-Scientific Meeting 'Water Supply and Sewerage'*, Kladovo, Serbia.

National Assembly 1999 *Rulebook on the Hygienic Quality of Drinking Water*. *Official Gazette of SRK, 42/98 and 44/99 Republic of Serbia*, Belgrade, Serbia.

National Assembly 2011 *The Law of on Public Utilities*. *Official Gazette of Serbia, 88/11 Republic of Serbia*, Belgrade, Serbia.

Nešković, D. 2014 Autonomous local water supply systems for remote settlements – municipality of Ruma (Serbia). *Acta Mineralogica-Petrographica Abstract Series* **8**, 95.

OJ 1998 *Council Directive 98/83/EC of 3 November 1998 on the Quality of Water Intended for Human Consumption*. *Official Journal of the European Communities (OJ) L 330/32*, EU.

Ostojić, A., Ćurčić, S., Čomić, Lj. & Topuzović, M. 2007 Effects of anthropogenic influences on the trophic status of two water supply reservoirs in Serbia. *Lakes & Reservoirs: Research and Management* **12**, 175–185.

Pantić, M. & Živanović Miljković, J. 2010 Regional differences between rural areas of Serbia in population aging and agricultural activities: case studies of the Indjija and Knjaževac municipalities. *SPATIUM International Review* **22**, 29–37.

Papic, P. 1984 *Practicum for Creation of Chemical and Microbiological Analysis of Water*. Faculty of Mining and Geology, Belgrade, Serbia.

Polomčić, D., Stevanović, Z., Bajić, D., Hajdin, B., Ristić Vakanjac, V., Dokmanović, P. & Milanović, S. 2012 Vodosnabdevanje i održivo upravljanje podzemnim vodnim resursima u Srbiji (Water supply and sustainable use of groundwater resource in Serbia). *Vodoprivreda* **44** (258–260), 225–231.

Schindler, D. W. 2012 The dilemma of controlling cultural eutrophication of lakes. *Proceedings of the Royal Society of London B: Biological Sciences* **279** (1746), 4322–4333. doi:10.1098/rspb.2012.1032.

Schindler, D. W., Hecky, R. E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J. & Kasian, S. E. M. 2008 Eutrophication of lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole-ecosystem experiment. *Proceedings of the National Academy of Sciences* **105** (32), 11254–11258.

Sedmak, B. & Svircev, Z. 2011 *Cijanobakterije i njihovi toksini-ekološki i toksikološki rizici i cvetanje cijanobakterija u Srbiji (Cianobacteria and its tocsin – ecological and toxicological risks and blooming of cyanobacteria in Serbia)*. Visoka šola za varstvo okolja, Velenje, Slovenia.

Smith, A. & Comeskey, A. 2010 *Sustainable Wells: Maintenance, Problem Prevention, and Rehabilitation*. CRC Press, Taylor and Francis Group, Boca Raton, FL, USA.

Špadijer, S. & Živanovic, V. 2005 *Projekat hidrogeoloških istraživanja za potrebe vodosnabdevanja preduzeca Almina (opština Aleksinac) (Project of hydrogeological research for water supply of Almina company (municipality of Aleksinac))*. Faculty of Mining and Geology, Belgrade, Serbia.

Svirčev, B., Tokodi, N., Drobac, D. & Codd, A. 2014 Cyanobacteria in aquatic ecosystems in Serbia: effects on water quality, human health and biodiversity. *Systematics and Biodiversity* **12** (3), 261–270.

Tsur, Y. & Graham-Tomasi, T. 1991 The buffer value of groundwater with stochastic surface water supplies. *Journal of Environmental Economics and Management* **21**, 201–224.

Vukmirović, D. 2014 *Statistički godišnjak Republike Srbije 2014 (Statistical Yearbook of the Republic of Serbia 2014)*. Statistical office of the Republic of Serbia, Belgrade, Serbia.

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