

Human impacts on Karst aquifers of Albania

Romeo Eftimi¹ · Hans Zojer²

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Abstract Albania is situated in the western part of the Balkan Peninsula, on the eastern coast of the Adriatic and the Ionian Sea. The karst landscape in Albania covers about 6750 km², approximately 24 % of the Albanian territory. There are 25 karst regions in the country, 23 in carbonate rocks and 2 in evaporites. The total renewable karst water resources are estimated about 227 m³/s, representing 80 % of the groundwater resources of Albania. About 70 % of the population of the cities, including also part of the capital Tirana, obtains the water from karst springs. However, the negative human impacts often are threatening the karst groundwater resources of Albania. Several bad experiences in Albania have demonstrated that the main human negative impacts on karst water are related to: (a) urbanised areas, (b) agriculture activities, and (c) quarrying activities. Understanding the vital importance of karst waters and the necessity for intensive scientific investigations and monitoring, to evidence their high vulnerability, are still at a low level in Albania.

Keywords Karst water · Pollution of karst water · Human impact on karst water · Albania

Introduction

In many countries karst aquifers represent the most important fresh water resource. Their importance is related to both the amount of karst groundwater and the overall very good quality. Several large cities populations, counting nearly or over a million of inhabitants, such as Rome, Vienna, Sarajevo, Tirana, Skopje, Podgorica, and Thessaloniki are supplied by karst springs (Stevanovic and Eftimi 2010; Kresic and Stevanovic 2010).

The population of Albania is 3.2 million of habitants, the total surface is 28,748 km² and nearly one fourth of the country is occupied by karst rocks (Fig. 1). The total natural karst water resources of Albania are calculated in 7.15×10^9 m³/y (227 m³/s). In Albania about 70 % of water supply of the cities derives from karst aquifers. Beside Tirana, some other big cities like Peshkopi, Kukes, Pogradec, Gramsh, Çorovoda, Berat, Vlora, Gjirokastra, Mamurras, Bilisht and many villages are supplied through boreholes in karst rocks. Most of the spring-based water supply systems are functioning by gravity (Eftimi et al. 1985).

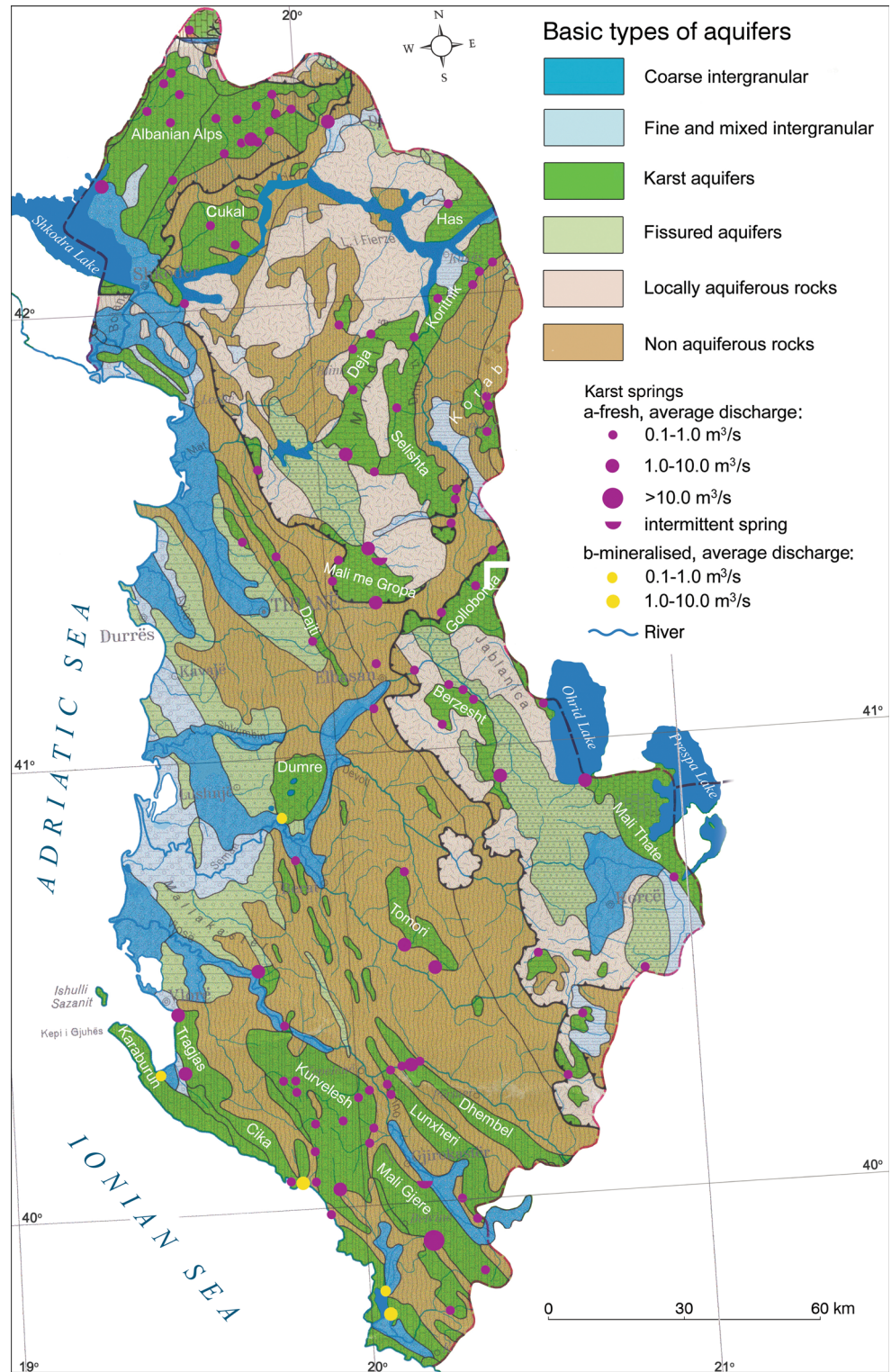
It is already known that due to their very high permeability the karst areas are highly sensitive toward any negative action performed at the surface (Goldscheider 2005). Although the karst water in Albania is the main drinking water supply source, so far specific studies for the assessment of the human impacts on karst waters still remain at a very modest stage. The problem of human impact on karst water pollution in Albania is discussed for the first time in some studies mainly focused on the natural and anthropogenic hazards in karst areas (Parise et al. 2004, 2008). The authors point out the main factors contributing to the decreasing of the good water quality in karst areas of Albania, such as: the uncontrolled urban sewage, effluent

✉ Romeo Eftimi
eftimiromeo@gmail.com

¹ Geological Service of Albania, Tirana, Albania

² Institute of Applied Geosciences, Graz University of Technology, Graz, Austria

Fig. 1 Location of karst rocks and of the main karst springs of Albania (modified from Eftimi et al. 2009)



and industrial discharges in lakes and rivers, quarrying in karst areas, the use of karst landforms as illegal dumping sites, and the use for irrigation of water from karst lakes.

The base for protection zoning and land-use planning is the groundwater vulnerability mapping. Some popular

methods for estimation of vulnerability of karst aquifers are EPIK (Dörfliger and Zwahlen 1998), “European approach” (Daley et al. 2002; Zwahlen 2004), PI method (Goldscheider et al. 2000), a simplified methodology for the application in data-poor environments (Nguyet and

Goldscheider 2006) and the Slovene Approach (Ravbar and Goldscheider 2007). Other important methods of vulnerability mapping are SINTACS (Civita and De Maio 1997), AVI (van Stempoot et al. 1993), COP (Vias et al. 2006) and PaPRIKa (Kavouri et al. 2011). The methods of vulnerability mapping differ by the parameters taken in consideration for characterisation of the karst area under investigation. The comparison of the results of the applied methods showed that they are liable to subjectivity and unreliability in the assessment procedure (Neukom and Hötzl 2007; Ravbar and Goldscheider 2009). The results are often influenced by various factors such as the availability and quality of data, and their interpretation (Kovačič and Ravbar 2015).

DRASTIC method, mostly used for mapping vulnerability of porous aquifers (Aller et al. 1987), has been used for a preliminary mapping of the groundwater vulnerability of Albania (Beqiraj et al. 2014). According to this unpublished map, 20 % of the territory is classified as very highly vulnerable, 30 % as highly vulnerable, 30 % as moderately to low vulnerable, and about 20 % as low vulnerable. The areas with high vulnerability belong to karstic and shallow alluvial aquifers. Regarding the karst aquifers, the results show that about 80 % of the total karst outcrops is considered as highly vulnerable, which seems to be exaggerated compared to vulnerability maps of many karst areas (Goldscheider 2005; Ravbar and Goldscheider 2009; Andreo et al. 2009; Loborec et al. 2015). As the practice of vulnerability mapping shows, when applying the DRASTIC method in karst or fissured aquifers one or more additional factor need to be introduced (Celico et al. 2007; Amharref et al. 2015).

At the moment the problem of vulnerability mapping, and particularly the dimensioning of protection areas of karst spring, is certainly one of the most important hydrogeological and social problems related to the effective management of karst water of Albania. The main aim of the present paper is to widen the so far available information about the importance of karst groundwater resources of Albania and to pay attention to the high risk of their pollution by uncontrolled human activities.

Materials and methods

Due to their high permeability, extreme heterogeneity and the frequent direct connection between the surface and the underlying, karst aquifers are extremely vulnerable to pollution (Zwahlen 2004; Bakalowicz 2005; Gutiérrez et al. 2014). As a consequence, karst groundwater needs special sustainable protection schemes based on detailed knowledge of the hydrogeological karst systems (Goldscheider 2005, 2012).

For the investigation of high mountain karst aquifers of Albania, two methods appear to be the most important: (a) conventional hydrogeological investigation, which helps to know the general functioning of the karst system, and (b) environmental and artificial tracer investigation, enabling in particular to establish the underground drainage pattern.

The hydrogeological map of Albania, at the scale 1:200.000 (Eftimi et al. 1985), is a good starting point for an overall recognition of the karst aquifers and for planning further detailed karst water studies. Some studies with environmental and artificial tracer methods (Akiti et al. 1989; Eftimi 1991, 2010b; Eftimi and Zoto 1996), have provided specific information about groundwater circulation in important karst aquifers of Albania.

For the investigated case studies, described in chapter 4, all the available geological and hydrogeological data have been collected and analysed, most of which represent archive materials like reports, chemical analyses and historical monitoring by the Geological Survey of Albania (GSA). The existing data are compared to field observations by the authors, and to new chemical analyses performed in the GSA laboratory. The output of this activity was the updating of the hydrogeological maps in different study areas, and compilation of sections. The final goal was the conceptualisation of the hydrogeological functioning of investigated karst aquifers.

To calculate the groundwater recharge in the karst aquifers the empirical methods of Turc (1954) and that of Kessler (1967) have been used. The first method requires the climatic data (mean temperature and precipitation), whilst the application of the second method requires only the pluviometric data. The obtained values by the empirical methods, as tested in many karst aquifers of Spain, are similar with those obtained with APLIS method (Andreo et al. 2008). The meteorological data, and the discharge data of the springs used for comparison with balance calculations, have been taken from the Institute of Hydrometeorology of Tirana. The results of the water turbidity analyses were provided by the Laboratory of the Institute of Public Health of Tirana, which is monitoring this issue.

Karst aquifers of Albania

Albania is mainly mountainous with mean elevation of 764 m above sea level (a.s.l.). The climate of Albania is typically Mediterranean, with annual mean air temperature between 15 and 16° C in the coastal areas and around 10° C in mountain areas. The mean precipitation reaches about 1450 mm, but their spatial and time distribution changes significantly, from about 800 mm in the SE of the country to more than 3000 mm in the Albanian Alps to the N.

From the geological standpoint, Albania belongs to the southern branch of the Alpine orogenic system. The geological structures extend to the north as Dinarides, and to the south as Hellenides. Carbonate rocks in the central part of Albania form some important Mesozoic limestone structures, mostly overthrust on magmatic rocks. The Albanian Alps, in the north, represents the largest karst region of the country. In central and southern Albania there are some SE-NW oriented anticline and syncline chains, dipping toward the Adriatic Sea. The anticline structures consist of Mesozoic to Upper Eocene carbonate rocks, often intermixed with siliceous rocks, while in vast areas of the syncline structures the carbonate rocks are covered by Palaeogene flysch deposits (Meço and Aliaj 2000; Xhomo et al. 2002).

In Albania there are known 25 karst regions, 23 of them in carbonate rocks covering a total surface of 6500 km², whilst the two remaining have a total surface of 260 km², and are made up by evaporite deposits. The carbonate rock structures generally occupy the higher elevated mountain areas. The absolute values of the mean annual infiltration range from about 500 to 1300 mm in central and southern Albania and to about 2000 mm in the northern Albanian Alps (Eftimi et al. 1985). In Albania about 110 karst springs with an average discharge exceeding 100 l/s have been mapped. Among these, 17 outflow discharges more than 1000 l/s. The average yearly discharge of the Bistrice spring, the biggest spring of Albania, reaches about 18.4 m³/s (Eftimi 2010a, b).

As the limestone formations are widespread in Albania, most of karst water is of HCO₃-Ca type, while the HCO₃-(SO₄)-Ca-(Mg) type is characteristic mainly for the Dajti and Makareshi dolomite massifs. In the Ionian Zone, in contact with evaporites there are some other springs of HCO₃-SO₄-Ca-Mg type. Along the southern Ionian carbonate rock coast there are some big mineralized karst springs of Cl-Na type; the chloride concentration varies from about 250 to about 5000 mg/l (Eftimi 2010a).

Human impacts on karst aquifers

Actually the groundwaters in Albania are suffering the quality deterioration in the regions with extensive demographic and industrial development (Beqiraj et al. 2014). Quarrying activity is pointed out as producing the main negative impact (Gelaj et al. 2014). To face the problems of sustainable groundwater management during the last decade a monitoring network has been established which includes also about 30 springs (Gelaj et al. 2014).

The human impact on karst aquifers is favoured not only by their physical characteristics, but also by the low level of understanding of these characteristics by the community

(Gunai and Ekmekci 1997), and often is the result of the business pressure on community interests. A number of experiences in Albania have demonstrated that the main human negative impacts on karst water are related with: (a) urbanised areas; (b) agriculture activities, and (c) quarrying.

Impact of urbanised areas

Urbanised areas in karst areas represent a potential pollution risk (De Waele and Follesa 2004). The urbanisation of the karst areas often leads to more areas with destroyed surfaces, removed cover systems and extremely exposed rocks (Hötzl 1999). Because of lack of filtration within the aquifer (in particular in a conduit type aquifer) and the short underground residence, micro-organisms are almost certain to appear in water supplies (Goldscheider et al. 2010). The karst aquifers with good quality groundwater represent a valuable asset (Custodio 2010), which not always is managed responsibly, as shown in the examples described below.

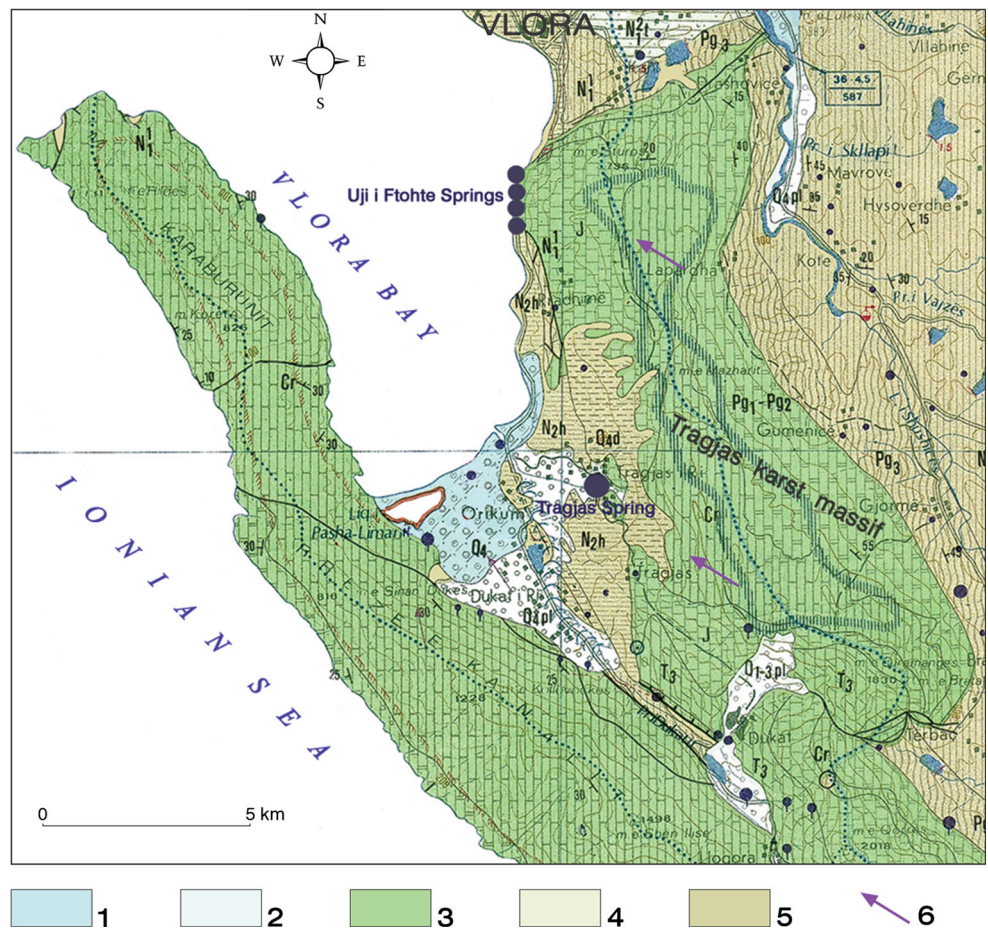
Uji i Ftohtë Springs

The karstic coastal area of Albania, about 154 km long, is situated along the Ionian Sea starting from Vlora in the north to the Albanian-Greek border in the south. The coastal karst aquifers are related to the high mountain Mesozoic to Eocene carbonate structures and most of their water resources, consisting of about 15–20 m³/s, drain directly to the Ionian Sea (Eftimi 2003a).

The northernmost coastal karst aquifer is related to the Tragjas carbonate anticline with its highest peak at 1864 m a.s.l., located near Vlora, the third largest town of Albania (Fig. 1). The core of the structure is made up by Triassic dolomite, continuing with Jurassic, Cretaceous and Palaeocene–Eocene limestone and thin bedded cherts. The Tragjas structure on the N and E, and partially in SW sides contact Paleogene flysch and Neogene clayey formations. On the NW part of the structure, in the area of Uji i Ftohtë Springs, a transgressive contact of carbonate rocks with Neogene clayey formations is present (Meço and Aliaj 2000; Xhomo et al. 2002). The Neogene clay formations work as a barrier that prevents the intrusion of seawater into the Tragjas karst aquifer (Fig. 2).

Karst in Tragjas aquifer is well-developed both at the surface and in depth. Numerous dolines and poljes are developed in an area of approximately, 40 km² at the top of the karst massif. In the coastal area of Uji i Ftohtë Springs, and in the water tunnels many 60–70 cm-wide water conduits can be observed. The mean annual rainfall in Tragjas karst is about 2050 mm, and the mean efficient infiltration into the karst aquifer is about 1100 mm, which corresponds to overall karst water resources of 5.0 m³/s (Eftimi 2003a).

Fig. 2 Hydrogeological map of Tragjas area (after Eftimi et al. 1985). Explanation: 1 Gravelly aquifer (Q₄), 2 Sandy to gravelly aquifer (Q_{4pl}), 3 Karst aquifer (T₃, J, Cr, Pg₁–Pg₂^{1–2}), 4 Sandstone aquifer (N₂^t), 5 Non aquiferous rocks (N₂^h, N₁¹, Pg₃), 6 Karst water flow direction



Two groups of karst springs, located at a distance of about 10 km on the western side of the aquifer, are recharged by the Tragjas karst aquifer. The first is the group of coastal springs of Uji i Ftohtë which is located at sea level over a length about 1.7 km. Along this stretch, 32 springs are identified, concentrated in three sectors, respectively 185, 350 and 500 m wide (Tafilaj 1979). To capture the springs at sea elevation three tunnels are placed landward and parallel to the sea coast at a distance 60–70 m from the shoreline and at elevation 0.2–0.5 m a.s.l. (Fig. 3). The mean annual discharge of all the three tunnels is about 2.0 m³/s (Eftimi 2003a). The second group of springs known as Izvori is located near Tragjasi Village at elevation of about 40 m a.s.l. and at the same contact line of the Mesozoic carbonate rocks with Neogene clays. The mean discharge of this spring group is about 1.8 m³/s.

Many chemical analyses performed in the past confirmed the good quality of the Uji i Ftohtë waters. Based on non-systematic water quality monitoring, the main chemical parameters measured at drainage tunnels, are as follows: conductivity 400–760 μS/cm at 25 °C, TDS 250–540 mg/l, Cl 20–150 mg/l, SO₄ 35–50 mg/l, Na 20–90 mg/l, 50–60 mg/l, NO₃ 1–5 mg/l, NO₂ is below

detection limit, pH 7.2–7.7; the hydrochemical type is HCO₃–Ca–Mg (Eftimi 2005). A recent survey of this area stated that “there is neither evidence of contamination nor relevant effects of sea water intrusion” (Polemio et al. 2011), but does not deal with the water bacteriological situation.

However, the situation in the catchments areas of Uji i Ftohtë Springs is undergoing rapid changes; instead of the fruit trees, brushwood, meadows and outcropping rocks, an uncontrolled urban area is under development in the immediate vicinity to the Uji i Ftohtë Springs, at elevation from 20 to about 250 m (Fig. 3). The new urban area does not have a properly planned waste water system and all the houses have septic tanks mostly constructed without any special isolation layer.

The bacteriological analyses performed at least since 2009 confirm that Uji i Ftohtë Springs result heavily polluted. The values of some measured bacteriological indexes confirm the groundwater pollution; *total coliforme* 10–20, *faecal coli forms (Escherichia coli)* 10–17 and *faecal streptococcus* 2–4. The presence of *E. coli* in a water sample indicates faecal contamination and therefore the possible presence of various pathogens (Goldscheider

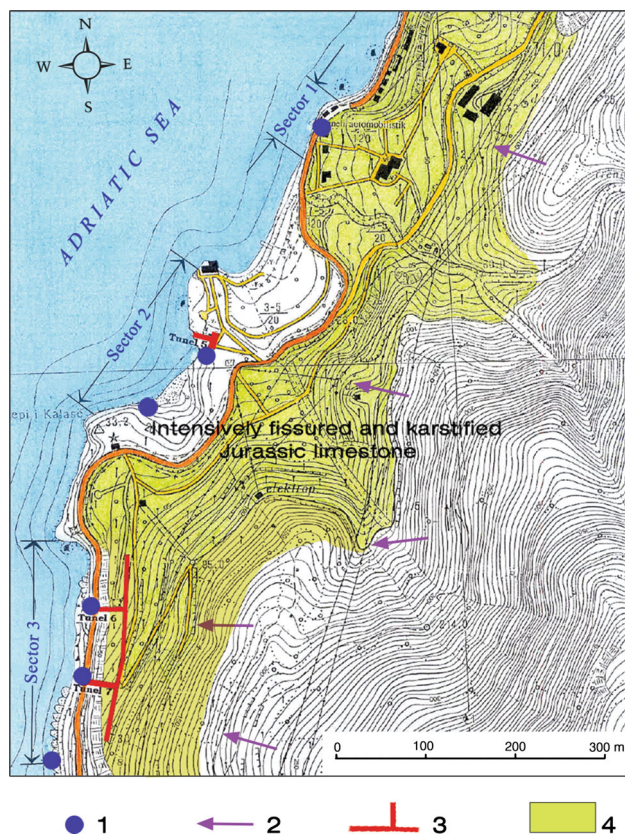


Fig. 3 The new urban area is developing upstream and in the immediate vicinity to Uji i Ftohtë Springs (after Eftimi 1985). Explanation: 1 Spring average discharge more than 100 l/s, 2 Karst water flow direction, 3 Water drainage tunnel, 4 New urban area

2010). With respect to microbiological quality, the European Guidelines and standards specify a complete absence of indicator organisms such *E. coli*, enterococci or other thermo-tolerant coliform bacteria (Council Directive 98/83/EC 1998).

With regard to the numerous possible hazards emanating from the urban area, the only mitigating element seems to be the thick, impervious, cover sequence (Hötzl 1999). An increased thickness of this layer reduces the vulnerability and gives a reasonable amount of protection. The new urban area of the springs is covered by red clays (“terra rossa”) with variable thickness, but this is often removed during the excavation of the foundation. Such a removal diminishes the self-purification capacity of the clays and increases the risk of the seepage of wastewater into the karst system.

Another issue is the thickness of the unsaturated zone, which in the area of Uji i Ftohtë Springs varies from less than 20 to 200 m and cannot prevent significant breakthroughs into karst groundwater in case of long-lasting pollution (Fig. 4). As Carré et al. (2011) state, in such cases the purification process is also limited by the short time the water stay in the aquifer. The process is facilitated also by

presence of wide groundwater flowing channels, as is the case at Uji i Ftohtë Springs. As a result, the spring water is bacteriological polluted and the Vloëa City water supply is compromised.

To protect the water quality of Uji i Ftohtë Springs the following measures are recommended: (a) forbidding the construction of new houses in the upstream area, (b) to insure that water impermeable septic tanks are constructed, (c) to construct the wastewater drainage system respecting the peculiar conditions in the considered area, (d) monitoring the water quality and establishing the protective areas of the groundwater catchment. For the moment the only adopted solution is an increasing in the dosage of chlorination.

Impact of agriculture activities

The cultivation of karst landforms facilitates the erosion, causing sediments to enter more easily the karst aquifer because of the availability of solutionally enlarged openings, which allow the input of suspended sediment load (Coxon 1999). Karst landforms in Albania such as polje, dolines, and uvalas in some places have been transformed into arable fields for the production mainly of wheat, tobacco and potatoes (Parise et al. 2004). Often the cultivated karst areas are located in remote mountain areas and the negative impact on groundwater is not considered, but in some cases deterioration of karst water quality is evident.

Shën Mëria and Selita Springs

Shën Mëria and Selita Springs are located about 20 km east of Tirana; in the western part of the high elevation Mali me Gropa massif (Fig. 1). From the geological point of view Mali me Gropa represents an allochthonous block mainly



Fig. 4 The new urban area is developed above the drainage tunnels and close to the main pumping station (photo Eftimi R)

consisting of Upper Triassic pure limestone resting on Low Triassic radiolarites with limestone strata overthrust to the west and the south on Paleogene flysch formations (Liko 1962). The Linos Valley filled up of Upper Jurassic-Lower Cretaceous flysch-like deposits of marls, sandstone and conglomerate separates the eastern from the western part of the massif (Fig. 5).

The surface morphology at Mali me Gropa (Mount with Holes) area is characterized by a high frequency of dolines, uvalas and small poljes. In the karst plateaus developed at elevations around 1500–1600 m a.s.l., the density of dolines may reach hundreds per square kilometre. Most of the dolines have circular morphology with diameters of about 15–40 m, and maximum depth from about 10 to more than 30 m. Uvalas result mostly from the coalescence of several dolinas, measure up to 700 m across, and are 40–80 m deep. The outstanding exokarstic-erosion landform, the dry Vali Valley about 12 km long located in the eastern part of the area (Fig. 5), is formed by the Biza River when it flows into the Mati River. As the drainage base, represented by the Mati River, was lowered after the Middle Pleistocene (Aliaj 2012), the underground karstification was intensified and become more active than the surface erosion. As a result, the Biza River disappeared underground at the Vali Cave, at the begging of the Vali Valley, to re-emerge at the karst springs in the deep Mati River canyon (Fig. 5). Mali me Gropa does not offer very interesting results as regards karst caves: a Dutch speleological expedition found only seven relatively big caves, most of which are shorter than 100 m, the longest one being Vali cave, with development of 330 m (Denneborg 1993).

The karst water resources of the western part of Mali me Gropa, are in average about $7.24 \times 10^6 \text{ m}^3/\text{y}$ or $2.3 \text{ m}^3/\text{s}$ and recharge three big springs named Uji Bardhe, Shën Mëria and Selita. The last two springs average discharges, respectively 1110 and 523 l/s, are both used for Tirana

water supply. The quality of the water is excellent, the electrical conductivity is about $230 \mu\text{S}/\text{cm}$, the total hardness is about $2.2 \text{ meq}/\text{l}$, and the water chemical type is $\text{HCO}_3\text{-Ca}$ (Eftimi 1991).

In Mali me Gropa karst plateau there is no intensive human activity, apart from some scattered farm families, which cultivate the terra rossa cover mainly in Vali Valley, as well as the sheep grazing. However, about 40 years ago the Government decided to increase the food production increasing the cultivated land surface, mostly achieved without taking account of the eventual negative impacts. In Mali me Gropa some karst landforms such as polje, dolines and uvalas of the karst plateau have been transformed into arable fields; cultivating mainly potatoes. One of the larger newly cultivated poljes was in the recharge area close to Shën Mëria and Selita Springs.

The first relatively heavy precipitation event was enough to demonstrate the negative impact of the change in land use of karst poljes. The land cover was partially removed and the well-developed underground karst system facilitated the flushing of soil material underground. The turbidity of Shën Mëria and Selita springs reached the highest historical value and the spring water was for the first time disconnected from the water supply system of Tirana for 1–2 days. Such “reaction of the nature” to the negative impact of the cultivation of the karst landforms of Mali me Gropa was a good lesson, which at least till now has not been forgotten.

Prespa and Ohrid lakes system

The Small and Big Prespa Lake and the Ohrid Lake are a common hydraulic system shared between Albania, FYR of Macedonia and Greece (Fig. 6a). Prespa Lake is located at 850 m a.s.l. and Ohrid Lake at 695 m a.s.l.; their open water surfaces are respectively, 274 km^2 and 348 km^2 .

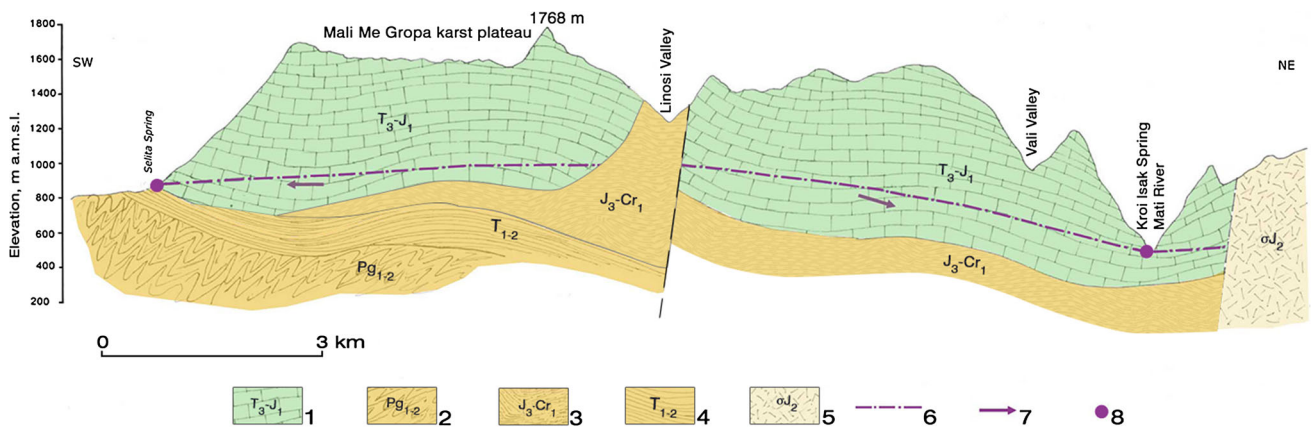


Fig. 5 Hydrogeological cross section of the Mali me Gropa karst plateau (after Eftimi 1991). Explanations: 1 Karst aquifer ($T_3\text{-}J_1$), Impermeable rocks; 2 Flysch (Pg_{1-2}), 3 Radiolarites with limestone

strata (T_2), 4 Effusive-sedimentary rocks ($J_3\text{-}Cr_1$), 5 Intrusive ultrabasic rocks (σJ_2), 6 Groundwater level, 7 Karst water flow direction, 8 Spring average discharge higher than 100 l/s

High mountains like the Mali Thate (2287 m) in the south and the Galichica (2262 m) in the north separate the two lakes.

Geologically, these mountains represent a horst, with wide graben structures located at both the sides: Prespa Lake to the east, and Ohrid Lake to the west. Mali Thate–Galichica Mt consists mainly of Upper Triassic–Low Jurassic massive limestone laying on Palaeozoic phyllite schists, while the bottom of the Prespa and Ohrid lakes is filled by Pliocene deposits (clay, sandstone and conglomerate). The horst is traversed by some N–S faults, particularly developed along the Ohrid Lake near St Naum and Tushemisht springs (Melo 1965; Meço and Aliaj 2000). Karst phenomena are well-developed at the surface and at depth. The highest density of dolines and uvalas can be observed in the large Petrinska and Pllaja e Pusit plateaus, developed at elevations from 600 to 1800 m a.s.l., and covering a total surface of about 80 km². Caves are generally small, with many present along the limestone coastal area of the Prespa Lake (the largest is Treni Cave, about 315 m long). There are also some tenths of small high elevation caves, the biggest being Samoska Dupka (279 m).

At the edge of Pliocene deposits of the Prespa Lake bottom the Zaver swallow hole is located, the most prominent karst phenomenon of this area (Fig. 6b), in which Prespa Lake water disappears to re-emerge in Ohrid lake coastal line.

At the border between Albania and Macedonia the big karst springs of St. Naum and Tushemisht are situated, discharging in total about 255×10^6 m³/year (8.1 m³/s). Additional groundwater quantities of about 1.5 m³/s drain into the lake as sub-lacustrine springs (Eftimi and Zoto 1996; Eftimi et al. 2007).

Lake Ohrid harbours a large number of endemic species like freshwater snails and a variety of endemic plankton species, as well as fish (Ohrid trout). Lake Prespa is an important breeding ground for various water birds, such as the Dalmatian Pelican. For these reasons in 2000 Lake Prespa was declared Ramsar site (Ramsar 2000). The main reason for concern in the Prespa–Ohrid karst aquifer is the allochthonous recharge through the large swallow hole of Zaver (Fig. 6b) followed by very rapid discharge to the St. Naum and Tushemisht Springs (Amataj et al. 2007).

Some isotopic investigation ($\delta^{18}\text{O}$, δD) have been undertaken to characterize the karst groundwater circulation between the two lakes. An investigation performed in the Albanian territory established that the Tushemisht Spring is recharged for 53 % (1.3 m³/s) by the Prespa Lake and for 47 % (1.2 m³/s) by the precipitation infiltrated in the Mali Thate karst massif (Eftimi and Zoto 1996). Similar investigations carried out in the territory of FYR of Macedonia have established that the St. Naum Springs for 42 % are recharged by the Prespa Lake and for about 58 % by the precipitation infiltrated in the karst massif (Anovski et al. 1991). Practically, the same numbers have been determined

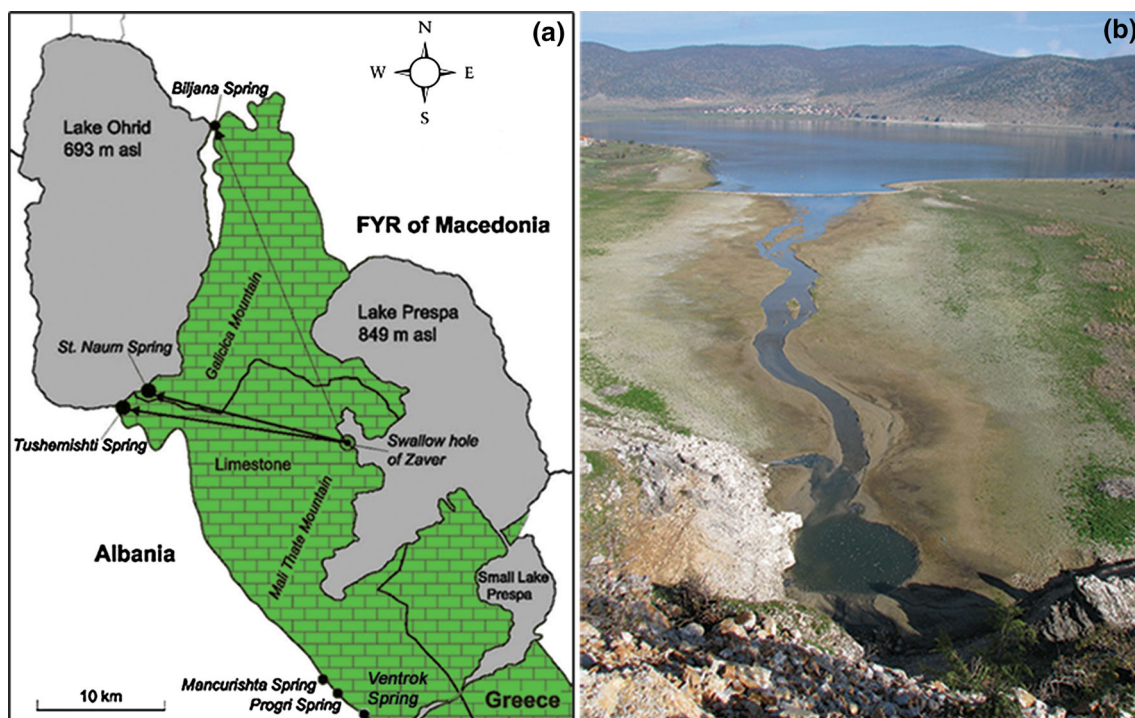


Fig. 6 **a** Recharge of Lake Ohrid from Lake Prespa (modified after Matzinger et al. 2006). The *black arrows* show the proven underground connection; **b** The *swallow hole* of Zaver where the Lake Prespa waters disappear to re-emerge at the Lake Ohrid coastal line

for both springs also by more recent investigations (Amataj et al. 2007; Matzinger et al. 2006).

An artificial tracer experiment was performed to further investigate the karst groundwater movement of Prespa-Ohrid karst aquifer. The maximum velocities between the Zaver swallow hole (injection point) and the St Naum and Tushemisht springs (sampling points), located at a distance of about 16–17 km, range between 233 and 3200 m/h (Amataj et al. 2007). The big differences between maximum velocities of the karst flow lines testify the presence of differently developed underground water passageways in the investigated karst massif, even at small distances.

The public attention is focused on the preservation of the oligotrophic state of Lake Ohrid, which seems to be in jeopardy due to rapid increase of population and tourism (Matzinger et al. 2006). Lake Prespa contributes 50 % of the total catchment of Lake Ohrid and the total phosphorous concentration (TP) is seven time higher than in Lake Ohrid. The TP in Lake Prespa is 31 mg/m³, whilst in the Lake Ohrid it is 4.5 mg/m³. Any development in the Lake Prespa is a worrying concern for the eutrophication of the downstream Lake Ohrid. The high TP is probably the result of a combination of intensified agriculture, village waste disposal sites scattered along the coastal area of Lake Prespa (Fig. 7), increased use of P-containing detergents in Prespa Lake coastal area, and lack of sewage treatment. The increase of TP in Prespa Lake is also influenced by the lake water level decline after 1965.

However, it is concluded that 65 % of the TP leaving Lake Prespa entering into the karst aquifer is retained (Matzinger et al. 2006). This is because the phosphorous reacts with calcium carbonate to form a precipitate of hydroxyapatite (Fetter 1993). Coxon (1999) analysing this phenomenon concludes that “even in a conduit flow system, phosphate may be retained within the aquifer”, also when “phosphate enters the aquifer via a swallow hole”, as is the case of the Zaver swallow hole. Nevertheless, for the phosphorous retaining capacity of karst aquifer, if



Fig. 7 Disposal of different types of wastes along Lake Prespa coastal area, near the village of Gollomboc (Photo Eftimi R)

measures for protection of Prespa Lake are not taken, its water could become a factor of increase to the Ohrid Lake trophy.

Eventually polluted Prespa Lake water seeping in Mali Thate karst massif could pollute the karst water, and also the Ohrid Lake water. The concentrated groundwater flow in big conduits, like those of Mali Thate karst massif, reduce the self-purification and the high flow velocities shorten the transit, reducing the necessary time for microorganisms to die off (Drew 1999; Coxon 1999).

In the same area an important environmental concern is related to the *Small Prespa Lake*, which is located in the bordering area between Albania, Greece and FYROM. A karst aquifer separates the Small Prespa Lake from the Devoll valley in Albania hosting some big karst springs (Fig. 6a). Some observations of spring water temperature and conductivity indicate that Ventrok spring is mostly recharged by Small Prespa Lake (Eftimi 2003b).

In 1976 Devoll River, in Albanian territory, was diverted to flow to Small Prespa in winter and to drain from the lake in summer for irrigation of Korça plain. This intervention caused disastrous consequences for both the surface and subsurface water systems of the area. During the period 1976–1996 the water input of Devoll River to the lake was about 30–70 million m³/year. In the same time, about 40.000 m³ of fine-grained sediments were deposited every year, or in total about 800.000 m³ of such sediments are deposited in the lake at the Albanian side (Kanari et al. 1997). The huge quantities of sediments changed completely the littoral zone and transformed the beautiful Small Prespa Lake into a wetland (Fig. 8). The aquatic habitat altered which caused additional changes in the Prespa Lakes ecosystem.

Together with the silting of the lake, many karst water transmitting fissures and conduits were filled and the recharge of some karst springs from Small Prespa Lake diminished (Progri Spring) or totally stopped flowing. Very indicative is the situation with Ventrok Spring which discharge suffered a catastrophic reduction; from an important permanent spring average discharge about 80 l/s, the spring is presently dry (Eftimi 2003b). No realistic interventions will be able to restore the former situation of the Small Prespa Lake.

Impact of extractive industries

Limestone quarrying is actually the most important extractive industry in Albania. The extraction of limestone through quarrying activity has several dramatic impacts: (a) the damage of areas with high scenic value; (b) the destruction of caves, as well as of surface karst landforms; (c) pollution and other negative impacts on groundwater.



Fig. 8 Most of Small Prespa Lake within the Albanian territory is silted and is transformed into a wetland (Photo Eftimi R)

The scenic impact of quarrying in limestone areas is related to the removal of the subcutaneous zone, destruction of the existing ecosystem, which is not followed by quarry reclamation, living the exploited areas as anti-aesthetic landscapes. Two examples of anti-aesthetic transformation of the landscape as a result of quarrying worth to be mentioned are the beautiful karst massifs of Makaresh, near the capital Tirana, and of Tomor in central Albania.

Often during the quarrying activity are found caves which afterwards are destroyed, as is the case of Shahinova cave, near the town of Berat, which had great naturalistic importance (Parise et al. 2004). The quarrying activity in Albania is developed mostly in the unsaturated zone of karst aquifers and in such cases the first impact is the removal of soil vegetation, reducing the evapotranspiration losses, increasing runoff (Hess and Slattery 1999) and the pollution of groundwater by the infiltration of the turbid water. One of the examples worth to mention is the pollution of Bogova spring in the Tomor karst massif.

This massif, with a total surface of 145 km² and the highest peak at 2379 m a.s.l., is an asymmetric carbonate anticline with N–S orientation, overthrown to the west. The northern part of the massif called Tomor Mt is made up by Upper Cretaceous dolomites and limestone followed by Eocene limestone, while the southern part called Kulmaka Mt is made up mainly by Upper Cretaceous limestone (Kondo et al. 1971; Meço and Aliaj 2000). The Tomor anticline is surrounded by Palaeogene flysch deposits which act as impermeable barrier for the karst groundwater of the massif.

As reported by an Italian expedition (Savino et al. 2003), the Tomor Mt resulted in a restricted number of caves, mostly of small size. In Kulmaka Mt the karst landscape is much better developed; the mountain hosts a wide and beautiful karrenfield, some 20 caves, mostly concentrated at elevations between 1250 and 1500 m a.s.l., and some vertical shafts as Sterra e Kakrukës (−203 m) and Sterra U' Vlen (−227 m). About 4 km east of the Guaku spring is located Pirogoshi cave, the biggest of Albania, about

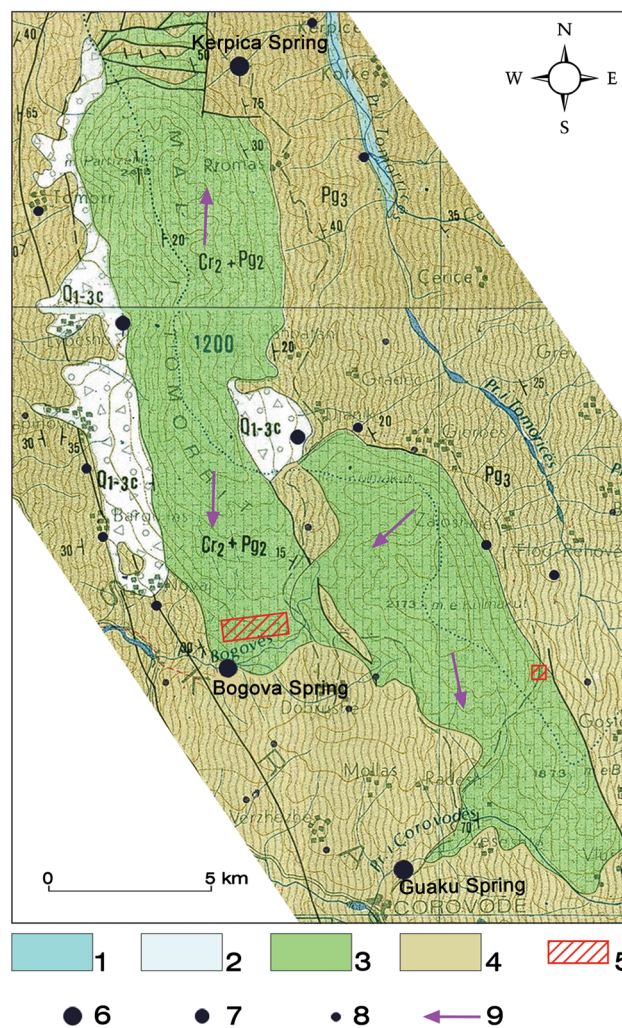


Fig. 9 Hydrogeological map of Tomor area (after Eftimi et al. 1985). Explanation: 1 Gravelly aquifer (Q₄), 2 Slope debris (Q_{1-3c}), 3 Karst aquifer (Cr₂+Pg₂), 4 Flysch, non aquiferous rocks (Pg₃), 5 Location of quarries, Springs average discharge: 6 Greater than 100 l/s, 7 10–100 l/s, 8 1–10 l/s, 9 Karst water flow direction

1550 m and some vertical shafts, about 100 m deep (Denneborg 1993).

Based on the climatic data of the Ujanik meteorological station, located at elevation of 1150 m a.s.l., the average calculated renewable groundwater resources result in $12 \times 10^7 \text{ m}^3/\text{y} = 3800 \text{ l/s}$ (Eftimi 1991). Most of groundwater of Tomor massif is discharged by three big springs located at the edge of the carbonate formations, at the contact with the flysch. The springs and their mean discharges are Kerpica-725 l/s, Bogova-1350 l/s and Guak-1500 l/s (Fig. 9), with all the three that are used for urban water supply.

Bogova spring is located in the western part of Tomori massif at an elevation of 344 m a.s.l. The water quality is excellent, the conductivity is 224 $\mu\text{S}/\text{cm}$, the total hardness is 2.54 meq/l and the water type is HCO₃-Ca–Mg (Eftimi

Fig. 10 Large quarrying areas are developed in the recharge area of Bogova Spring (photo Eftimi R, detail courtesy Andrejczuk W)



1991). Bogova Spring is used for the water supply of the towns of Berat, Poliçan and Kuçova, with a total population of about 100,000 inhabitants.

In natural conditions the recharge area of Bogova spring is characterized by a clean limestone area with high naturalistic and touristic importance. This situation completely changed after 1995 when the quarrying activity accelerated as a result of the increased demand of limestone by the construction industry. The quarrying activity continues to be particularly intensive upspring, at elevations about 600–1000 m a.s.l. at distances of about 1.0–3.0 km north-east of Bogova. The first impression one has passing through the quarrying area is the scenic impact related to the removal of the subcutaneous zone, and the destruction of the existing ecosystem, which is not followed by any action of quarry reclamation (Fig. 10).

The intensive quarrying activity is responsible also for the pollution of Bogova Spring; from time to time the spring water becomes turbid. The turbidity of Bogova Spring is allochthonous, as it originates from the soil zone and from the surface, favoured also by the thin or missing red clay in wide areas of the Tomori massif. This facilitates the fast transport of the rock particles produced by the explosions to reach the aquifer after every significant precipitation event. Favoured by the well-developed conduit network of the karst aquifer, the turbidity rapidly spreads over large distances and impacts the springs.

The turbidity of Bogova Spring is monitored by the sanitary authorities, which order the disconnection of the spring water from the water supply system when the turbidity reaches unacceptable values. Brief contamination episodes interrupt more or less long periods of clean spring

water. In some turbidity events the measured turbidity in the water distribution system of Berat varies about 2 to 4 NTU (nephelometric turbidity units), whilst the European guidelines specify for turbidity a value not to be exceeded of 1.0 NTU (Council Directive 98/83EC 1998). The turbidity and particularly the finest particles have a very good correlation with *E. coli* (Goldscheider et al. 2010), but such a study for Bogova Spring has never been performed.

The recommendation to stop the quarrying within the spring immediate protection area with a perimeter of 1 km in upstream direction is not respected yet and individuals oppose the constraints. For the moment the only adopted “solution” is using small charged explosive in quarrying yards, but also this measure is not under control.

Conclusions

Karst aquifers are particularly vulnerable to human impacts and a number of experiences have demonstrated that in Albania the phenomenon is mainly related to: (a) urbanised areas; (b) agriculture activities and (c) quarrying and industrial activities.

The most beneficial use of karst groundwater resources depends on the sustainable development and this is considerably linked with efficient governmental law, with the public education and the consensus between land use and water supply (Gunai and Ekmekci 1997, León and Parise 2009). The public education should encourage the understanding of the links between land use and water supply; otherwise the activities become extremely irresponsible and careless (North et al. 2009). Karst systems in general,

beside the underground water, contain also many natural resources, which are vulnerable to human impacts. Therefore, the protection of karst groundwater requires a holistic approach including also the protection of the biodiversity, soils and other karst ecosystem values and services (Goldscheider 2012).

Karst groundwaters are particularly vulnerable to human impact and the necessity to protect them is a process appreciated only in recent years in Albania, but much work still needs to be done. The study and control of karst groundwater quality, directed especially towards microbiological content, nitrite and nitrate, phosphates, salinity and periodically also heavy metal content (De Waele and Follesa 2004) is a priority for Albania. Works on vulnerability and risk mapping of karst aquifers should be intensified and the establishment of protection zoning of karst springs used as water supply sources appear to be among the most important and urgent tasks to be undertaken by the responsible authorities.

These requirements can be achieved by the development of national governance for water utilization based on environmental issues in a close link with the European Water Framework Directive. The special procedure should be adjusted with the priorities of the new European programme on “European Innovation Partnership on Water” which might be considered as an initial ambition for future sustainable activities to keep an environmental balance between resources availability and demands.

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