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Romeo Eftimi

Viacheslav Andreychouk

Tadeusz Szczypek

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Romeo Eftimi[1], Viacheslav Andreychouk[2], Tadeusz Szczypek[3], Wojciech Puchejda[4]

[1]Geological Service of Albania, Rr. Rreshit Collaku, pll.Eurocol nr 43, 1001 Tirana, Albania; e-mail eftimiromeo@gmail.com
[2]Warsaw University, Faculty of Geography and Regional Studies, Krakowskie Przedmieście str. 30, 00-927 Warszawa, Poland; e-mail: czeslaw.andrejczuk@gmail.com
[3]University of Silesia, Faculty of Earth Sciences, Bedzinska str. 60, 41-200 Sosnowiec, Poland; e-mail: bajkal58@wp.pl
[4]Bielsko-Biała, Poland; e-mail: puchejda@poczta.onet.pl

Karst springs of Albania and their management

Eftimi R., Andreychouk W., Szczypek T., Puchejda W. **Źródła krasowe Albanii oraz ich wykorzystanie**. Albania jest położona w zachodniej części Półwyspu Bałkańskiego, na wschodnim wybrzeżu Morza Adriatyckiego i Jońskiego. Krajobrazy krasowe zajmują 24% powierzchni kraju. Odnawialne zasoby ogólne wód krasowych stanowią 80% wszystkich zasobów wód podziemnych Albanii. Około 70–80% ludności miast, łącznie ze stolicą Tiraną, oraz inne ważne miasta takie jak: Korcza, Pogradec, Berat, Vlora i Girokastra są zaopatrywane w wody krasowe. Znaczna ilość wód krasowych jest także wykorzystywana do produkcji energii elektrycznej. Masowe wykorzystanie wód krasowych Albanii związane jest z ich szerokim rozprzestrzenieniem oraz bardzo dobrą jakością, jak również dominowaniem niedrogich grawitacyjnych systemów zaopatrzenia i względnie prostym magazynowaniem. Zrównoważone wykorzystanie zasobów wód krasowych jest utrudnione ze względu na wysokie zróżnicowanie wodonośców krasowych w zakresie ich przepuszczalności hydraulicznej, prędkości ruchu wód, sposobów i wielkości zasilania oraz podatności na oddziaływanie człowieka.

Эфтими Р., Андрейчук В., Щипек Т., Пухэйда В. **Карстовые источники Албании и их использование.** Албания расположена в западной части Балканского полуострова, на восточном побережье Адриатического и Ионического морей. Карстовые ландшафты занимают около 24% территории страны. Общие запасы возобновляющихся ресурсов карстовых вод составляют 80% всех запасов подземных вод Албании. Около 70–80% населения городов, включая столицу – Тирану, а также другие важные города такие как Корча, Поградец, Берат, Влора и Джирокастра водоснабжаются за счет карстовых вод. Значительные количества вод задействованы также в производстве электроэнергии. Массовое использование карстовых вод Албании связано с их значительным количеством и преимущественно очень хорошим качеством, а также преобладанием недорогих гравитационных (самотечных) систем водоснабжения и относительно простым магазинированием. Стабильное использование ресурсов карстовых вод затрудняется высокой неоднородностью карстовых водоносных горизонтов в смысле типов и развитости их гидравлической проницаемости, скоростей течения, характера и объемов питания, качества карстовых вод, а также их высокой восприимчивости к воздействию человека.

Keywords: karst morphology, karst springs, karst water quality, management of karst water, Albania.
Słowa kluczowe: morfologia krasu, źródła krasowe, jakość wód krasowych, wykorzystanie wód krasowych, Albania
Ключевые слова: морфология карста, карстовые источники, качество карстовых вод, использование карстовых вод, Албания

Abstract

Albania is situated in the western part of Balkan Peninsula, on the eastern coast of the Adriatic and the Ionian Sea. The karst landscape in Albania covers nearly 24% of the countries territory. The total renewable karst water resources represent 80% of the groundwater resources of Albania. Nearly 70–80% of the population of the cities, including the capital Tirana, and other important are cities like Korça, Pogradec, Berat, Vlora and Gjirokastra are supplied by karst water; important resources are used for the production of the electricity, also. The massive use of karst waters in Albania is related to their abundant and mostly very good quality, as well as of the prevailing inexpensive gravity distribution systems and their relatively simple maintenance. The sustainable management of karst water resource is difficult due to the high heterogeneity of karst aquifers in terms of type and development of hydraulic porosity, flow velocity, hydraulic head, recharge type and quantity, karst water quality, as well as to the high vulnerability to the human impact.

Introduction

Karst rocks are may be one of the most important aquifer formations in the world, along with alluvium deposits. Their importance is related to both the amount of karst groundwater and the overall very good quality. The draft karst aquifer map of Europe shows that about 13% of the land surface is carbonate rocks outcrop (CHEN et al., 2017). On this map are shown also two big karst spring of Albania: Uji Ftohte and Blue Eye, which are described in this paper. MARGAT (1998) estimates that carbonate outcrops cover at least 15% of the surface of the Mediterranean catchment area and the carbonate aquifers supply at least 25% of the domestic water supply. The water supply from the karst is dominant along the area of Alpine orogenic belt and in Carpathian-Balkans coastal area and inner Balkans; since ancient times 11 long aqueducts delivered more than 13 m^3/s of water to Rome from distances ranging from 16–91 km (LOMBARDI, CORAZZA, 2008); two major pipelines, 130 and 200 km long provide an average of 4.5 m^3/s for 1.7 million citizens of Vienna (ZÖTL, 1974). At present four capitals of SEE (Sarajevo, Tirana, Skopje and Podgorica), and numerous large towns utilize karstic water for drinking water supply (STEVANOVIC, EFTIMI, 2010).

The present paper is a short overview of the karst and of the biggest fresh karst springs of Albania; karst thermal springs are described in a separate publication (EFTIMI, FRASHRI, 2016, 2018).

Karst aquifers

Albania is situated in the western part of the Balkan Peninsula, on the eastern coast of the Adriatic and the Ionian Sea (fig. 1). The total surface of Albania reaches 28,748 km^2 and the population 3.2 million. The country is mainly mountainous with the mean elevation of 764 m above sea level (a.s.l.); many peaks higher than 2 000 m a.s.l. are located in the inner part of the country and associate mostly with the karst areas. The climate is typical Mediterranean.

The annual mean air temperature varies between 15 and 16°C in the coastal and around 10°C in mountainous areas. The mean precipitation reaches about 1 450 mm; the highest precipitation of more than 3 000 mm is measured in North Albanian Alps.

Karst rocks can be found in all tectonic zones of Albania. In Korabi zone two tectonic windows embodying Permian gypsum-anhydride rocks outcrop. Carbonate rocks in Mirdita Zone, constitute some important Mesozoic limestone syncline structures mostly overthrusted on magmatic rocks. The Albanian Alps Zone, the largest karst regions of the country consist the southernmost part of the High Karst Zone. In most of central and south Albania (in Kruja and Ionian zones), including the Adriatic depression, the carbonate structures are covered by thick flysch deposits and dip to Adriatic Sea.

In Albania karst rocks cover about 6,750 km^2 consisting about 24% of country territory, of which 6 500 km^2 are carbonate rocks and 260 km^2 consist of gypsum. Karts of Albania is intensively developed in wide horizontal or gently sloping carbonates mainly of massive and thick

Fig. 1. Location of karst rocks and big karst springs of Albania; with numbers are shown the springs mentioned in the text (based on IHM of Europe, Albania; sc. 1:1.5, after EFTIMI, SHEGANAKU, TAFILAJ, 2009)

Rys. 1. Rozmieszczenie skal krasowiejących i dużych źródeł krasowych w Albanii: numerami zaznaczono źródła wspomniane w tekście (na podstawie IHM of Europe, Albania; sc. 1:1.5, after EFTIMI, SHEGANAKU, TAFILAJ, 2009)

Рис. 1. Распространение карстуюшихся пород и крупных карстовых источников в Албании: номерами обозначены источники, упоминающиеся в тексте (на основе IHM of Europe, Albania; sc. 1:1.5, after EFTIMI, SHEGANAKU, TAFILAJ, 2009)

bedded Triassic and Cretaceous formations. Karst terrains usually have unusual subsurface hydrology and particular landforms resulting from a combination of high rock solubility and well developed secondary porosity (FORD, WILLIAMS, 2007). However the karst network is different from the fracture pattern (BAKALOWICZ, 2005) and karst permeability is self organised (KLIMCHOUK, ANDREICHUK, 2010). The karst morphology of karst landscape of Albania is very reach with karren fields, sinkholes, uvalas, poljes, blind valleys, karst plateaus, tower karst, swallow holes, vertical shafts and caves. One of most attracttive karst landforms of Albania are the karst plateaus which are developed mainly in the wide syncline structures located in all the tectonic zones of Albania at absolute elevation about 1 200–2 000 m; their surfaces vary from about 20 km^2 to about 80 km^2. The largest caves are about 3 000–4 000 m long, while the maximal depth of the vertical caves is about 300–400 m. Some typical forms of karst morphology of Albania are shown in fig. 2.

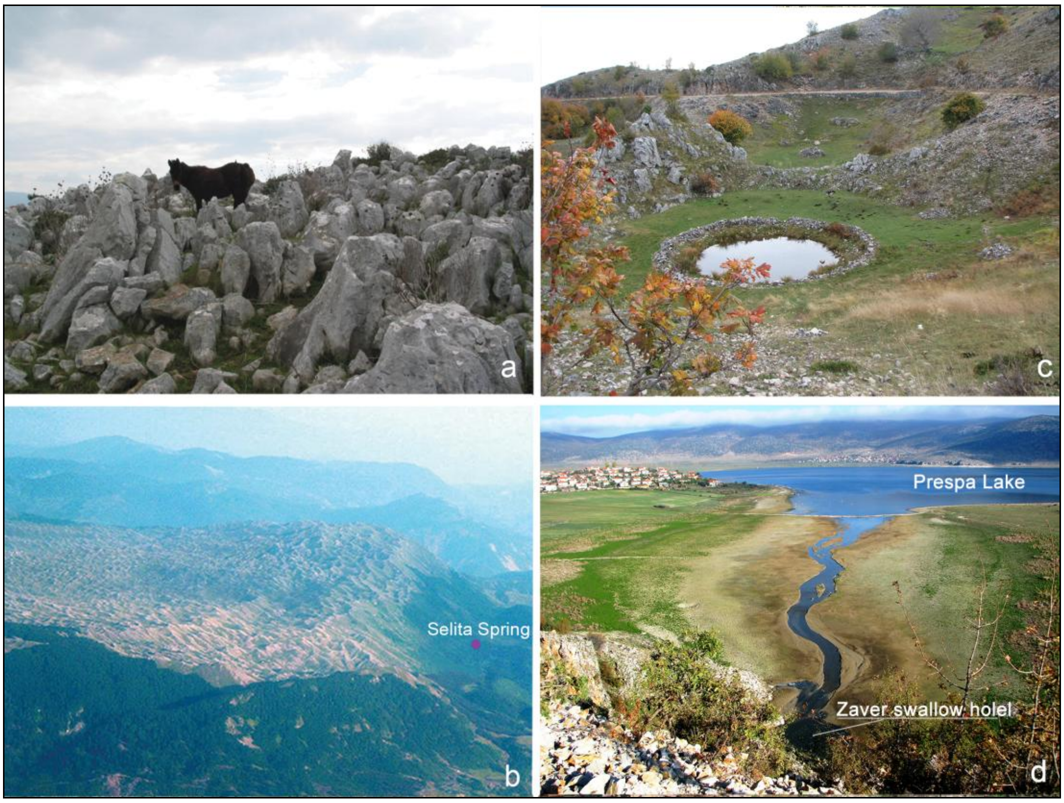

Fig. 2. Some karst forms of Albania:
a – Deep karen field in Saranda coastal line (South Albania), b – Mali me Groppa karst plateau at elevation about 1 600–1 800 m asl, c – A water pool situated at the bottom of a sinkhole; d – Zaver swallow hole where disappear Prespa Lake water to reappear at the big karst springs in Ohrid lakeside (phot. a, b, c – by R. Eftimi, phot. d – by V. Andreychouk)

Rys. 2. Niektóre przykłady form krasowych Albanii:
a – pola żłobków krasowych w strefie brzegowej około Sarandy (Albania Południowa), b – płaskowyż krasowy Mali me Groppa wznoszący się na około 1 600–1 800 m n.p.m., c – jezioro w dnie leja krasowego; d – ponor Zawer pochłaniający wody jeziora Prespa, które ponownie wypływają w dużych źródłach na brzegu Jeziora Ochrydzkiego (fot. a, b, c – R. Eftimi, fot. d – V. Andreychouk)

Рис. 2. Некоторые примеры карстовых образований Албании:
a – поля глубоких карров в береговой зоне около Саранды (Южная Албания), b – карстовое плато Мали ме Гропра с абсолютными высотами около 1 600–1 800 м, c – озеро на дне карстовой воронки, d – понор Завер, поглощающий воды оз. Преспа, которые вновь появляются в крупных карстовых источниках на берегу Охридского озера (фот. a, b, c – Р. Эфтими, фот. d – В. Андрейчук)

The natural recharge of a karst aquifer is affected by many factors related to the land surface, surface water, soil zone and unsaturated zone (RUSHTON, WARD, 1979). Most widespread of recharge processes is the areal infiltration of precipitation directly to the carbonate rocks, but the recharge from rivers or lakes water, or the inflow from shallow gravely aquifers of some karst aquifers of Albania is present, also (EFTIMI, DHAME, 2006, EFTIMI, SKËNDE, ZOTO, 2002; EFTIMI et al., 2017; EFTIMI, 2009).

The most reliable method to determine karst aquifer recharge certainly is based on the discharge measurements of all the springs of the aquifer (STEVANOVIC, 2015), but some empirical methods (TURC, 1954; KESSLER, 1967) are quite applicable in engineering practice (BONACI, LJUBENKOV, 2005). The calculated average yearly efficient infiltration range in a wide scale; in the Albanian Alps vary about 1,500 to more than 2,000 mm, in MMG 1,100 mm, in Mali Thate 400–450 mm and in Mali Gjerë about 1,750 mm.

The total natural karst groundwater resources of Albania are calculated with $7.15 \cdot 10^9$ m^3/y (227 m^3/s). Karst water flow module of Albania is calculated 33.6 $l/s/km^2$, but it is varying in wide limits from place to place from 43–45 $l/s/km^2$ in Albania Alps to 11 $l/s/km^2$ in Central south Albania.

Karst springs

Karst water refers to subsurface mobile waters present in a karst area. Groundwater moves along the fissures and fractures, but also often crosses them. In a regional scale the direction of karts water flow is governed by the regional erosion and corrosion basis, which not necessarily coincides with the development of the secondary porosity (MANDEL, 1963; BAKALOWICZ, 2005; GOLDSHEIDER, 2005). Many authors afford classification of springs as outlet of aquifers. MAINZER (1923) classifies the spring groups based on the discharge, LAMOREAUX and TANNER (2001) use four criterions for spring's classification, while a recent comprehensive classification of the springs is based on ten criterions (STEVANOVIC, 2015).

The karst aquifers of Albania, as the karst aquifers in general, are characterised by the high seasonal variability and high vulnerability (BAKALOWICZ, 2015). On the Hydrogeological Map of Albania, scale 1 : 200.000 (EFTIMI at al., 1985), are shown more than 2 000 karst spring varying greatly in productivity. In Albania there are 110 karst springs which average discharge is more than 100 l/s, and 17 of them have discharges more than 1 000 l/s; some of them are shown in fig. 1. Main factors controlling the location of karst springs of Albania are: a) the erosion/corrosion activity, b) the surface hydrology, and c) tectonics. Many contact-springs issue in the edges of geological structures, while other springs escape at or near the valley floor of rivers, deeply intersecting the carbonate rocks (fig. 3). Large groundwater quantities drain to the big lakes of Shkodra and Ohrid, as well as to the seaside in some places as submarine springs (South Albania coastal area).

Very interesting results are reviled by speleodiving realised for the investigation of the siphons of some big karstic springs in South Albania (TOULOUMDJIAN, 2005; ZHALOV, 2015). The depth of the major investigated siphons varies about 60 to 83 m but some of the explored hydrologic systems are still deeper. The siphon springs and submarine springs indicate the presence of deep karstification below the ground surface or below sea level.

The southern high mountain rocky part of Albanian coastal chain is about 154 km long and consists of important high elevation karstic aquifers draining to Ionian Sea in average about 17–18 m^3/s (EFTIMI, 2010). The type of drainage depends on the hydrodynamic conditions of the karst aquifers which mostly are opened to sea, or those discharging over complete barriers (STEVANOVIC, 2014; BAKALOWICZ, 2015).

Most of the coastal karstic aquifers of Albania are open to sea and are characterised by a diffuse drainage without forming concentrated springs (EFTIMI et al., 1985). However particularly important for the water supply of the coastal area are some large overflow springs discharging over complete barriers of underlying impermeable Eocene flysch sediments, thus eliminating sea water intrusion.

Fig. 3. Some karst springs issuing in the river valleys:
a – Vrella Shoshanit spring, b – Black Eye spring issues in Vjosa River canyon, c – Kroi Isake spring is located in the deep Mat River canyon, d – Trebeshina spring issues in Vjosa River canyon (phot. by R. Eftimi)
Rys. 3. Niektóre źródła krasowe zlokalizowane w dolinach rzecznych:
a – źródło Wrella Szoszanit, b – źródło Czarne Oko w kanionie rzeki Wjosa, c – źródło Kroj Isake w głębokim kanionie rzeki Mat, d – źródło Trebeszyna w kanionie rzeki Wjosa (fot. R. Eftimi)
Рис. 3. Некоторые карстовые источники приуроченные к речным долинам:
а – источник Врелла Шошанит, b – источник Черный Глаз в каньоне р. Вйоса, c – источник Крой Исаке в глубоком каньоне реки Мат, d – источник Требешина в каньоне р. Вйоса (фот.: Р. Эфтими)

Karst water quality

Karstic water has significant differences in physic-chemical characteristics which have a clear relation to the lithology of the karst rocks (Eftimi, 1998; Eftimi et al., 2017). The spring waters of pure limestone of MMG have low hardness (1–3 mlg.eqv/l), low SO_4^{2-} concentrations (usually less than 15 mg/l), and therefore also a low EC varying about 150–230 μS/cm, while the ratio rCa/rMg varies about 7 to 13.

The dolomite waters are hard (total hardness varies about 5 to 10 mlg/eqv/l); the EC is relatively higher, it varies about 350–850 μS/cm, SO_4^{2-} concentrations vary about 80 mg/l, coming probably from the oxidation of the trace pyrite and marcasite and gypsum present in dolomites of the investigated massif (Hem, 1985); the ratio rCa/rMg varies about 1.2 to 3.5.

In some carbonate structures of South Albania, which are in contact to the gypsum deposits the concentration of SO_4^{2-} increases to more than 120 mg/l and EC varies about 500 to 700 μS/cm. The spring water is saturated with respect to calcite and is near saturation with respect to dolomite and the rSO_4/rMg ratio usually is more than 5.0.

Along the southern Ionian carbonate rocky coast, mixing of karst water with seawater takes place and there are some big mineralized karst springs of Cl-Na type; the chloride concentration varies from about 400 to about 5,000 mg/ l.

Some important karst springs

Syri Sheganit spring

Syri Sheganit spring (fig. 1, nr 1, fig. 4) is located in south-western part of Albanian Alps, at the eastern margins of Shkodra Lake. The Albanian Alps represents the southernmost part of High Karst Zone of the Dinarides; they consist mainly of Mesozoic limestone deposits. The neotectonic uplift and intensive denudation have led to the contemporary complex relieve, with altitudes exceeding 2 000 m a.s.l. (the highest peak is Jezerca 2 692 m a.s.l.). The topography is rugged, the peaks are sharp, and the river valleys are steep and narrow.

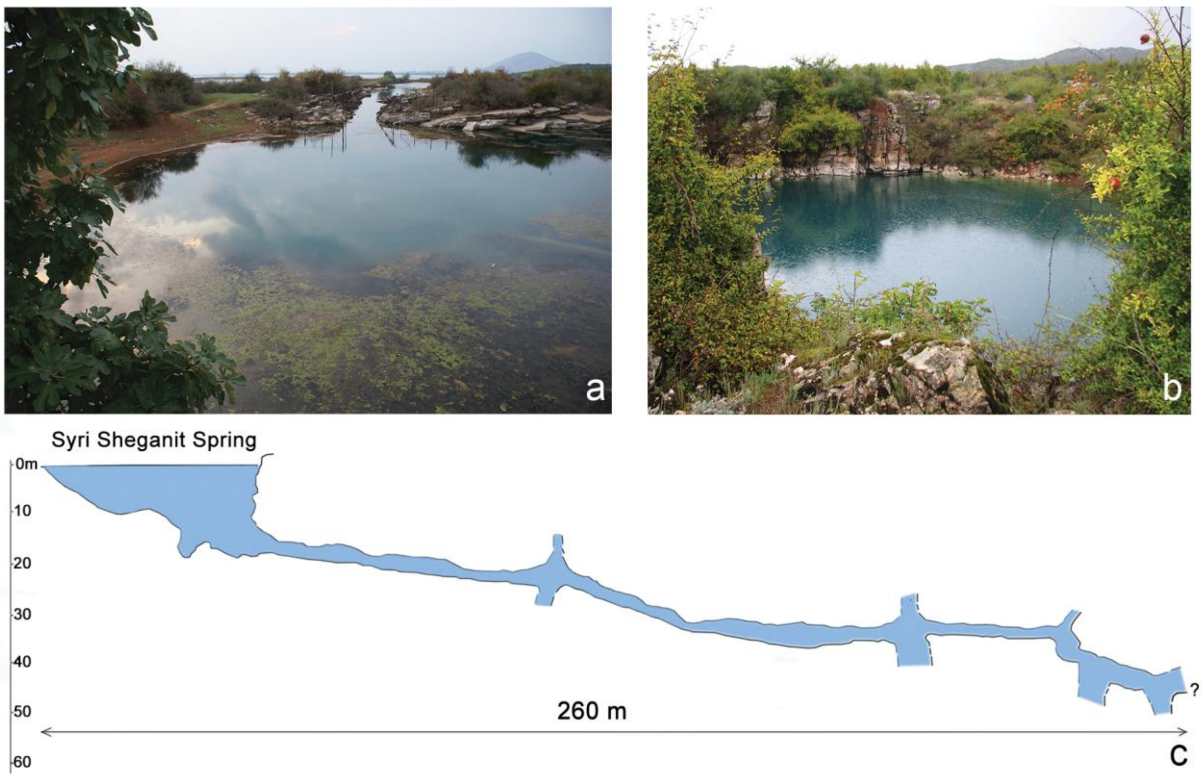

Fig. 4. Syri Sheganit spring:
a – main spring orifice, b – a collapse lake connected with the recharge canal of spring; c – cross-section of the submerged spring siphon (phot.: a – by R. Eftimi, phot. b – by V. Andreychouk)
Rys. 4. Źródło Syri Szeganit:
a – otwór główny, b – jezioro zapadliskowe związane z kanałem odpływowym źródła, c – przekrój przez zawodniony syfon źródła (fot.: a – R. Eftimi, fot. b – V. Andreychouk)
Рис. 4. Источник Сыри Шеганит:
a – главное отверстие, b – провальное озеро связанное с каналом разгрузки источника, c – разрез через подтопленный сифон источника (фот.: a – Р. Эфтими, фот. b – В. Андрейчук)

The high precipitation (usually more than 2 000 mm/year) and relatively low temperatures of the Alps enable the effective infiltration to be also high; it is calculated that the average value for all the area varies about 1 250 mm, and the calculated total renewable karst water resources of the Albanian Alps result at about 50 m^3/s (equal to 1.575*10^9 m^3/year), and the module of karst water flow is about 43 l/s/km^2.

The karst groundwater resources of Albanian Alps drain mostly as big springs which are concentrated in two well defined sectors; the first one, includes their northern-central and eastern part, and the second one includes the Shkodra Lake-side. In the first sector the springs emerge at the bottom of deep cutting river valleys, and cold be mentioned two of them, Gurra Ftohte (fig.1, nr 2) mean discharge about 1.2 m^3/s and Vrella Shoshanit (fig. 1, nr 3, fig. 3a) varying from 0.8 m^3/s to more than 3.0 m^3/s. The second sector is a wide area of about 450 to 500 km^2 of the southern part of Albanian Alps zone drai-

ning to Shkodra Lake. It is calculated that about 40% of the total karst water resources of Albanian Alps, equal at about 18 m^3/s, drain to Shkodra Lake. The biggest spring draining in Shkodra Lake is Syri Sheganit discharging about 0.1 m^3/s to more than 10 m^3/s.

The water discharges through a well-connected system of submerged channels. At the top there is a vertical shaft diameter nearly 20 m which depth, as measured by the speleodivers, reaches about -20 and after that the spring recharge channel continue for about 260 m, but the end is not reached (fig. 4). At distances about 200 m east to the Syri Sheganit spring, two collapse lakes each diameter nearly 30 m are situated (fig. 4, b), both connected with the main recharge canal of the spring.

By installation, at vertical shaft, of big the pumps capacity more than 2 m^3/s, for many years it was possible to pump and provide water for irrigation without creating sensitive drawdown. Along the north most limestone edge of Shkodra Lake there are also other important coastal springs, and sublacustrin spring not yet investigated.

Selita and St. Maria springs

Selita and St. Maria springs are located about 20 km east of Tirana, in western part of Mali me Groppa (MMG) karst plateau (fig. 1 nr 4 and 5; fig 5). MMG represents an allochthonous block mainly consisting of Upper Triassic pure limestone. The surface morphology at MMG area is characterized by high frequency of dolines, uvalas and small poljes, which density at the karst plateaus developed at elevations around 1 500–1 600 m a.s.l., may reach hundreds per square kilometre.

Linosi valley consisting of the flysch-like deposits separates the MMG in two hydrogeological blocks: the eastern surface 85 km^2, and the western one 55 km^2. The estimated water resources of western karst block of about $7.25 \cdot 10^6$ m^3/year (or 2.3 m^3/s) recharge three big karst springs: St. Maria, Selita and Uji Bardhe (fig. 5), with mean discharges respectively 1 110 l/s, 522 l/s and 670 l/s. The mentioned springs issue at the contact of impermeable flysch basement with the pure limestone. The water resources of eastern karst block estimated at about $11.2 \cdot 10^6$ m^3/year (or 3.55 m^3/s) drain in the deep erosion Mat River valley where the biggest spring is Kroi Isake spring (fig. 3c, fig. 5b).

The water quality is excellent, the conductivity is about 230 μS/cm, the total hardness is about 2.2 meq/l, and the water chemical type is HCO_3-Ca (EFTIMI, 2005). Since fifties of the last century Selita and St Maria springs are used for the water supply of Tirana. In MMG karst plateau there is no intensive human activity, apart some scattered farm families, which cultivate the "terra rossa" (red clay) cover of small poljes as well as the sheep grazing. However, some tentative to cultivate intensively the large karst poljes in recharge area close to Selita and St, Maria springs resulted with negative impact. The first heavy rains after the cultivation have been enough to partially remove the land cover and the turbidity of springs reached the highest historical value compromising the Tirana water supply (EFTIMI, ZOJER, 2015).

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Fig. 5. Mali me Groppa karst plateau (MMG):
a – A Google photo of MMG karst plateau and location of main springs, b – Hydrogeological cross-section of MMG karst plateau (after R. Eftimi); 1 – Karstic aquifer (T_3-J_1), Impermeable rocks, 2 – Flysch (Pg_{1-2}), 3 – Radiolarites with limestone strata (T_2), 4 – Effusive-sedimentary rocks (J_3-Cr_1), 5 – Intrusive ultrabasic rocks (σJ_2), 6 – Groundwater level, 7 – Karst water flow direction, 8 – Spring with average discharge higher than 100 L/s, 9 – Geologic boundary

Rys. 5. Płaskowyż krasowy Mali me Groppa (MMG):
a – MMG na zdjęciu Google wraz z lokalizacją głównych źródeł, b – przekrój hydrogeologiczny przez płaskowyż MMG (wg R. Eftimi); 1 – wodonosiec krasowy (T_3-J_1), skały nieprzepuszczalne, 2 – flisz (Pg_{1-2}), 3 – radiolaryty z warstwami wapieni (T_2), 4 – skały efuzywno-osadowe (J_3-Cr_1), 5 – skały intruzywne ultrazasadowe (σJ_2), 6 – poziom wód podziemnych, 7 – kierunki ruchu wód krasowych, 8 – źródła o średniej wydajności ponad 100 l/s, 9 – granice geologiczne

Рис. 5. Карстовое плато Мали ме Гроппа (ММГ):
a – ММГ на снимке Google и локализация главных источников, b – гидрогеологический разрез плато ММГ (по Р. Эфтими); 1 – карстовый водоносный горизонт (T_3-J_1), водонепроницаемые породы, 2 – флиш (Pg_{1-2}), 3 – радиоляриты с прослоями известняков (T_2), 4 – эффузивно-осадочные породы (J_3-Cr_1), 5 – интрузивные ультрабазитовые породы (σJ_2), 6 – уровень подземных вод, 7 – направления движения карстовых вод, 8 – источники со средним расходом больше, чем 100 л/с, 9 – геологические границы

Tushemisht springs

In south-east Albania, in the border area with North Macedonia are located two big transboundary lakes: Ohrid and Prespa separated by high elevation Mali Thate-Galichica karst massif (highest peaks – Mali Thate 2 288 m a.s.l., fig. 6). The karst massive consists of Upper Triassic–Lower Jurassic massive limestone. Clay-sandstone-conglomerate Pliocene deposits fill the bottom of the lakes Prespa and Ohrid.

Because Mali Thate-Galichica karst massive consists of carbonate rocks, and the level of lakes has a difference of about 155 m, a hypotheses was formulated by CVIJIC (1906) that the big karst springs of Tushemisht and St. Naum issuing in the southern edge of Ohrid Lake (fig. 1, nr 7, fig. 6) are partially recharged by the Prespa Lake. In fig. 2d is shown Zaver swallow hole where Prespa lake water disappear to reappear in the big karst springs of Tushemisht and St. Naum in Ohrid lakeside. The picture is of 2008 and coincides with the lowest level of the Prespa Lake at least of the last 200 years.

The mean discharge of Tushemisht Spring is 2.5 m^3/s (equal to $79*10^6$ $m^3/year$) and that of St. Naum Spring is 5.58 m^3/s (equal to $175*10^6$ $m^3/year$). Some unknown water quantity drains in the Ohrid Lake, also. In the Zaver swallow hole located in Prespa lakeside, the intensive loss of the lake water into karst rocks could be observed (fig. 2d).

The altitude effect of the isotopic composition of the meteoric water is used for the identification of the waters coming from different potential groundwater recharge sources of study area. The local precipitation and Prespa Lake water are examined as some potential source to Mali Thate–Galichica karst groundwater. Based on the results of the isotopic analyses a correlation

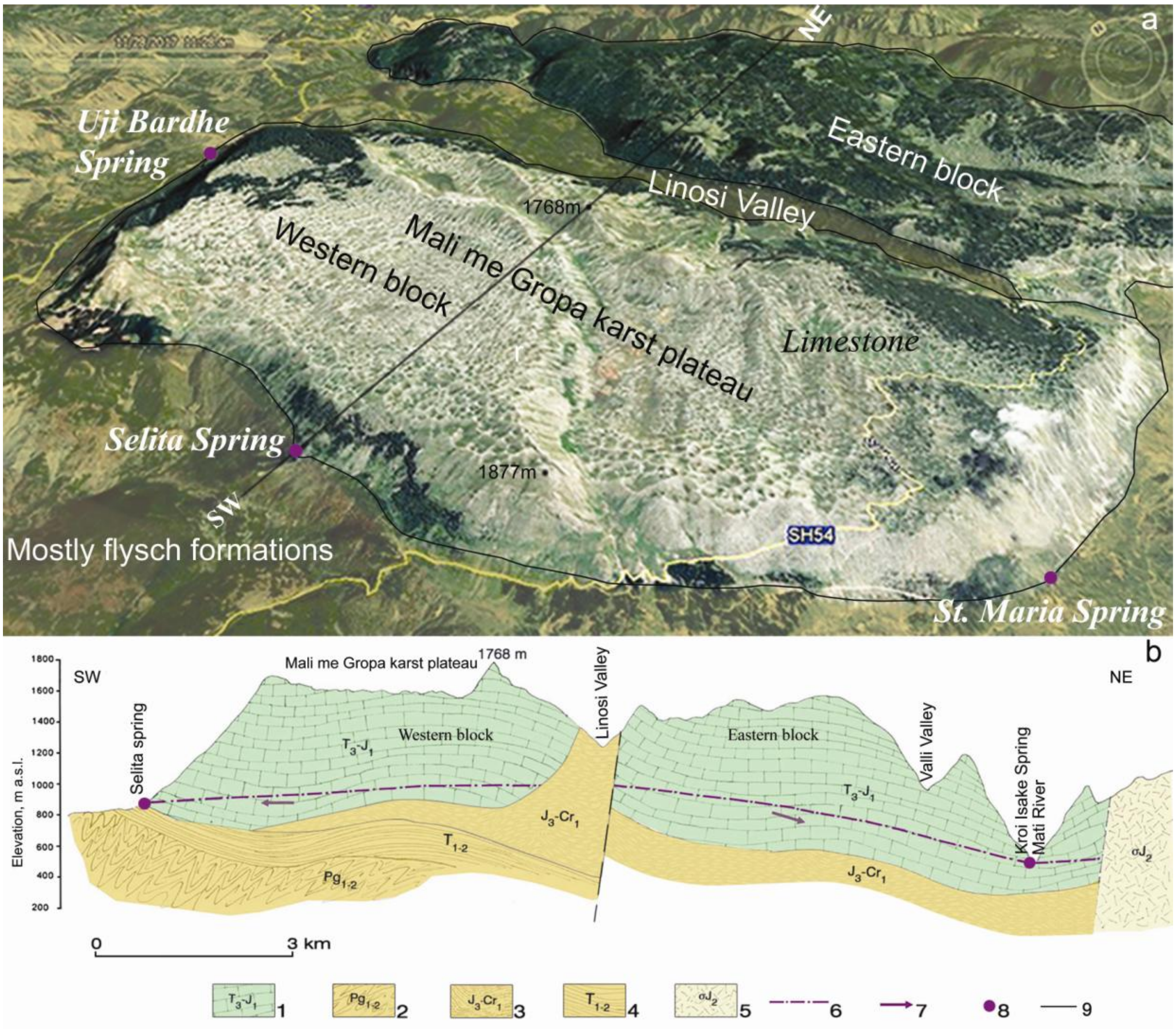

Fig. 6. Hydrogeological map of part of Mali Thate-Galichica karst massif (after: EFTIMI, SKËNDE, ZOTO, 2002). Inset photo shows the construction of the impermeable diaphragm of the intake structure of an orifice of Tushemisht spring at Ohrid lakeside.

Rys. 6. Mapa hydrogeologiczna części masywu Tate-Galićica (wg EFTIMI, SKËNDE, ZOTO, 2002). Na zdjęciu wstawce pokazano budowę wodoszczelnej diafragmy w części wlotowej źródła Tuszemiszt kolo Jeziora Ochrydzkiego.

Рис. 6. Гидрогеологическая карта части массива Тате-Галичица (по: EFTIMI, SKËNDE, ZOTO, 2002). Фото-вставка показывает сооружение непроницаемой диафрагмы впускного сооружения устья родника Тушемишт у Охридского озера.

function between mean $\delta^{18}O$ ‰ and δD ‰ values of sampling points which enabled to calculate the mixing proportion of the Prespa Lake water with the infiltrated in the karst massif precipitation. It was calculated that the Tushemisht Spring is recharged at 53% (1.3 m^3/s) by the Prespa Lake and at 47% (1.2 m^3/s) by the infiltrated precipitations in the karst massif. The percent proportion of recharging water of St. Naum Spring resulted different; the recharge from Prespa Lake consists 38% and that of infiltrated precipitation in the karst consist 62% of the total yearly discharge of the subjected spring (ANOVSKI. ANDONOVSKI, MINCEVA, 1991; EFTIMI, SKËNDE, ZOTO, 2002; EFTIMI et al., 2017).

With the support of IAEA, an artificial tracer experiment was performed, also, to further investigate the karst groundwater movement of Mali Thate-Galichica karst massif (AMATAJ et al., 2005). It was injected at Zaver swallow hole, at Prespa

Lake, and sampling included some outlets of Tushemisht and St. Naum Spring. The resulted maximum velocities of karst water vary from 233 m/h to 3 200 m/h. Slight differences of groundwater velocity exist not only from one spring to another, but even within the outlets of the same spring and such testifying the presence of differently developed underground water passages at close distances.

The water quality of Tushemisht Spring is excellent, the electrical conductivity vary about 300–310 µS/cm, the total hardness 3.0–3.87 meq/l and the water chemical type is HCO_3-Ca; the water temperature vary about 11.3 to 11.9°C.

When for increasing the water quantity of captured springs are used pumps the protection of karst springs become more difficult (COTECHIA et al., 1982; MILANOVIC, 2000; STEVANOVIC, 2010, 2014). In Tushemisht karst spring, for the increasing the spring rate-flow, as well as for the protection from pollution by the eventual seepage of the lake water, an impermeable protection diaphragm is constructed (fig. 6). The diaphragm consists of 74 alternating cemented and reinforced boring piles diameter 600 mm and maximal depth 7.5 m tightly incised in the basement rock. The pumping capacity of the new intake structure was increased from about 100 l/s to about 250 l/s assuring the spring water quality from the mixing with the lake water.

Uji Ftohte Spring

Near to the city of Vlora is situated the Tragjas carbonate anticline which consist the northernmost coastal karst aquifer with the highest peak at 1 864 m a.s.l. This structure is made up by Mesozoic and Paleocene-Eocene carbonate rocks and thin bedded cherts. On the NW sector, in the area of Uji Ftohtë Spring (fig. 1, nr 8, fig. 7) a transgressive contact of carbonate rocks with Noegene clayey formations is present (MEÇO, ALIAJ, 2000; XHOMO et al., 2002). The Neogene clay formations work as a barrier that prevents the seawater intrusion into the karst aquifer.

Uji Ftohtë Springs is a group of coastal springs located about 5 km south of city of Vlora flowing at sea level. Along the seaside, in a starch about 1.7 km long, are identified 32 springs, concentrated in three sectors, respectively 185, 350 and 500 m long (TAFILAJ, 1964). To capture the springs three tunnels are placed landward and parallel to the sea coast at a distance 60–70 m from shoreline and at elevation 0.2–0.5 m a.s.l. The mean annual discharge of all the springs is about 2.0 m^3/s and the total mean discharge of the intake tunnels used for the Vlora city water supply vary about 0.8 to 2.0 m^3/s (EFTIMI, 2003).

The main chemical parameters of the karst water drained measured at the drainage tunnels, are as follows: conductivity 400–760 µS/cm at 25°, TDS 250–540 mg/l, Cl 20–150 mg/l, SO_4 35–50 mg/l, Na 20–90 mg/l, Ca 50–60 mg/l, NO_3 1–5 mg/l, NO_2 is below detection limit, pH 7.2–7.7; the hydrochemical type is HCO_3-Ca-Mg (EFTIMI, 2005).

However, the situation in the catchments area of Uji Ftohtë Springs is undergoing rapid changes: instead of the fruit trees, brushwood, meadows and outcropping rocks, an uncontrolled urban area is under fast development in the immediate vicinity to the subjected springs (fig. 7). The new urban area without a properly planned waste water system, and with septic tanks mostly constructed without any special isolation, is a constant mincing factor.

Viroi and Blue Eye Springs

Viroi and Blue Eye Springs (fig. 1, nr 11 and nr 12) issue from the Mali Gjere karst massif which is located in South Albania on the border with Greece; its total surface area 440 km^2, mostly located in Albanian territory (54 km^2 in Greek territory). The mountain crest of Mali Gjere (the highest peak 1 798 m a.s.l.) is the natural water divide between the Drinos River basin located on the east, and Bistrica River basin located on the west (fig. 8). Mali Gjere is an anticline structure consisting of Mesozoic carbonate sequence overthrown to Perm-Triassic gypsum and clay deposits, surrounded by Paleogene and Neogene flysch formations. The carbonate rock are well stratified and dip to the east, to Drinos River plain, with angles about 20–25° (fig. 3 RE). While the stratification fractures are well developed the big surface karst forms are very rare; only some small karren fields and two vertical spring shaft orifices depth about 50 m are present.

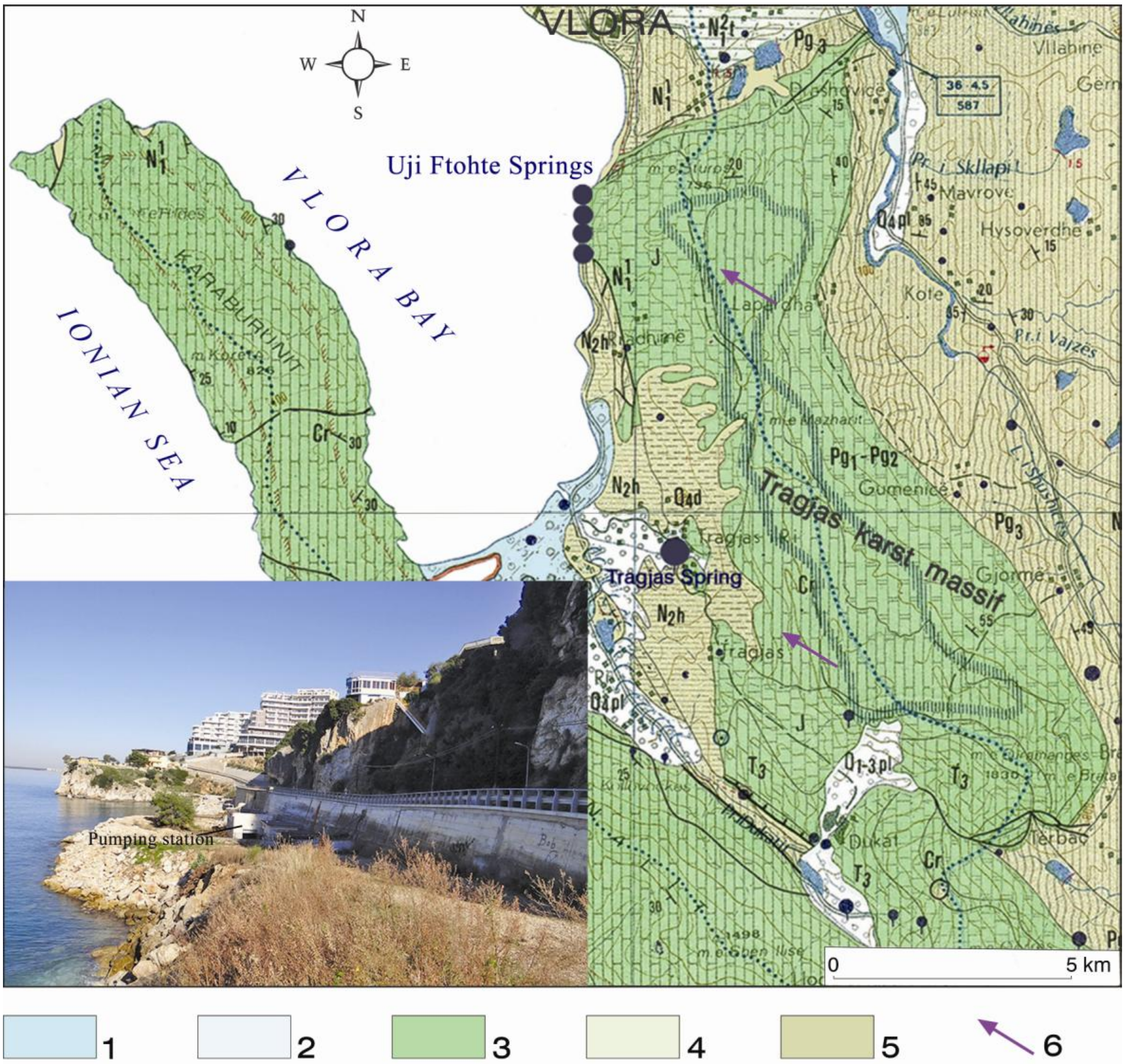

Fig. 7. Hydrogeological map of Vlora area:
1 – Gravelly aquifer, 2 – Sandy to gravelly aquifer, 3 – Karst aquifer, 4 – Sandstone aquifer, 5 – Non aquiferous rocks, 6 – Karst water flow direction (after EFTIMI et al., 1985). Inset photo shows the new urban area located, above the intake tunnels.

Rys. 7. Mapa hydrogeologiczna rejonu Vlory:
1 – wodonosiec w żwirach, 2 – wodonosiec piaszczysto-żwirowy, 3 – wodonosiec krasowy, 4 – wodonosiec w piaskowcach, 5 – skały bezwodne, 6 – kierunki ruchu wód krasowych (wg EFTIMI et al., 1985). Na zdjęciu we wstawce pokazana jest nowa strefa zabudowy miejskiej położona nad wlotowymi tunelami.

Рис. 7. Гидрогеологическая карта района Влоры:
1 – гравийный водоносный горизонт, 2 – песчано-гравийный водоносный горизонт, 3 – карстовый водоносный горизонт, 4 – водоносный горизонт в песчаниках, 5 – породы не содержащие вод, 6 – направления движения карстовх вод (по: EFTIMI et al., 1985). На фото-вставке показана новая городская зона, расположенная над впускными туннелями.

The total discharge of all the springs of Mali Gjere karst massif results about 743·10^6 m^3/year, equal to 23.6 m^3/s (EFTIMI, AMATAJ, ZOTO, 2007). Mali Gjere karst massif recharge two much known springs of Albania, Viroi Spring Blue Eye Spring.

Viroi Spring (fig. 9a) issue at elevation about 195 m a.s.l. which represent the lowest elevation of the outcrop of karstic rocks on the eastern foothils of Mali Gjere. The spring orifice is located just in the contact of Paleogene limestone rocks with the Paleogene flysch deposits. The water discharges through a well-developed siphon which maximal investigated depth is -83 m (TOULOUMDJIAN, 2005). Viroi spring is the biggest temporary one of Albania with a maximal discharge more than 30 m^3/s. Usually, during the

period July-September the spring drays up totally, but during the flowing period a beautiful temporary lake is formed close to the spring (fig. 9a). At ground surface, close to the top of the siphon for many years, before 1990, has functioned a big pumping station (fig. 9b), with capacity 2 m^3/s, and the water was used for the irrigation.

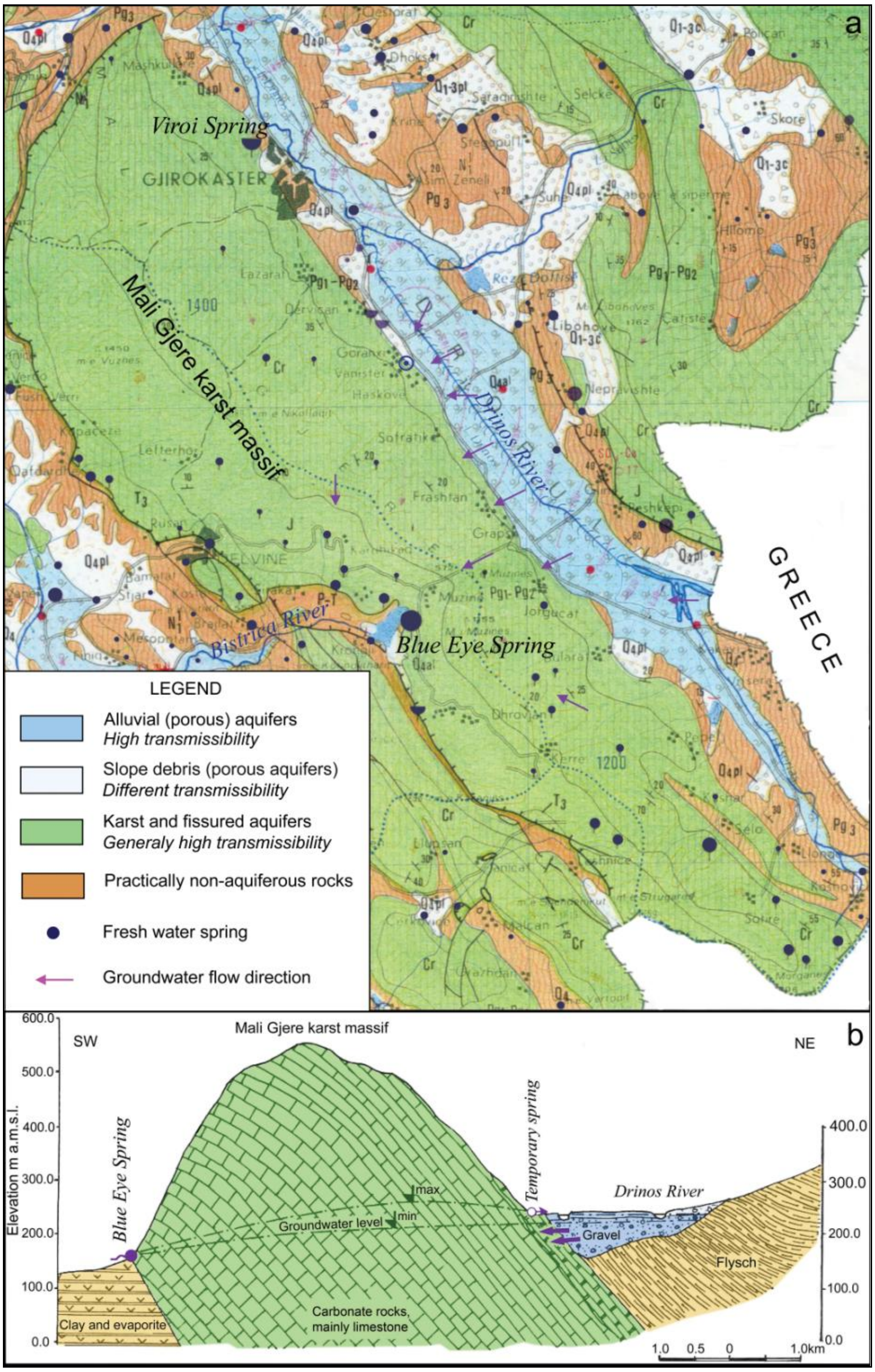

Fig. 8. Blue Eye Spring (after EFTIMI et al., 1985):
a – Hydrogeological map of the Mali Gjere karst aquifer, b – Hydrogeological cross-section through the Blue Eye Spring
Rys. 8. Źródło Niebieskie Oko (wg EFTIMI et al., 1985):
a – mapa hydrogeologiczna wodonośca krasowego Mali Gjere, b – przekrój hydrogeologiczny źródła Niebieskie Oko
Рис. 8. Источник Голубой Глаз (по: EFTIMI et al., 1985):
a – гидрогеологическая карта карстового водоносного горизонта Мали Гьере, b – гидрогеологический разрез источника Голубой Глаз

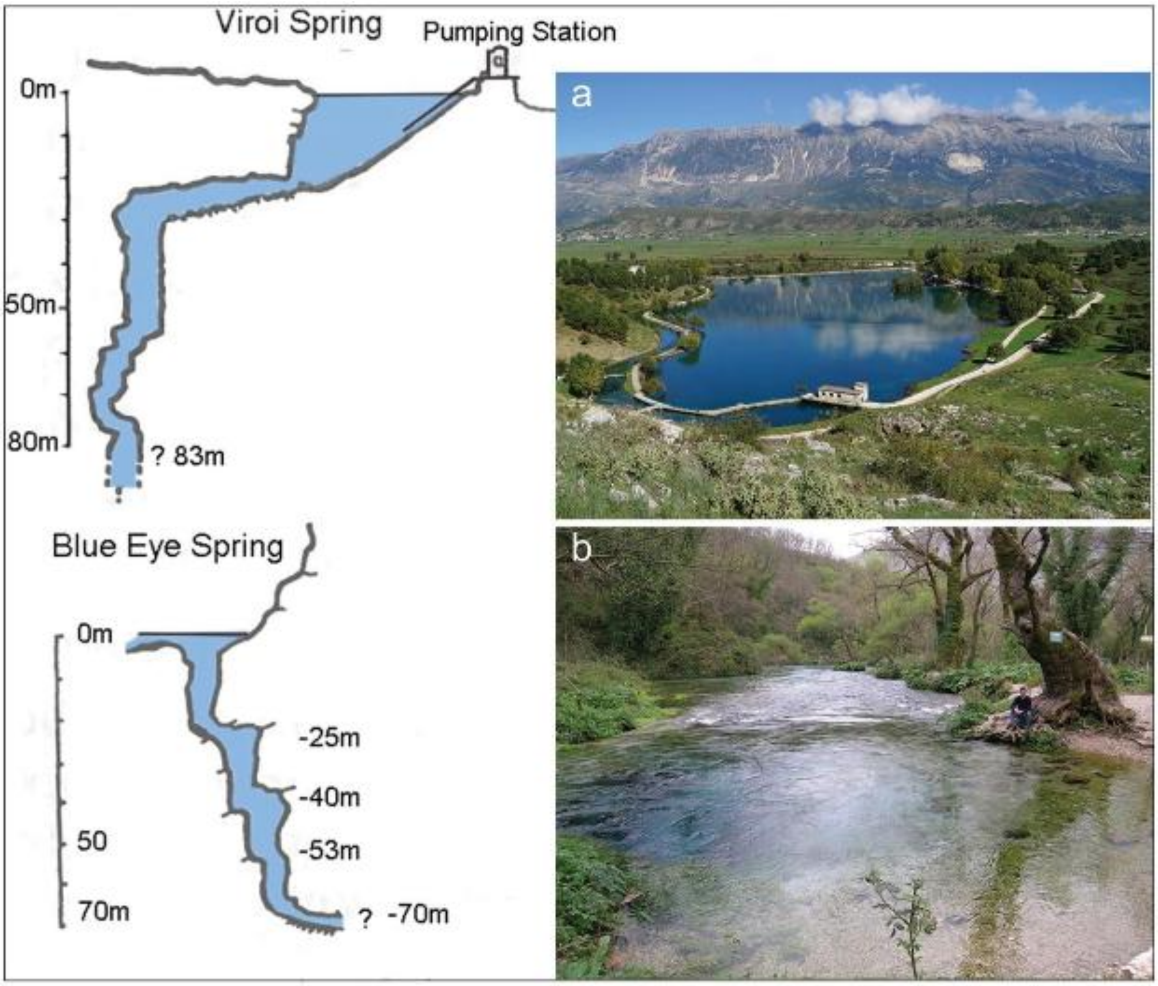

Fig. 9. Two siphon springs:
a - Viroi Spring, b – main orifice of Blue Eye Spring (profiles after C. Touloumdjian, phot. by R. Eftimi)
Rys. 9. Dwa źródła syfonowe:
a – źródło Viroi, b – wypływ główny źródła Niebieskie Oko (przekroje wg C. Touloumdjian, fot. R. Eftimi)
Рис. 9. Два сифонных источника:
а – источник Вирой, b – главный исток источника Голубой Глаз (разрезы по C. Touloumdjian, фот.: Р. Эфтими)

The spring water is of HCO_3-Ca and the average values of some water chemical parameters are as follow: conductivity 370 µS/cm, Ca-62 mg/l, HCO_3-161 mg/l, SO_4-46.5 mg/l and the temperature is 11.2°C.

Blue Eye Spring emerges on the western foothill of the Mali Gjere karst massif, which is located in the south-eastern part of Albania (fig. 9b). The total surface of Mali Gjere is 440 km^2, mostly located in Albanian territory (about 400 km^2).

Most of the karst water resources of this massif discharge in its western side, where Blue Eye Spring with a mean discharge of 18.2 m^3/s issues at elevation about 155 m a.s.l., or at 55 m lower than the Drinos River Valley. The spring has six main orifices, and the biggest of them shown in Fig. 9b, discharges about 60% of the total spring dischar-ge (fig. 9b).

Using the environmental isotope and hydrochemical techniques combined with the balance investigations is verified that about 65% of the yearly discharge if Blue Eye Spring is recharged by the effective infiltrations in the MGM karst massif and about 35% of the total discharge of is replenished by the ground waters of the Drinos River gravelly aquifer (EFTIMI, AMATAJ, ZOTO, 2007; EFTIMI, DHAME, 2009a). This is facilitated by the good hydraulic connection of between

Fig. 10. Some additional photographs to the issue of karst springs of Albania:
1–2 – large springs at the Albanian bank of Shkoder Lake; 3 – ponor (Zaver) in the rocky bank of Big Prespa Lake in which lake waters disappear and flow under Galichica Ridge to Ohrid Lake located 200 m below, 4 – stream flowing into Ohrid Lake from springs (St. Naum Springs at Macedonian bank of the Lake) supplied by waters coming from Big Prespa Lake, 5–6 – Blue Eye Spring and the river birthed by Spring (phot. by V. Andreychouk)

Rys. 10. Wybrane dodatkowe fotografie do tematu krasowych źródeł Albanii:
1–2 – duże źródła na albańskim brzegu Jeziora Szkoderskiego; 3 – ponor (Zawer) w skalistym brzegu jeziora Wielka Prespa pochłaniający wody jeziora, które płyną dalej pod Grzbietem Galiczica ku Jezioru Ochrydzkiemu położonemu o 200 m niżej, 4 – potok wpływający do Jeziora Ochrydzkiego zasilany źródłami (Źródła Św. Nauma na macedońskim brzegu Jeziora) z wód docierających z Jeziora Wielka Prespa, 5–6 – źródło Niebieskie Oko i rzeka biorąca z niego swój początek (fot. V. Andreychouk)

Рис. 10. Некоторые дополнительные иллюстрации к теме карстовых источников Албании:
1–2 – крупные источники на берегу Шкодерского озера; 3 – понор (Завер) в скалистом берегу озера Большая Преспа, поглощающий воды озера, которые затем подземным путем движутся под хребтом Галичица к Охридскому озеру, расположенному на 200 м ниже, 4 – поток, втекающий в Охридское озеро, берущий начало в источниках (источники Св. Наума на македонском берегу озера), питающихся водами из озера Большая Преспа, 5–6 – источник Голубой Глаз и река, рожденная источником (фот.: В. Андрейчук)

both aquifers, and by the natural karst groundwater slope to the Blue Eye Spring, (fig. 8b).

The spring is typically ascending, and cave diving explorations have established a deep almost vertical karstic channel (TOULOUMDJIAN, 2005). At a depth -73 m, the channel diminishes and become nearly horizontal and then continues even deeper (fig. 9b).

The spring water is of HCO_3-SO_4-Ca type and the average values of some water chemical parameters are as follow: conductivity 535 µS/cm, Ca-95 mg/l, HCO_3-203 mg/l, SO_4-118.6 mg/l and the temperature is 12.2°C. Since the sixties of the last century, the spring water after collection in a small like is diverted for the production of the electricity.

It should be mentioned that karst springs of Albania are important not only from the economic point of view, but they represent also objects that can constitute excellent tourist attractions – due to their size, uniqueness and the surrounding scenery. Some additional photos of springs are given in fig. 10.

Conclusions

The present paper is a short overview of the karst and of karst springs of Albania, where some of the biggest of them are described more in detail.

The total natural karst groundwater resources of Albania are calculated with $7.15 \cdot 10^9$ m^3/y (227 m^3/s) and consist about 80% of the total groundwater resources of the country. Karst water usually discharges from karstified rock in the form of karst springs that can vary greatly in productivity. In Albania there are 110 karst springs which average discharge is more than 100 l/s, and 17 of them have discharges more than 1 000 l/s (EFTIMI et al., 1985; fig. 1). The discharge of the Blue Eye Spring, the biggest spring of Albania is 18.2 m^3/s.-Many contact-springs issue in the edges of geological structures, while other springs escape at or near the valley floor of rivers, deeply intersecting the carbonate rocks. Large groundwater quantities drain to the big lakes of Shkodra and Ohrid, as well as to the seaside (South Albania coastal area). As reviled by speleodiving some important karst springs, mostly located in the Western Albania, have deep siphons which maximal depth vary about 60 to more than 83 m. Most of karst springs of Albania have excellent quality.

Nearly 70–80% of the population of the cities in Albania, including the capital Tirana, are supplied by karst water. The main problems related to the intensive use of the karst water are related to: a) unstable groundwater regime as result by uneven reinfall distribution throughout the year, as well as, the fast discharge of the karst water resources through the well developed flow-paths, and b) high vulnerability to human impact.

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