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Karstic sources of water supply for large consumers in Southeastern Europe – sustainability, disputes and advantages

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ABSTRACT

Southeastern Europe is known worldwide as classic karst terrain. In the Alpine orogenic belt the karstified carbonate rocks are either dominant, as in the Dinarides, or widely distributed, as in the Carpathian-Balkans, Hellenides or Pindes. Concerning karstic groundwater resources, this region is by far the richest in all of Europe. Some areas, such as southern Montenegro, are characterized by an intensive and high precipitation affecting the water balance. In several countries in the region, water supply from karstic aquifers prevails. There are very large cities with populations of over a half million that depend on a water supply from karst aquifers. Among them are five capitals.

Tapping large springs is the traditional method of water supply in the region but the main concern is their unstable discharge regime. This is why many aquifer control projects have been prepared or proposed in the region, particularly in the Mediterranean coastal area. Unfortunately, few have been executed and completed. Even some springs have been abandoned and water supply reoriented towards surface waters or alluvial aquifers. In contrast, with the tapping of the large sublacustrine spring Bolje sestre in Montenegro, the largest of the projects concerning regional water supply in karst is currently being implemented. Some 1.5 m^3/s of the water from the Skadar basin will supply the coastal zone. It is expected that this project, essential for the national economy, will be completed in 2011. Some other proposed large projects such as overseas karstic spring water transportation from Albania to Italy are still under evaluation. However, large and rich karstic reservoirs in this part of Europe should remain a reliable source for water supply in the future despite some possible negative impacts of climatic variation. There is, in fact, the prospect of and interest in exporting and supplying water to both neighbouring and remote areas.

Keywords: karst, aquifer, water supply, groundwater control, SE Europe

1. INTRODUCTION

When one talks about southeastern Europe (SEE), the first thing that comes to mind may be its beautiful sea, mountains and karst. The Dinaric Kras in the central part of the SEE is a typical area for dissolution landforms and aquifers; the regional names kras, crasso, Germanicised as “karst”, are now applied to modern and palaeo-dissolution phenomena worldwide, thanks mostly to Jovan Cvijić and his numerous followers (FORD, 2005).

Exploration and utilization of karstic waters is an ancient art in the area. For example, 11 long aqueducts delivered more than 13 m^3/s of water to ancient Rome from distances

Figure 1: Main branches of the Alpine orogenic system and locations of the springs discussed here (modified from STEVANOVIĆ, 2010a).

ranging from 16–91 km (LOMBARDI & CORAZZA, 2008). Several water supply systems from that time have been completely reconstructed but still use the same springs and pipeline routes. Some "modern" water systems constructed in the 19th century still function perfectly and deliver pure karstic water over a long distance, as in the case of Vienna.

SEE is one of the most water-rich regions of the world, but due to its specific water regime and the behaviour of the karst, the local population often suffers from water shortages. For this reason karst and its features are still attracting scientists, particularly hydrogeologists and karstologists, but also engineers searching for an optimum solution to tapping and controlling karstic groundwater (Fig. 1).

2. CURRENT GROUNDWATER SUPPLY FROM KARST

In the Alpine orogenic belt, the karstified carbonate rocks are either dominant, as in the Dinarides, or widely outcropping, as in the adjacent Carpathian-Balkans, Hellenides or Pindes. The water supply from the karst is dominant along the coastal area and in the islands where karstic waters are commonly even the sole resource. In the continental part, numerous large karstic springs along the foothills of karstic massifs are also regularly tapped. At present, five capitals of the SEE (Vienna, Sarajevo, Tirana, Skopje and Podgorica), and numerous large towns utilize karstic waters for drinking purposes, and rarely for industrial purposes or for irrigation (STEVANOVIĆ, 2010a).

Within the official EU boundaries of the SEE region, Vienna has the largest water supply system based on karst waters (Figs. 2a,b). It serves some 1.7 million inhabitants and the yield covers around 97% of the water demands. The system consists of two major gravity pipelines, 130 and 200 km long (DRENNIG, 1973). The first pipeline was completed in 1873, the second in 1910. The long concrete tunnels and channels provide an average yield of 4.5 m^3/s from several tapped springs that drain catchments in the Alps of around 600 km^2. The water is of excellent quality; only chlorination is required, generally for cleaning the distribution pipes.

Sarajevo gets part of its necessary waters from the Vrelo Bosne springs. The discharge of this group of springs that drain a rich Triassic aquifer of the Igman Mt. is in the range of 1.4–24 m^3/s (ČIČIĆ & SKOPLJAK, 2004). Currently, 0.4 m^3/s is an average discharge directly tapped from the springs while the Water Master Plan counts on roughly an additional 1 m^3/s to be used by the intake in the open course located downstream (KOVAČEVIĆ & LONČAREVIĆ, 2003).

The Albanian capital Tirana obtains its water in part from the source that drains a Triassic and Jurassic karstic

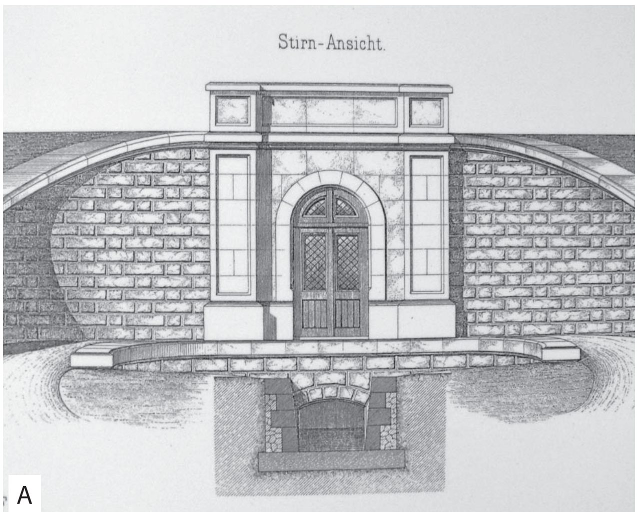

Figure 2: Kaiserbrunn spring tapped for Viennas water supply. a) original sketch from waterworks museum (left) and b) current view (right).

aquifer of the Mali me Gropa plateau. Since World War II the two main springs, Selita (0.24 to 0.86 m^3/s) and Shemria (0.45 and 1.50 m^3/s), have been tapped for the city (EFTIMI, 1971), while a large reservoir has been constructed (EFTIMI, 1998) downstream from the third important spring Buvilla, issuing from Dajti Mt.

The Mareza spring (2.0–10.0 m^3/s) in the Skadar basin is the main source of the Montenegro capital city of Podgorica. This group of typical ascending springs discharges at the 2 km long, point of contact between the Cretaceous limestone and limnoglacial sediments of the basin (RADULOVIĆ, 2000).

The capital of FRY of Macedonia, Skopje, obtains most of its drinking water from a karstic aquifer formed within Palaeozoic marbles. Rašče Spring situated on the Vardar River bank is characterized by a relatively stable discharge regime (Q_{av}=2.5 m^3/s). According to the results of tracing tests and isotopic analyses, the main recharge of Rašče water is from a porous aquifer of the upstream Pološko Polje and percolated Vardar water.

Along the Adriatic, Ionian and Aegean coasts, almost all cities and tourist centres consume karstic groundwater. Perhaps the most famous and the largest spring on the northern Italian coast, Timavo, with an average discharge rate of 30 m^3/s, supplied water to Trieste in the past.

Rižana near Koper is the main source for supplying water to the Slovene coastal zone. Its average discharge is 4.3 m^3/s (Q_{min}= 0.03 m^3/s, KOLBEZEN & PRISTOV, 1998).

The Zvir group of springs were tapped at the end of the 19th century to supply water to Rijeka, the largest Croatian port. The discharge varies between 0.6 and 3.0 m^3/s (BIONDIĆ & GOATTI, 1984a).

Jadro Spring is the main source for the water supply of Split. The average minimum discharges of Jadro during the recession period are 3–5 m^3/s, while maximum discharges are often over 50 m^3/s (BONACCI, 1987, DENIĆ-JUKIĆ & JUKIĆ, 2003).

Ombla Spring is the largest permanent karstic spring in the South Adriatic. It supplies the city of Dubrovnik. Since the completion of the Trebisnjica hydro-electric system and the regulation of this biggest sinking river in Europe, the average discharge of Ombla has been reduced from 34 m^3/s to 24 m^3/s. However, the minimum discharge (2.3 m^3/s) is not affected by the applied measures (MILANOVIĆ, 2006).

In the continental part of the region, that is in Serbia, Romania and Bulgaria, there are several large cities that depend on karst aquifers and their discharge regimes (STEVANOVIĆ & FILIPOVIĆ, 1994). Among them are Niš, Pirot, Craiova, Trgu Jiu, Turnu Severin, Constanza, Gabrovo.

3. MAIN PROBLEMS OF KARSTIC WATER UTILIZATION

There are several problems encountered when tapping and utilizing karstic groundwater in the SEE. They can be classified into two major groups:

1. Quantity limitation
2. Quality deterioration.

1. The main concern in karst is an unstable groundwater regime as a result of an uneven rainfall distribution throughout the year. Many consumers in the region fight every year to ensure a water supply during low water periods (summer and autumn). The problem is growing in large urban areas: migration of the population towards the cities, their fast urbanization, and the growth of industry in the 20th century has caused an increase in the number of tapped springs. In addition, during the summer seasons, the number of consumers and demands significantly increase along the coastal area. During the last decade, tourist expansion and population density are particularly evident in Montenegro and in Albania, and the problem of water shortage has become the main obstacle to further development.

Concerning karstic groundwater resources, this region is by far the richest in all of Europe. Some areas, such as southern Montenegro, are characterized by very high specific yield, on average over 40 $l/s/km^2$. MILANOVIĆ (2005) stated that "only through three huge springs along the Neretva Valley and Adriatic coast (Buna, Bunica and Ombla) and a few spring zones in the Kotor Bay more than 150 m^3/s, average annually, are being discharged in the Adriatic Sea directly, or indirectly through the Neretva River".

Due to limited and unstable discharge, some springs have been completely abandoned and the water supply reoriented towards surface waters or other available sources such as alluvial groundwater. Some others, such as the Aravissos group of springs, are still in use, but the water supply system of Thessaloniki was first expanded by groundwater abstraction from the alluvial aquifer of the Axios basin and since 2003 has been supplemented with the water of the Aliakmon River (SPACHOS et al., 2006). Similarly, many wells were drilled near Tirana, Podgorica and Sarajevo in an attempt to fill the gap between demands and available waters.

2. The problems of water quality in the SEE karst centre on two main concerns: Aquifer vulnerability and high risk of pollution and intrusion of salty water.

Karstic aquifers are highly precious but also extremely vulnerable sources. The problem is greater along the coast due to the many pollutants present there, untreated wastewater, and improper disposal of solid wastes. Fast-growing tourist areas in Montenegro and in Albania are particularly in danger, and during the last few years systematic action to construct modern regional municipal landfills has started.

In order to mitigate problems of rapid urbanization and uncontrolled pollution, BIONDIĆ & GOATTI (1984b) proposed four sanitary protection zones and many mitigation measures for the water source of Rijeka. Similarly, the four protection zones in the recharge area of the Rižana Spring were defined based on detailed hydrogeological research and tracer tests (KRIVIC et al., 1989).

BENSI et al. (2005) stated that the water supply of the Trieste region from the Timavo Springs is compromised by anthropogenic and industrial development and today represents only an emergency water resource (an alluvial aquifer is used as the main source of water supply).

The coastal Uji i Ftohte spring near Vlore, issues 2.5 m^3/s on average but its high quality water is threatened by pollution from the new urban area constructed upstream. There are a few cases where large springs have been impounded and devastated by artificial reservoirs. In fact, karstic aquifers remain to feed those reservoirs, but the quality of the water has significantly deteriorated (first of all due to eutrophication). Therefore, the destiny of the Dumanli Spring in Turkey, one of the largest springs in the world, is also shared by several springs of the SEE: Buvilla for Tirana, Vrela Trebišnjice in Herzegovina (submerged by Bilećko lake), Vrutačka vrela in Serbia (impounded by Vrutci reservoir), etc.

The risk and intensity of salt water intrusion depends on: the source location and altitude and the extraction rate. As a result of intensive and fast karstification, epirogenic movements and the rise in sea level by about 100 m since the last glacial phase, many springs are discharging at or below the existing sea level. In Boka Kotorska Bay alone there are three very large springs that discharge over 100 m^3/s after heavy rains, but almost dry out during the summer months (Sopot, Spila Risanska and Ljuta).

The hydraulic mechanism of the Sopot Spring is particularly interesting. The spring cave has been explored by speleologists and divers to a depth of 35 m and length of about 380 m of both dry and flooded channels (MILANOVIĆ S., 2005). During the hydrological maximum, when the karst channel of the Sopot submerged spring is unable to accept all inflowing water, a huge amount of water erupts from the cave, and the groundwater level rises to over 40 m above sea level (asl). The lower caverns continuously discharge groundwater to the sea bed. The conducted analyses determined that, during the low-water period, even at the most remote inland point (500 m from the sea), there is an extensive intrusion of seawater.

Therefore, despite the water abundance all along the edges of the Boka Kotorska the population of this area suffers from an inadequate supply of freshwater.

Similarly, the problem of saline intrusion or mixing fresh and sea water exists on many islands. The Almiros Spring near Heraklion on Crete is a typical example of saltwater intrusion. Groundwater drains at an elevation of 5 m asl, but the deeper part of the aquifer is under the strong influence of saltwater percolating from the estavelle identified at a depth of 25 m on the sea floor. Cl ion can reach 6 g/l.

Figure 3: Blue eye vauclusian spring, Albania.

The problem is even greater if the constructed intakes enable pumping or there are drilled wells nearby. Under such circumstances any forced extraction could lead towards increased water salinity. It is thus preferable to have: a local barrier that diverts groundwater high enough over sea level; or natural discharge sufficient to cover demands when no artificial intervention is needed.

Few large springs along the coast are located far enough from the sea or at higher altitudes. Among the biggest of such springs are Jadro near Split, at 35 m asl at the contact with Eocene flysch sediments, and Blue eye, part of the Bistrica group of springs in Albania (Syri Kalter, Fig. 3) discharging at elevations of 152–157 m asl.

4. KARST AQUIFER CONTROL

In order to mitigate water shortages in the SEE many karst aquifer regulation projects have been prepared or proposed. Most of them aim to control discharge by constructing underground reservoirs. Unfortunately, only a very small number of these projects have been executed. There are many reasons for this, but generally it is due to the greater cost of the exploration of karst groundwater and its lower predictability in terms of final outcomes. Although the extraction of karstic waters by classical intakes is regularly much cheaper than other sources used, the cost of underground reservoirs is not low and alarms potential investors. This is the main reason why some good ideas, such as reservoirs proposed to control karstic springs along the Metohija basin edge (Beli Drim, Istok, Vrelo), have never been realized (PERIĆ et al., 1980). The Ombla reservoir is one of biggest such proposed projects for which complex research has been undertaken (MILANOVIĆ, 2006).

In the continental part of the region, hydrogeological surveys undertaken from 1987–1997 have made possible the construction of several successful systems for the artificial control of karst aquifers in Serbia (STEVANOVIĆ, 2006, STEVANOVIĆ et al., 2007). The largest system for aquifer control was constructed as part of the regional water system “Bogovina“ in Eastern Serbia. Similarly, a solution with pumping wells has been applied to the water supply of Contanza (Romania), a Black Sea coastal resort and port. The battery of drilled wells taps the semi-confined karstic aquifer in Jurassic limestones.

A solution that combines pumping from the siphon and drilled wells has been applied at the vauclusian Modro oko spring (Krupac source), one of the sources for the water supply of Niš (the second largest city in Serbia).

The regional system for the Montenegro coast is now under construction and should be completed in 2010 or 2011. The system is planned for a maximum capacity of 1.5 m^3/s in two stages. The total pipeline length is 140 km. The water will be tapped from one of the numerous sublacustrine karstic springs of Skadar Lake – Bolje sestre (Q_{min} = 2.3 m^3/s). The

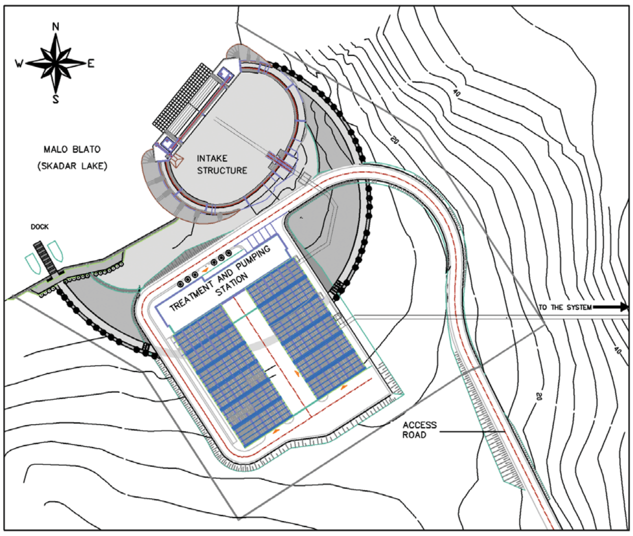

Figure 4: Coffer dam and water treatment plant of the Bolje sestre source.

Figure 5: Preparatory works for the foundation of a coffer dam at Bolje sestre spring (STEVANOVIĆ, 2010b).

water discharges through several registered points near the shore (STEVANOVIĆ et al., 2008). The problem of tapping an impounded spring will be solved by two means: the coffer dam and pumping shaft (located nearby the most productive drilled borehole). The basic idea was to tap the water before it reaches the submerged discharge points (Figs. 4, 5). Simply, this should be the best way to avoid mixture with waters of the lake and the threat of groundwater quality deterioration. The fact that the pumping capacity from the shaft-well must not result in significant drawdown and exaggerate lake water intrusion has been taken into consideration.

The concrete elliptical structure – coffer dam will cover an area of some 300 m^2. The concrete dam will have a rubber gate spillway, and its task will be both to evacuate untapped water, and to prevent inflow of lake water. In fact, the mobile gate has the form of a wide tube made from special resistant rubber that can be filled with compressed air (STEVANOVIĆ, 2010b).

5. PROSPECTIVES OF KARST GROUNDWATER SUSTAINABLE USE

The karstic aquifers will certainly remain the main source for water supply for a long time in most of the SEE. For the last several years we have been witnessing interest in large scale projects, and the export of good quality karstic waters to remote areas has increased. The options of water tankering or construction of overseas submarine pipelines to remote destinations has been discussed informally but openly at the conferences.

Such an idea to tap unutilized waters on the Albanian side and transfer them over the Otranto Channel to the Adriatic Sea which divides the Puglia Region in Italy from Albania

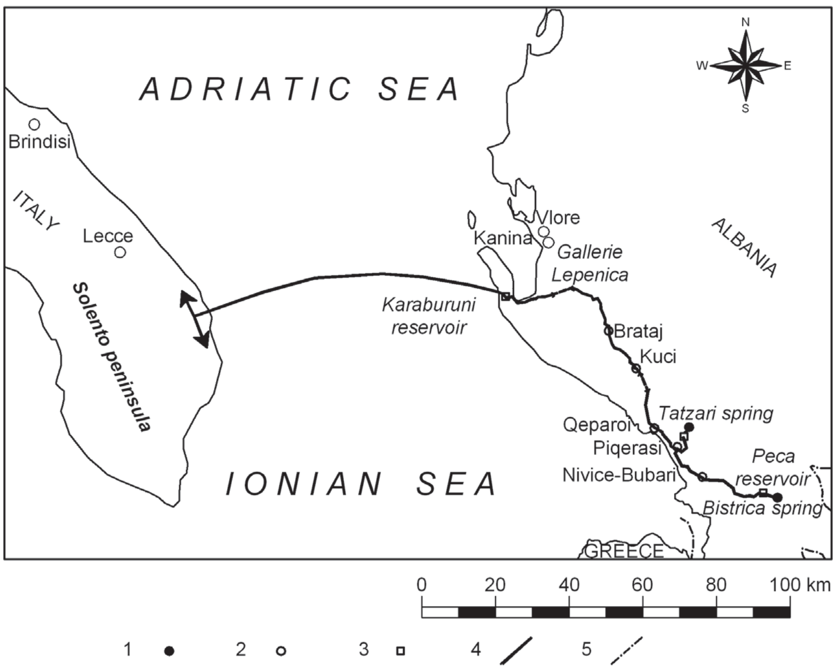

Figure 6: The scheme for the Trans-Adriatic water project. Legend: 1. Spring; 2. City; 3. Reservoir; 4. Pipeline; 5. State boundary.

(at the closest, a distance of 85 km), has been seriously proposed and evaluated. Out of an average yield of 18 m^3/s, distribution of 4 m^3/s is proposed from the Blue eye – Bistrica group of springs. This proposed system comprises three main sections: Albanian territory; Submarine section in the Adriatic Sea; and the Italian territory (Fig. 6).

There are still many steps that have been undertaken for more rational utilization and sustainable development of karstic aquifers in the SEE. Two essential ones are balancing and monitoring resources. For the first, interdisciplinary and comprehensive research programs should be undertaken in many countries of the region. This is particularly important for those in coastal areas where many underground flows towards the sea are still unidentified. New investigation techniques and sophisticated instruments should be used together with classic methods such as diving, remote sensing, tracing, geophysics, drilling, and hydrochemistry. Secondly, monitoring is a basic precondition for any environmentally safe water management. Discharge of many large springs or groundwater table fluctuations in the region are still unknown. For example, no single observation borehole for permanent measurements exists along the Adriatic coast from Dubrovnik to Saranda. Without essential historical data it would not be so easy to discuss the issue of the impact of climatic change on the groundwater.

6. CONCLUSION

Water management (including transboundary), monitoring and control of karst aquifers, and protection measures against the pollution of karstic surfaces are the most important aspects that require careful study in order to ensure the sustainable development of the SEE karst environment.

Difficulties in karst water resource management represent the main and real reason for possible conflict when they are internationally shared (BONACCI, 2008). This is particularly important in this region where almost no single river basin is exclusively domiciled. Furthermore, many large springs are characterized by having their catchment in one country and the drainage zone in another.

The former Yugoslavia is at the centre of the Balkans and South East Europe, where have recently ceased, and, new states and boundaries have been created. This has given rise to many questions regarding common and optimal water strategy in the region. However, during the last two or three years, many initiatives and concrete actions have been undertaken and now provide an optimistic ambience for future work and cooperation.

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