Karst groundwater quantity assessment and sustainability: the approach appropriate for river basin management plans

Veljko Marinović, Zoran Stevanović

Karst groundwater quantity assessment and sustainability: the approach appropriate for river basin management plans | Veljko Marinović, Zoran Stevanović | Environmental Earth Sciences | 2019 | |

10.1007/s12665-019-8364-3

http://dr.rgf.bg.ac.rs/s/repo/item/0006009

Environmental Earth Sciences (2019) 78:362
https://doi.org/10.1007/s12665-019-8364-3

THEMATIC ISSUE

Karst groundwater quantity assessment and sustainability: the approach appropriate for river basin management plans

Veljko Marinović[1] · **Zoran Stevanović**[1]

Received: 30 September 2018 / Accepted: 1 June 2019

Abstract

As a result of the fact that karstified rocks can accumulate large amounts of high-quality groundwater, karst aquifer is considered, throughout the world, one of the most important types of aquifers. Due to their high permeability, but also vulnerability to pollution, these precious groundwater resources need to be properly evaluated and protected. Taking into account heterogeneity and complexity of the karst environment, it is difficult to propose a uniform algorithm for managing karst groundwater, which causes the necessity to most often apply a case-by-case approach. The rules and standards of the EU Water Framework Directive require the development of Management Plans for all, and entire, river basins. Such plans include the estimation of pressures on water quality and quantity and have already been prepared for most basins of the European Union countries. This paper discusses the applied methodology and some of the results that have been obtained through the analyses of quantitative pressure on delineated groundwater bodies within the Danube and Sava River basins in Bosnia & Herzegovina and Serbia. The analyses confirmed the immense potential of karst aquifers in both countries as regards groundwater quantity.

Keywords Karst groundwater management · Pressure on water quantity · River Basin Management Plan · Bosnia & Herzegovina · Serbia

Introduction

Karst springs have been the subject of interest of the world's population since the earliest ages. Many ancient cities were situated near big karst springs, which provided water for sufficient supply of the local populations. Karst spring water had been tapped throughout the ancient Roman Empire, as well as in the Middle East, Egypt and China (Stevanović 2010; Krešić 2010; Stevanović 2018). In principle, karst groundwater naturally has excellent quality and is present in great quantities. Knowing this, one might be prompted to ask: what is the problem, then, if high-quality karst groundwater can meet all the water demands? The most common problem is the seasonal fluctuation of both quality and quantity of water in the course of a hydrological year. For instance, heavy rains and floods can deteriorate the quality of karst groundwater (especially its turbidity and microbiology), while seasonal depletion of karst groundwater reserves can jeopardise the local water supply. Figure 1 shows one typical karst spring hydrograph, where water shortages can occur at the time when the need for this resource is the greatest. Such great and rapid changes in karst groundwater quality and quantity can be explained by the natural complexity, heterogeneity and anisotropy of karst systems. These are the reasons why karst systems (and aquifers) are very difficult to explore, manage and protect (Bakalowicz 2010).

Groundwater management can be defined as a process that secures enough water of suitable quality to meet the demand at all times, provided that the demand is reasonable and that there is no waste of water (Krešić 2013). Groundwater management also needs to include water for dependent eco systems (WDEC). The safe yield concept implies determination of the amount of water that can be withdrawn from an aquifer without causing significant ecological impacts (Meinzer 1920). Also, some authors are of the opinion that the safe yield concept is achieved when

---

This article is a part of a Topical Collection in Environmental Earth Sciences on Sustainable Management of Karst Natural Resources, guest edited by Drs. Sasa Malinovic and Zoran Stevanovic.

✉ Veljko Marinović
veljko.marinovic@rgf.bg.ac.rs

[1] Department of Hydrogeology, Faculty of Mining and Geology, Centre for Karst Hydrogeology, University of Belgrade, Đušina 7, Belgrade 11000, Serbia

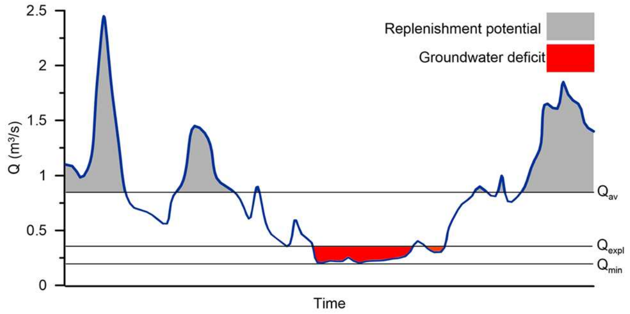

Fig. 1 Typical hydrograph of a karstic spring, which shows a possibility of regulation of karst aquifers Stevanović (2015a, b), modified

the amount of withdrawn groundwater is equal to the average replenishment (recharge) rate of the same aquifer from natural and artificial recharge, but this definition seems to be controversial for many scientists and professionals (Custodio 1992; Burke and Moench 2000; Bredehoeft 2002; Devlin and Sophocleous 2005; Alley 2007; Krešić 2013).

Managing groundwater in a sustainable way has been a priority task in the past decades of the twentieth century. There are many conventions, protocols and agreements that have been signed at the international and local level with the aim of regulating water management issues, considering mostly rational and balanced utilisation of surface and groundwater resources and their protection from pollution (Stevanović and Marinović 2016). Among them, the most important legislative document is the Water Framework Directive (WFD), which has been adopted by the European Union (EU) in 2000 with the aim to preserve, protect and improve the environment and the quality of water by also promoting reasonable and rational use of natural resources. WFD is actually a framework that describes several steps that need to be taken to achieve a good qualitative and quantitative status of all water bodies to protect and restore aquatic ecosystems, as a basis for ensuring long-term sustainable use of water for people, businesses and nature (EC report 2012). The European non-member countries have also incorporated the concept and solutions of WFD in most of their water regulations. The concept is based on precautionary and preventive actions, which in terms of groundwater will provide their 'good' quantitative and chemical status by 2015, or at the latest by 2027 (WFD 2005; Stevanović 2011). The planning process within the implementation of WFD starts with the transposition and the administrative arrangements, followed by the characterisation of the river basin district, monitoring and assessment of the status, setting of the objective, and finally the programme of measures and their implementation (EC report 2012). The European Commission has also developed a Common Implementation Strategy (CIS) to support the implementation of the WFD by publishing several guidance documents and technical reports, such as CIS Guidance Documents No. 15, 16, 17, 18 and 26, which refer exclusively to groundwater. WFD suggests the creation of River Basin Management Plans (RBMP) and Programmes of Measures (PoM), with a strong support to international coordination to achieve the above objectives. Such an approach is quite different than the one that was commonly applied earlier to create Water Management Plans at the country level. Nowadays such plans are replaced by the National Water Strategy, while RBMP is the main operational document for water management at the catchment level.

The preparation of RBMP for the largest, often international, river basins is regularly the first step, followed by the creation of several RBMPs for smaller, inner river basins (sub-catchments). Such a hierarchical approach has also been applied in South-East Europe and the Balkan region, where the first step was the creation of the Danube RMBP (coordinated by ICPDR, 2009) and Sava RBMP (coordinated by ISRBC, 2013), while in recent years all the countries of the region started preparing their RBMPs for inner basins.

South-East Europe is one of the most water-rich regions in the world, characterised by numerous large karst springs (Stevanović 2010, Stevanović et al. 2016). Karst aquifers are of particular importance for the countries of former Yugoslavia, considering the fact that almost one-third of the total former Yugoslavia region is covered by karst features (Herak 1972, Fig. 2) and that a large percentage of the population, including the citizens of three capital cities (Sarajevo, Bosnia & Herzegovina; Skopje, North Macedonia; and Podgorica, Montenegro), use exclusively karst groundwater for drinking. Montenegro is among the world's record-holders when it comes to the use of karst groundwater (more than 90% of its potable water originates from karst aquifers), while Bosnia & Herzegovina is the record-holder concerning the number of large karst springs on the surface area of its territory (8 springs are regularly discharging more than 2000 l/s; Stevanović et al. 2016). These facts define the obligation of such countries to create RBMPs that respect the specificities of karstic terrains in the river basins that are the subject of the analysis, as well as the local hydrogeological conditions. Therefore, in water strategies and master plans, special attention ought to be paid to karst groundwater.

Methodology

River Basin Management Plans is a document required by WFD (2005), which includes an integrated approach aimed to protect and improve the quantitative and chemical status of all the water bodies and protected areas, prevent any possible deterioration of water quality and/or quantity and manage sustainable usage of water resources. Among

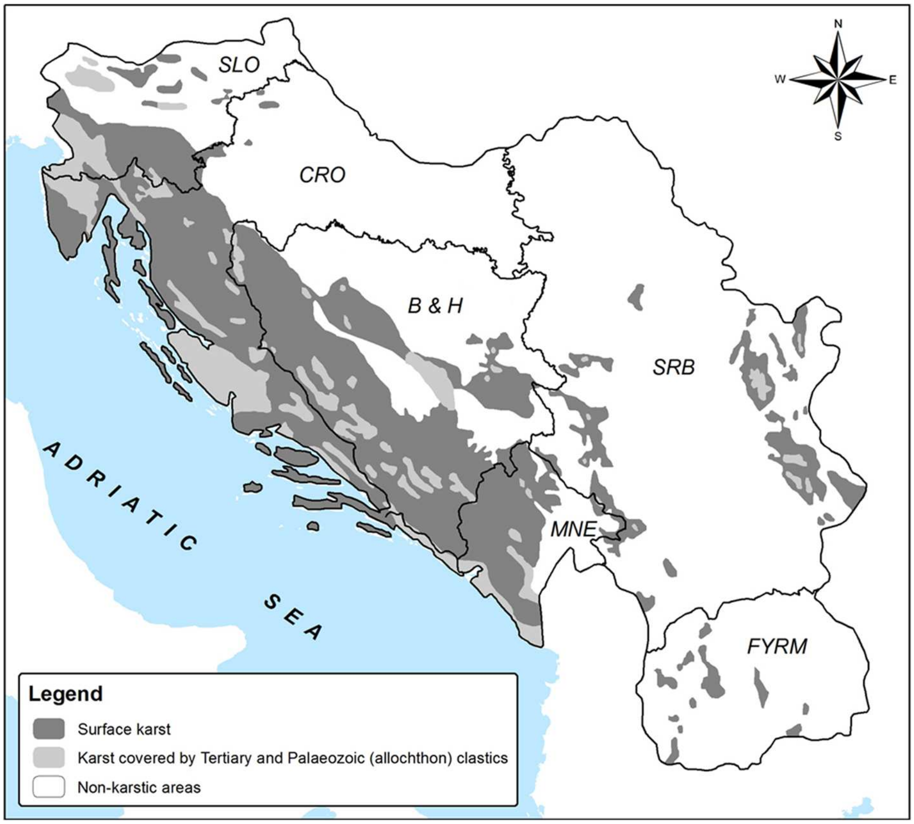

Fig. 2 Distribution of the main karst areas in former Yugoslavia Herak (1972), modified

them, groundwater plays a particularly important role because of the high percentage of its use for water supply in many European cities. Thus, each RBMP includes a section pertaining to groundwater. The analysis of several issues related to groundwater is required (Fig. 3). Based on that, the RMBP provides a programme of measures (PoM) to be used to maintain and/or improve the quantitative and chemical status of groundwater. When it comes to karst aquifers, these measures are not easy to implement due to karst aquifers' high intrinsic vulnerability, problems with catchment delineation and water resource assessment.

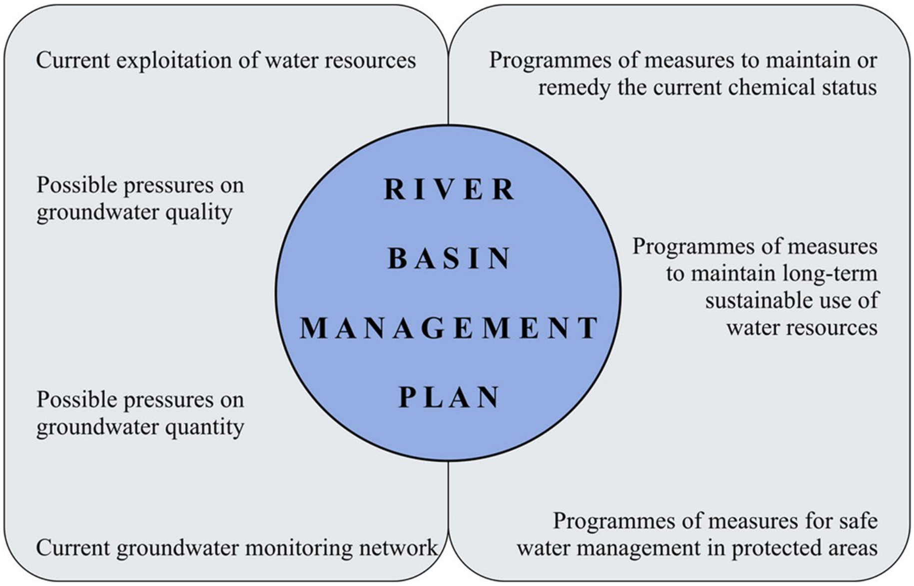

Fig. 3 Groundwater (GW) factors and outcomes included in RBMP

Hydrogeological analysis within a RBMP should include several steps:

- Delineation of groundwater bodies;
- assessment of pressures on groundwater quality and quantity;
- proposal of a groundwater monitoring network; and
- provision of a programme of measures.

As regards the delineation of groundwater bodies, the WFD and its Guideline No.2 state that there is no unique scheme or algorithm for water bodies' delineation since it depends on several factors that can vary greatly from one case to the next. This is particularly important in the case of karst aquifers, because it is very difficult to precisely determine the boundaries of a karst spring catchment area, which usually comprises autogenic and allogenic (attached) aquifer recharge zones (Stevanović 2015a). Many examples have shown that it is practically impossible to precisely determine the boundaries of a karst spring catchment area, due to high seasonal fluctuation of the water table and the reorientation of groundwater flow direction (Stevanović 2015b). For instance, there are situations where inactive karst springs located at higher elevations will start discharging, triggered by very high groundwater levels, causing an overflow from one catchment area to another (Roje-Bonacci and Bonacci 2013). Also, topographic boundaries of a karst spring catchment area are very often different from the same catchment area's hydrogeological boundaries (Bonacci 2015). Examples of karst springs in Croatia whose hydrogeological area is much bigger than their topographical catchment area were shown by Herak et al. (1981) and Bonacci and Andrić (2015). All these facts point to the "breathing" of karst spring catchment areas that takes place in the course of a single hydrological year, which significantly complicates water budget calculation and karst groundwater reserves assessment.

The WFD and its Guideline No. 2 recommend that each water body that supplies more than 50 people and whose abstraction is larger than 10 m^3/day be delineated. If this recommendation is applied consistently, the number of groundwater bodies in some countries would exceed several thousand (Stevanović 2011), which is practically impossible to monitor. Thus, grouping of groundwater bodies is absolutely necessary, as can be seen on the example of the Danube RBMP, where only transboundary groundwater bodies larger than 1000 km^2 were taken into account, while the detailed delineation of groundwater bodies was left to the RBMP of each country that belongs to the Danube River basin. As such, the so-called scale effect, which depends on the size of the concerned territory, is applied. The WFD has also set forth a logical concept "from the larger to the smaller river basin", and thus the plan for larger basins should contain data of a more general nature, while the degree of detail should increase with the transition to smaller river basins.

The next step in the hydrogeological analysis of RBMP is the conceptualisation of each groundwater body (or group of groundwater bodies). This step is essential for their characterisation. A conceptual model of an aquifer system defines the general hydrogeological conditions of groundwater flow. Several issues that must be evaluated to develop a proper conceptual model for each delineated groundwater (GW) body, particularly in karst, are shown in Fig. 4.

This step in hydrogeological analysis can be very delicate. It is not rare that a karst aquifer is actually a dual porosity system (Goldscheider 2015), which includes an uneven distribution of karst conduits and fractures in matrix porosity. That way, the degree of karstification defines the process of infiltration as well as groundwater flow direction, which is also changeable throughout a hydrological year. This is one of the reasons why detailed hydrogeological research needs to be carried out within groundwater monitoring, which is also recommended in the WFD.

The main aim of the WFD is the identification of all the groundwater bodies (or groups thereof) that are under pressure, the undertaking of measures to reduce the pressure, and—later on—the transition of bodies with 'poor' status into the group of those with 'good' status (WFD CIS 2009). This paper is focused mainly on the groundwater quantity component and the assessment of its status. There are several concepts that are used to estimate the pressures on groundwater quantity. For instance, CIS Guideline No. 15 (WFD CIS 2007) defined a groundwater body to be at good quantitative status "if the long-term annual average rate of abstraction does not exceed the available groundwater resource; groundwater levels and flows are sufficient to meet environmental objectives for associated surface waters; and

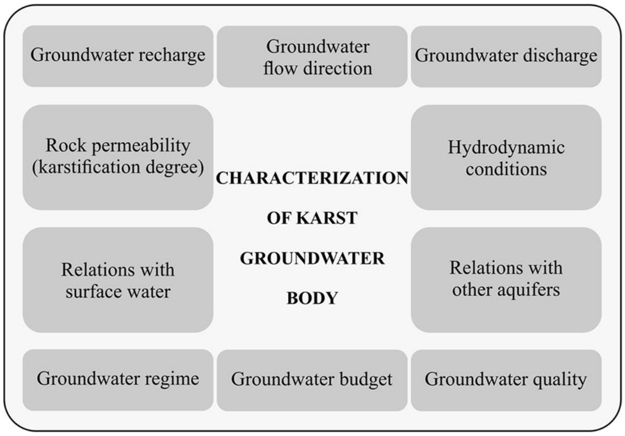

Fig. 4 An algorithm for developing a conceptual model to characterise a karst groundwater body within RBMP

groundwater-dependent terrestrial ecosystems and/or anthropogenic alterations to the flow direction resulting from the level change do not cause saline or other intrusion". According to this concept, pressures on groundwater quantity can be suitably assessed as a ratio of the totally available or renewable groundwater resources and the total water use. This could be a comparison between the total groundwater withdrawal or discharge and the total dynamic (and/or static) groundwater reserves.

Where is the risk level for pressure on groundwater quantity? This was not defined in WFD and CIS documents. The authors of this paper thus suggest two possible criteria:

1. A karst groundwater body is at risk (or under pressure) *if total groundwater abstraction exceeds two-thirds of total available groundwater reserves*. Otherwise (< 2/3), a karst groundwater body is not at risk (or not pressured).

   This criterion, which is more restrictive than usual, could be applied for ecological safety reasons and in the case of absence of proper monitoring data.
2. Another concept of groundwater quantity risk assessment can be based on a *comparison of the current groundwater exploitation rate and the total amount of water infiltrated into the aquifer*. This concept takes into account a ratio between the amount of groundwater abstraction and the amount of water that is newly infiltrated into the aquifer within a previously defined timeframe, i.e. during one hydrological year. For instance, if the annual groundwater exploitation rate exceeds 30% of the annual amount of newly infiltrated water, then a groundwater body is at risk, or under quantitative pressure, and vice versa—if that ratio is below 30%, then a groundwater body is not at risk (not pressured).

The main issue is the difference between the *renewable groundwater reserves* and the *total amount of infiltrated water*. Although many authors equalise them, the former category includes effective dynamic water reserves of an aquifer (groundwater body) confirmed over a longer period through observation of the discharge of springs or pumping of wells (well fields). The latter category does not consider confirmed groundwater reserves and is usually based on the assessed size of a catchment and the roughly estimated amount of water that could potentially infiltrate and recharge the aquifer system. Due to a lower level of confidence in the latter case, a more restrictive criterion should be systematically applied.

Although not defined by WFD, both concepts allow the setting up of an additional risk category—*potentially at risk* (*potentially under pressure*), which is the case when data on groundwater monitoring and groundwater regime are lacking. Thus, in case of the second concept, if the groundwater withdrawal is between 15 and 30% of the amount of infiltrated water, it is recommended that a karst groundwater body be placed in the category *potentially at risk* or *potentially under pressure*. However, if groundwater abstraction is still less than 15% of the amount of the newly infiltrated water, than a karst groundwater body remains in the *no-risk* (no pressure) category (Table 1). These two concepts of quantitative groundwater risk assessment have been applied in Bosnia & Herzegovina and Serbia and have shown that they are practically in line, providing almost the same final scores for pressures on studied groundwater bodies.

When it comes to determination of groundwater quantitative pressure, it should be pointed out that neither concept takes into account the fact that almost all abstracted groundwater actually returns to the groundwater body from which it was 'borrowed', either by discharge from the sewage outlet to the watercourses or through irrigation and watering of green areas. Practically, the total amount of groundwater withdrawal remains constantly within the same groundwater body, just circulating from one user to another (the so-called "return flow").

The main prerequisite for proper determination of the pressures on groundwater quantity is the application of methodology for groundwater budgeting. Groundwater budget or balance is the quantification of the recharge—discharge interrelationships within a watershed basin (Poehls and Smith 2009). Stevanović (1991) defines karst groundwater budget as an overall and complex dynamic process of recharging, circulating and discharging of groundwaters, which includes an analysis of input and output budget elements and all the factors that influence the budgeting process in specific time cycles. The karst groundwater budgeting process depends on the ratio of input parameters and output parameters, and the calculation that needs to be performed

Table 1 Different concepts of estimation of karst GW quantity pressures within RBMPs

Current extraction rate and demands of water-dependent ecosystems vs. renewable groundwater reserves (%)		Current exploitation rate vs. total amount of infiltrated water (%)
< 33	No risk (no pressure)	< 15
33–66	Potentially at risk (potentially under pressure)	15–30
> 66	At risk (under pressure)	> 30

for at least one—average—hydrological cycle (Stevanovic 2015b). Input parameters include recharge from precipitation, surface and subsurface inflow, while outflow parameters include surface and subsurface outflow, evapotranspiration, spring discharge and exploitation. The budgeting concept itself seems to be easy to solve and at the first glance does not fully reflect the complexity of a karst system. However, the problem can be posed by a particular element of the budget equation that is very difficult to measure, e.g. subsurface drainage. These karst groundwater balance elements can be determined by direct or indirect measuring methods, such as hydrometric methods or experimental and empirical methods and groundwater modelling.

Case studies

WFD recommends the creation of RBMPs and PoM to manage water resources in a sustainable way. Almost all EU countries (with the exception of Spain) have already adopted their second RBMPs for the period 2016–2021, while the situation in non-EU countries in the Balkans is slightly different: Croatia and Bosnia & Herzegovina (B&H) have mostly completed and adopted their national RBMPs for the Adriatic and Danube (Sava) basins for the period 2016–2021; Serbia has prepared the document only for the pilot areas; while Montenegro and Albania are currently in the process of preparing their RMBPs. However, a hierarchical approach has been applied in the Balkan region, so the first step in the implementation of the WFD in those countries was the creation of the Danube RMBP (coordinated by ICPDR, 2009) and Sava RBMP (coordinated by ISRBC 2013).

The methodology used for the creation of RBMPs will be shown on the examples of the Sava River Basin in Bosnia & Herzegovina and the Danube River Basin in Serbia. The delineation of karst groundwater bodies in Bosnia & Herzegovina and Serbia was based on collected geological, tectonics and hydrogeological data, historical tracer tests data, hydrogeological watersheds and recommendations from national and international water legislation. Thus, due to the large size of the river basins in Bosnia & Herzegovina in the Sava River Basin, most karst groundwater bodies were grouped. The process of grouping of karst groundwater bodies was carried out based on lithological and hydrogeological characteristics and topographical and hydrogeological watersheds. It is worth noting that in certain cases groups of groundwater bodies included two or more different aquifer types, while in others disconnected outcrops were also included in the same group of water bodies. Figure 5 shows all karst and combined (but mostly consisting of limestones and dolomites) groundwater bodies delineated in the Sava River Basin in Bosnia & Herzegovina. The main characteristics of those karst groundwater bodies are presented in Table 2. Figure 6 shows the final map of the quantitative groundwater risk assessment, where most of karst groundwater bodies were found to be not at risk, i.e. the groundwater quantity is much higher than the water use (demand), due to karst springs with high discharge rates and low population density. On the other hand, the only karst groundwater body that is at risk in terms of groundwater quantity is located near the capital city of Bosnia and Herzegovina—Sarajevo. Table 2 also shows categories of quantitative risk for all karst groundwater bodies.

Similar method was applied in Serbia, where not only open karst groundwater bodies, but also confined karst areas were delineated. The applied method is in line with the WFD and the accompanying Guidelines that define a groundwater body in three dimensions. The main difference between the groundwater delineation processes in Bosnia & Herzegovina and Serbia is that the entire territory of Serbia was covered by groundwater bodies that included impermeable rocks as allogenic parts. On the other hand, the groundwater delineation approach that was applied in Bosnia & Herzegovina included only aquifers, which means that impervious rocks were excluded from the analysis and further calculations. Figure 7 shows all karst groundwater bodies delineated in Serbia, while their main characteristics are presented in Table 2. Figure 7 (on the right) also shows the final map of the quantitative groundwater risk assessment, where most karst groundwater bodies were found to be not at risk, i.e. the groundwater quantity is much higher than the actual water use (demand), due to the presence of karst springs with high discharge rates and low population density. Table 2 also shows the risk category assessment for all those karst groundwater bodies. It should be highlighted that there is no karst groundwater body in Serbia that is actually under pressure in terms of groundwater quantity, i.e. that belongs to the ‘at risk’ category.

In most of the studied karst groundwater bodies, utilisation of karst groundwater does not exceed one-third of the total renewable karst groundwater reserves. However, this precious water resource needs to be properly utilised, especially if we bear in mind potential water scarcity caused by global warming. Thus, Bonacci (2012) studied surface air temperature regime in western Balkans during previous 30 years and showed that air temperature increased by 0.807 °C. Same author stated that in the Balkans region warming started between 1987 and 1997, mostly in 1988. These changes in air temperature have not been caused by anthropogenic factors only, but several others (Bonacci 2012). This fact points out that global warming in future may have strong influence on karst groundwater resources and their assessment in terms of reduced rainfalls in the region which are the main recharge factor of karst aquifers. Therefore, regulation of karst aquifers by artificial recharge or temporary over-pumping needs to be taken into account

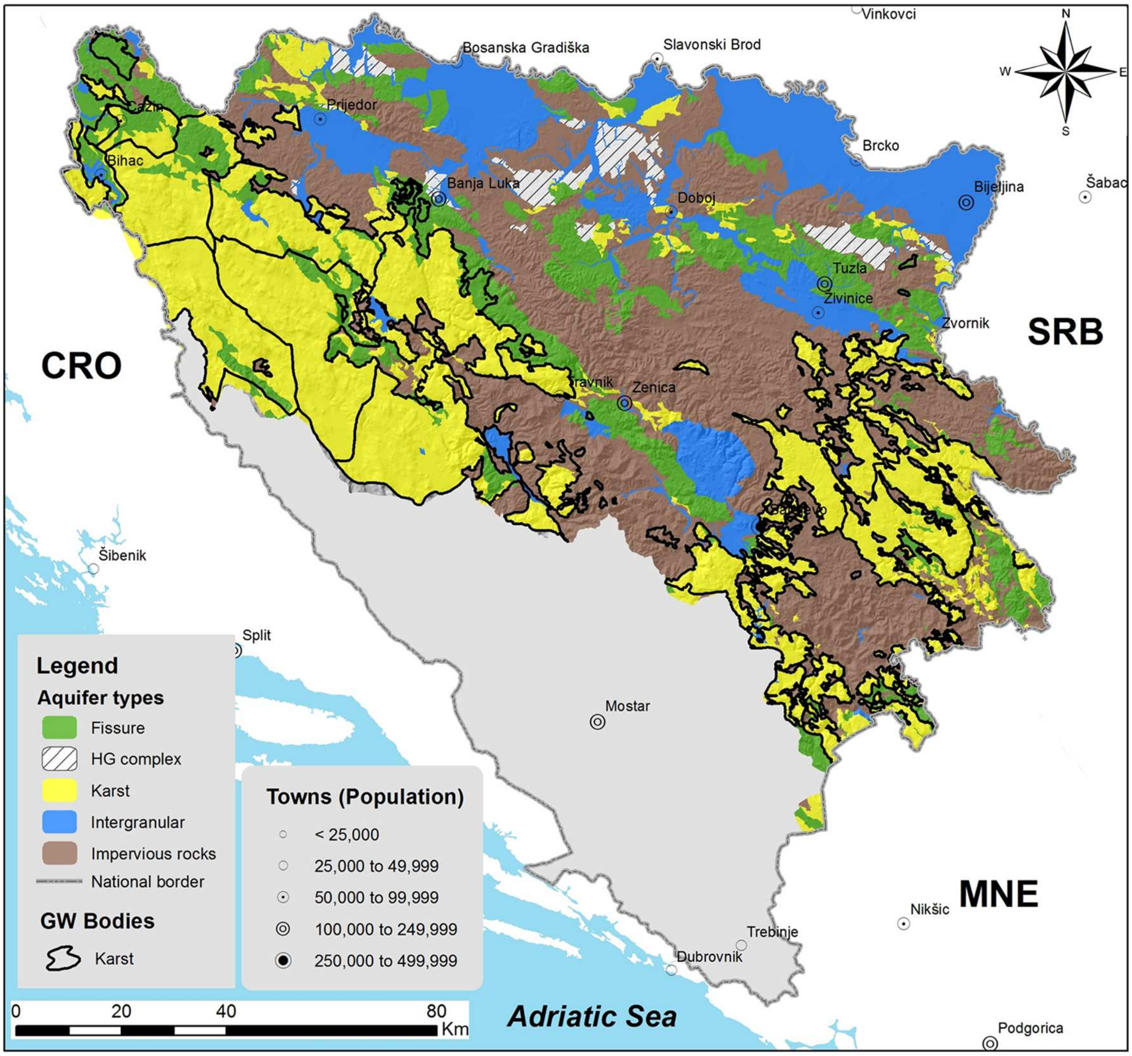

Fig. 5 Delineated karst groundwater bodies in Bosnia & Herzegovina (in the Sava River Basin)

Table 2 General characteristics of karst groundwater bodies delineated within the RBMP in Bosnia and Herzegovina (Sava River Basin) and the entire Republic of Serbia (Danube Basin)

	Number of karst GWBs	Total area of karst GWBs (km^2)	% of total area of GWBs (%)	% of total area covered by RBMP (%)	Number of karst GWBs not at quantitative risk	Number of karst GWBs potentially at quantitative risk	Number of karst GWBs at quantitative risk
B&H	17	12.426	76	32.5[a]	13	3	1
Serbia	34	9.950	12.2[b]	12.2[c]	28	6	0

[a] RBMP was done only for the Sava River Basin in Bosnia and Herzegovina

[b] Including parts of impermeable rocks

[c] Delineation of groundwater bodies in Serbia has not been done on the territory of Kosovo and Metohija

as a solution for reliable water supply throughout a whole hydrological year.

Conclusion

Many documents and protocols have already been created with the aim of protecting and defining sustainable use

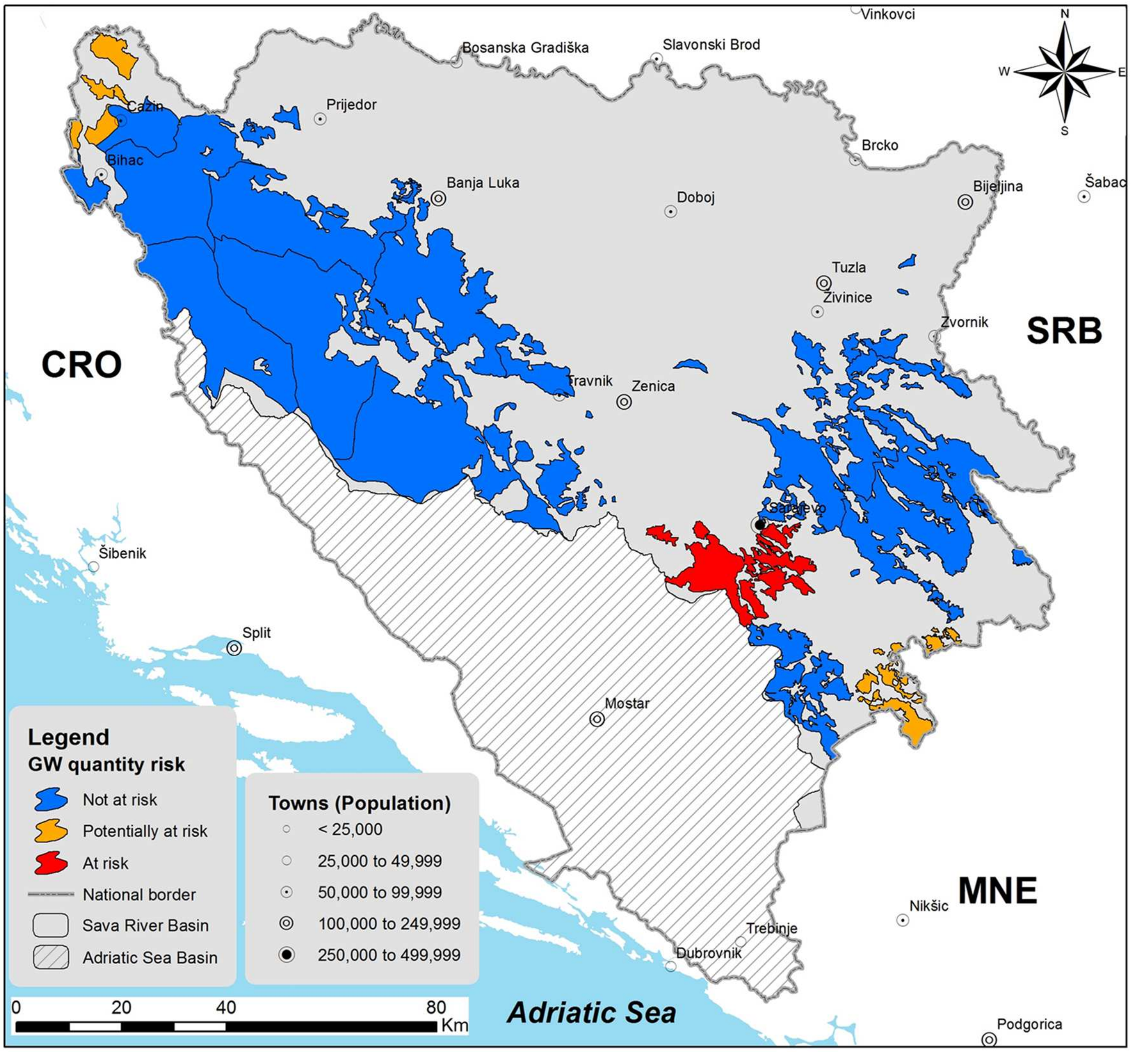

Fig. 6 Pressures on karst groundwater quantity in karst GW bodies in B&H According to ASRB (2016); PIVS (2016); GBD (2016), modified

of groundwater. The most important among them is the EU Water Framework Directive and its River Basin Management Plans (RBMPs). RBMPs are a tool that directly addresses the characteristics of ground and surface waters and their role and importance in water resources management. These documents set targets for all the water resources (surface and groundwater) and summarise all the measures that are necessary to achieve these goals. Implementation of RBMPs fulfils one of the important prerequisites for adequate and rational exploitation of water resources for various needs. Those plans, besides socio-economic and other analyses, include the determination of hydrogeological characteristics of groundwater as one of the basic prerequisites for successful implementation.

Karst terrains cover a large part of the ice-free surface of the Earth (about 14%) and it is estimated that approximately 9.2% (or around 670 million) of the world's population is supplied with karst waters. In many countries, they are the essential water resource. This is also why in many countries, and their water management plans, special attention should be paid to karst aquifers and groundwater bodies they create.

Such an experience was presented in two case studies: from Bosnia & Herzegovina and Serbia. RBMP implementation included several steps within a hydrogeological analysis: delineation of groundwater bodies; groundwater quality and quantity assessment; recommendation for groundwater monitoring; and a programme of measures that need to be undertaken in order to achieve the goals specified in the EU Water Framework Directive. Large numbers of delineated karst groundwater bodies in Serbia and B&H confirmed the high importance of karst in both countries, especially for water supply. The analyses, which included the application of two possible concepts of the assessment of pressures on

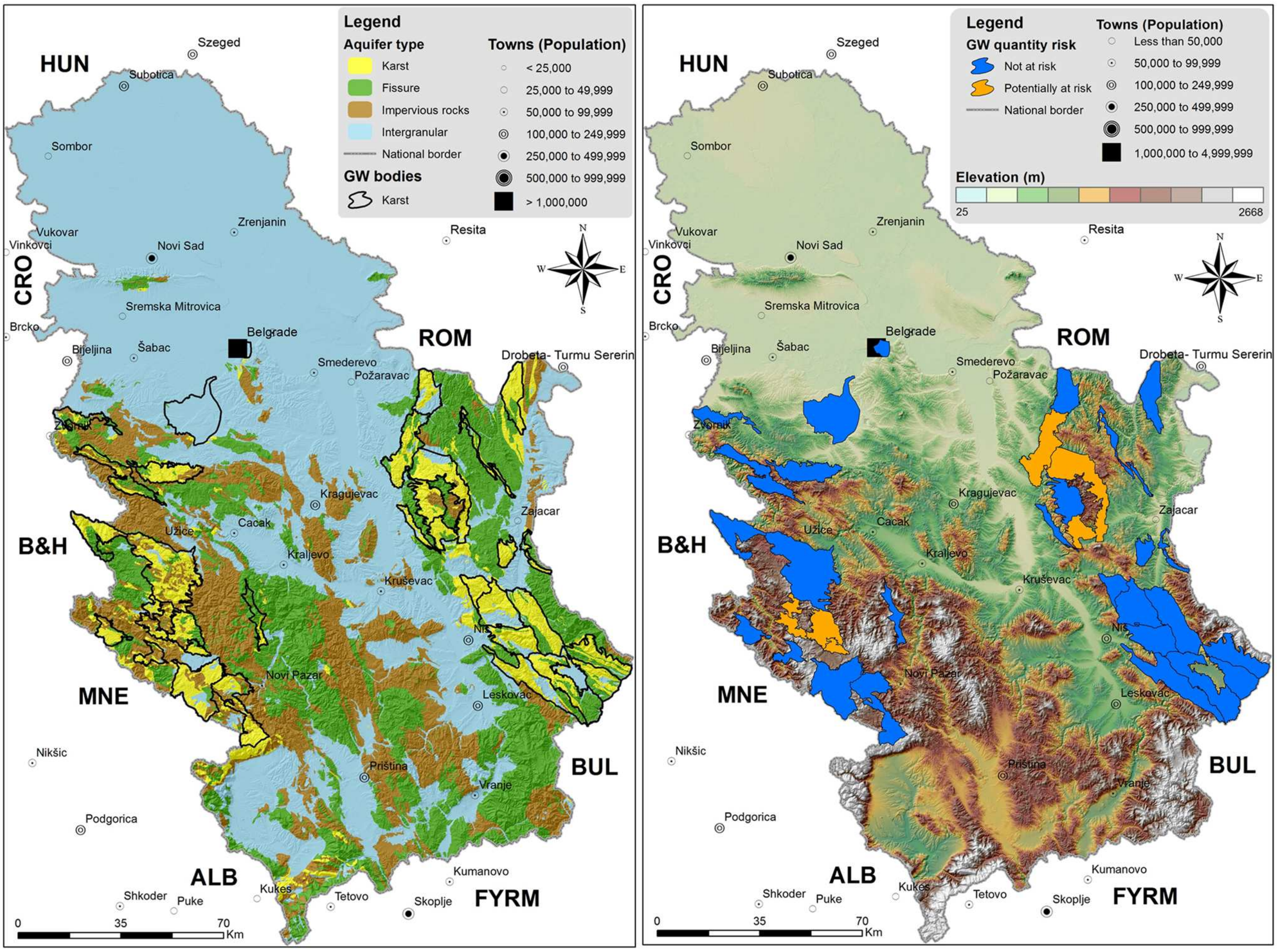

Fig. 7 Delineated karst groundwater bodies in Serbia, on the left. Pressures on karst groundwater quantity in karst GW bodies in Serbia, on the right

groundwater quantity as a ratio between utilised and replenishable resources, show relatively low pressures on karst groundwater quantity. Nevertheless, karst groundwater resources in the western Balkan region should be utilised in a sustainable way, especially because air temperature in this region raised by almost 1 °C during past 30 years, which may have direct influence on precipitation regime in this area and thus, affect to karst groundwater quantity.

This analysis shows that calculation of karst groundwater reserves is a very difficult task to perform without access to reliable data. For this reason, one of the most important objectives of RBMPs is the establishment of groundwater monitoring networks which would provide representative data based on which groundwater budgeting process and reserves' assessment could become much easier and more reliable.

EU WFD suggests the creation of a Programme of Measures, to be incorporated in every RBMP. The measures towards more sustainable water use including karst aquifers could include proper issuance of water permits and concessions, making efforts to decrease water losses in water supply systems, possible activation of new groundwater sources, artificial recharge and regulation of karst aquifers, while water permit and concession holders should be obliged to submit annual (or monthly) reports on groundwater withdrawal and water quality to achieve and/or maintain good karst groundwater status.

References

Agency for Sava River Basin (ASRB) (2016) Sava River Basin Management Plan in Federation of B&H, draft version, Sarajevo. https://www.voda.ba

Alley WM (2007) Another water budget myth: the significance of recoverable ground water in storage. Ground Water 45(3):251

Bakalowicz M (2010) Management of karst groundwater resources. In: van Beynen Philip E (ed) Karst management. Springer International Publishing, Cham, pp 263–282

Bonacci O (2012) 2012: Increase of mean annual surface air temperature in the western Balkans during last 30 years. Vodoprivreda 44(255–257):75–89

Bonacci O (2015) Surface waters and groundwater in karst. In: Stevanović Z (ed) Characterization and engineering of karst aquifers. Springer International Publishing, Cham, pp 149–169

Bonacci O, Andrić I (2015) Hydrological analysis of Žrnovnica karst spring near Split (in Croatian). Croat Waters 23(94):311–320

Bredehoeft JD (2002) The water budget myth revisited: why hydrogeologists model. Ground Water 40(4):340–345

Burke JJ, Moench HM (2000) Groundwater and society: resources, tensions and opportunities. Spec ed. of DESA and ISET, UN public. st/esa/265, New York, pp 170

Custodio E (1992) Hydrogeological and hydrochemical aspects of aquifer overexploitation. Selec. Pap. of IAH, vol 3. Verlag Heinz Heise, pp 3–27

Devlin JF, Sophocleous M (2005) The persistence of the water budget myth and its relationship to sustainability. Hydrogeol J 13:549–554

EC Report (2012) EC Report from the Commission to the European Parliament and the Council on the implementation of the Water Framework Directive (2000/60/EC), Brussels

Goldscheider N (2015) Overview of methods applied in karst hydrogeology. In: Stevanović Z (ed) Karst aquifers characterization and engineering. Springer International Publishing, Cham, pp 127–149

Government of Brčko Distrikt (2016) Sava river basin management plan in Brčko Distrikt, draft version, Brčko. https://www.bdcentral.net

Herak M (1972) Karst of Yugoslavia. In: Herak M, Stringfield VT (eds) Karst: important karst regions of the northern hemisphere. Elsevier Press, Amsterdam, pp 25–83

Herak M, Magdalenić A, Bahun S (1981) Karst hydrogeology. In: Halasi Kun GJ (ed) Pollution and water resources. Columbia University seminar series, part 1, Hydrogeology and other selected reports, vol XIV. Pergamon Press, New York, pp 163–178

Krešić N (2010) Sustainability and management of springs. In: Krešić N, Stevanović Z (eds) Groundwater hydrology of springs—engineering, theory, management and sustainability. Butterworth-Heinemann, Burlington, pp 1–29

Krešić N (2013) Water in karst—management, vulnerability and restoration. McGraw Hill, New York, p 708

Meinzer OE (1920) Quantitative methods of estimating groundwater supplies. Bull Geol Soc Am 31:329–338

Poehls DJ, Smith GJ (2009) Encyclopedic dictionary of hydrogeology. Elsevier Inc., Amsterdam

Public Institute "Vode Srpske" ("Water of Srpska") (2016) Sava river basin management plan in the Republic of Srpska, draft version, Bijeljina. https://www.voders.org

Roje-Bonacci T, Bonacci O (2013) The possible negative consequences of underground dam and reservoir construction and operation in coastal karst areas: an example of the hydro-electric power plant (HEPP) Ombla near Dubrovnik (Croatia). Nat Hazards Earth Syst Sci 13:2041–2052

Stevanović Z (1991) Hydrogeology of Carpathian-Balkan karst of eastern Serbia and water supply opportunities, (in Serbian). Faculty of Mining and Geology (spec. ed.), Belgrade, p 245

Stevanović Z (2010) Utilization and regulation of springs. In: Krešić N, Stevanović Z (eds) Groundwater hydrology of springs—engineering, theory, management and sustainability. Butterwoth-Heinemann, Burlington, pp 339–387

Stevanović Z (2011) Management of groundwater resources (in Serbian). University of Belgrade, Faculty of Mining & Geology, Belgrade, p 340

Stevanović Z (2015a) Characterization of karst aquifers. In: Stevanović Z (ed) Characterization and engineering of karst aquifers. Springer International Publishing, Cham, pp 47–122

Stevanović Z (2015b) Budget and general assessment of karst groundwater resources. In: Stevanović Z (ed) Characterization and engineering of karst aquifers. Springer International Publishing, Cham, pp 171–205

Stevanović Z (2018) Global distribution and use of water from karst aquifers. In: Parise M, Gabrovsek F, Kaufmann G, Ravbar N (eds) Advances in karst research: theory, fieldwork and applications, vol 466. Geological Society, London, Special Publications, pp 217–236

Stevanović Z, Marinović V (2016) The role and importance of hydrogeology in the creation of river basin management plans at a regional scale. In: Conference proceedings and book of abstracts / IWA specialist groundwater conference, Jaroslav Černi Institute for the Development of Water Resources, pp 180–186

Stevanović Z, Kukurić N, Pekaš Ž, Jolović B, Pambuku A, Radojević D (2016) Dinaric karst aquifer—one of the world's largest transboundary systems and an ideal location for applying innovative and integrated water management. In: Stevanović Z, Kresic N, Kukuric N (eds) Karst without boundaries. Taylor & Francis Group, London, pp 3–25

WFD (2005) Common implementation strategy for the water framework directive (2000/60/EC) groundwater summary report. Directorate General Environment of the European Commission, Brussels

WFD CIS Guidance Document No. 15 (2007) Common implementation strategy for the water framework directive (2000/60/EC) guidance on groundwater monitoring. Directorate General Environment of the European Commission, Brussels

WFD CIS Guidance Document No. 18 (2009) Common implementation strategy for the water framework directive (2000/60/EC) guidance on groundwater status and trend assessment. Directorate General Environment of the European Commission, Brussels