Geological Quarterly, 2026, 70, 16
http://dx.doi.org/10.7306/gq.1861

# Karst groundwater of the Tomorri massif: an important resource for South Albania

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Eftimi, R., Orehova, P., Qiriazi, P., 2026. Karst groundwater of the Tomorri massif: an important resource for South Albania. Geological Quarterly, 70, 16; https://doi.org/10.7306/gq.1861

Associate Editor: Tatiana Solovey

The most significant aquifers in Albania are in carbonate rocks, consisting of 23 separate karst structures, often referred to as karst areas. Their total area covers ~6,440 km², roughly 24% of the country's surface. The natural groundwater resources in these regions amount to ~227 m³/s. These resources supply ~80% of the water for the population in Albanian cities. The Tomorri karst massif is one of Albania's most important karst structures because it is located in a large area of southern Albania, built on flysch and other low-permeability strata that are very deficient in groundwater. High-quality groundwater resources in this massif provide water to >150,000 residents in Berat, Poliçan, Çorovoda, Gramsh, and several villages. In this paper we assess the quantity and quality of groundwater resources within this massif to help ensure their safe use and protection, providing the first compilation, analysis and synthesis of all available groundwater data for the area, primarily collected from separate investigations conducted for practical purposes. Our analysis covers observations on spring discharges related to climate patterns, estimates of renewable general karst water resources of the massif, groundwater quality, environmental isotope concentrations, and the overall environmental conditions and pollution vulnerability. We relate this information to the geological structure and karst geomorphology of the Tomorri massif. This massif is a groundwater basin with high permeability, where the main factor influencing groundwater movement and drainage is the direction of hydraulic slope. This means that karst groundwater flows towards the boundary between the carbonate formations and nearly impermeable flysch layers surrounding the massif. The karst water resources mainly discharge through four large springs: Guaku, Bogova, Kërpica and Sotira. We also highlight environmental issues associated with intensive quarrying in the massif, and emphasize the importance of raising public awareness of karst areas, particularly as regards protecting the abundant groundwater resources of the large Tomorri karst massif.

Key words: Tomorri karst massif, karst springs, water resources, Albania.

## INTRODUCTION

Karst aquifers are widely recognized as a vital source of drinking water worldwide. They are especially common in the Mediterranean region (Margat, 1998; Bakalowicz, 2015; Stevanović, 2019; Liso and Parise, 2020) and in southeastern Europe (Stevanović and Eftimi, 2010). Albania has an extensive karst aquifer system covering ~6750 km², roughly a quarter of the country's territory. These aquifers include 23 carbonate karst regions and two evaporitic regions (Eftimi, 2020). Approximately 80% of the urban population relies on karst spring water (Eftimi and Zojer, 2015). In this paper, we focus on Tomorri Mountain, a karst massif in southern-central Albania (Figs. 1 and 2), which recharges several large springs supplying water to the towns of Berat, Poliçan, Çorovoda and Gramsh, as well as numerous villages. We explores the springs in relation to geological, tectonic and karstic morphology, with special focus on describing the quantity and quality characteristics of the springs as key indicators of their intensive usage. We also assess the renewable karst water resources, and the potential for the Tomorri massif to degrade due to intensive quarrying.

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Received: March 13, 2026; accepted: May 19, 2026; first published online: August 12, 2026

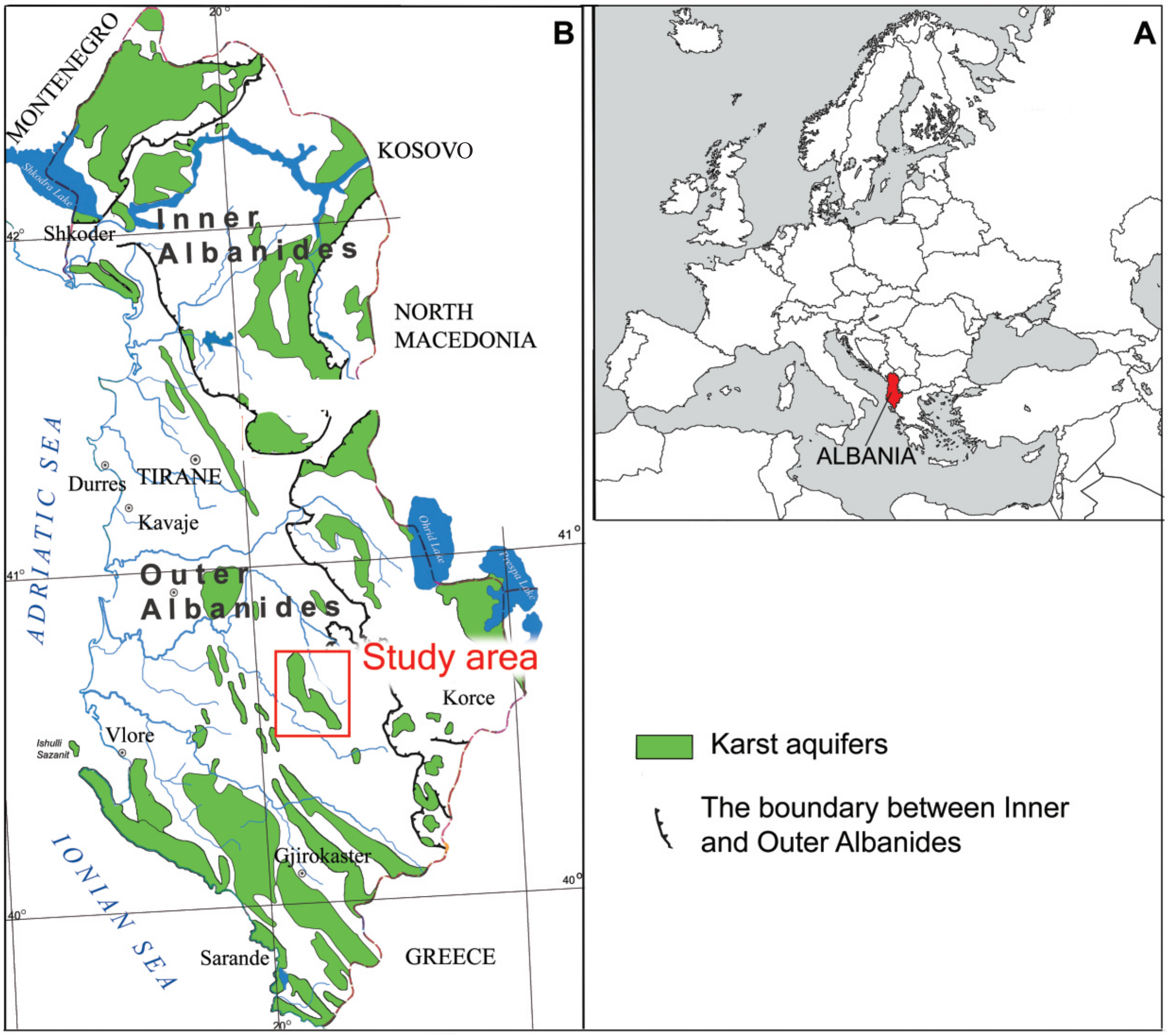


**Fig. 1. Location map of the study area; Tomorri karst massif shown in red quadrangle (after Eftimi et al., 1985)**

## PHYSICAL AND GEOGRAPHIC CONTEXT

The Tomorri karst massif is located in south-central Albania and consists of two mountains, Tomorri and Kulmaka, covering an area of 140 km² (Fig. 2). This massif stands out as a prominent block relative to the surrounding hilly terrain, especially along its northern edges, where it has near-vertical slopes. The relief of the Tomorri massif, like that of many carbonate anticline structures in southern Albania, is asymmetrical: the western slope is generally much steeper than the eastern slope. Morphologically, the Tomorri massif is a ridge ~5 to 5.5 km wide and ~35 km long, with an average elevation between 1,500 and 2,000 m a.s.l. (Qiriazi, 2019). The highest peaks are located in the northern section, with Partizani reaching 2,416 m a.s.l.; in the central section, Kulmaka is at 2173 m a.s.l.; and in the southern section, Bostanak Peak is at 1,873 m a.s.l. Two mountain passes of tectonic origin, Kulmaka at 1,673 m a.s.l., and Devrie, at 1,300 m a.s.l., cross the Tomorri Mountain. Part of the northern area of Tomorri Mountain, covering 24.723 hectares, has been designated as a National Park. The natural resources of Tomorri Park include geological, geomorphological, groundwater, floral, and ecological features.

## HISTORY OF RESEARCH

The geology of the Tomorri massif has been examined in several regional studies (Meço and Aliaj, 2000; Xhomo et al., 2002). Albania's karst landscape has primarily been explored by geographers (Kristo, 1973; Qiriazi, 2019; Parise et al., 2004). The 1:500,000 geomorphological map of Albania (Anonymous, 1992) depicts the Tomorri massif as an area rich in karst features. Over the past 25 years, extensive speleological research has documented numerous caves and shafts (Denneborg, 1993; Savino et al., 2003; Zhalov, 2015).

A general hydrogeological survey of the Tomorri massif was conducted as part of the compilation of the hydrogeological map of Albania at a scale of 1:200,000 (Eftimi et al., 1985). Several detailed hydrogeological studies focus on large karst springs, such as Kërpica, Bogova, and Guaku, which supply water and are also used for electricity generation (Archive of the Albanian Hydrogeological Service, AHS). About 150,000 residents rely on the karst springs of the Tomorri massif. Discharge from these springs has been measured irregularly, primarily between 1980 and 2000. Water samples were primarily analysed in the AHS laboratory for major elements such as $Mg^{2+}$, $Ca^{2+}$, $Na^{+}+K^{+}$, $Cl^{-}$, $SO_4^{2-}$, and $HCO_3^{-}$. The ion com-

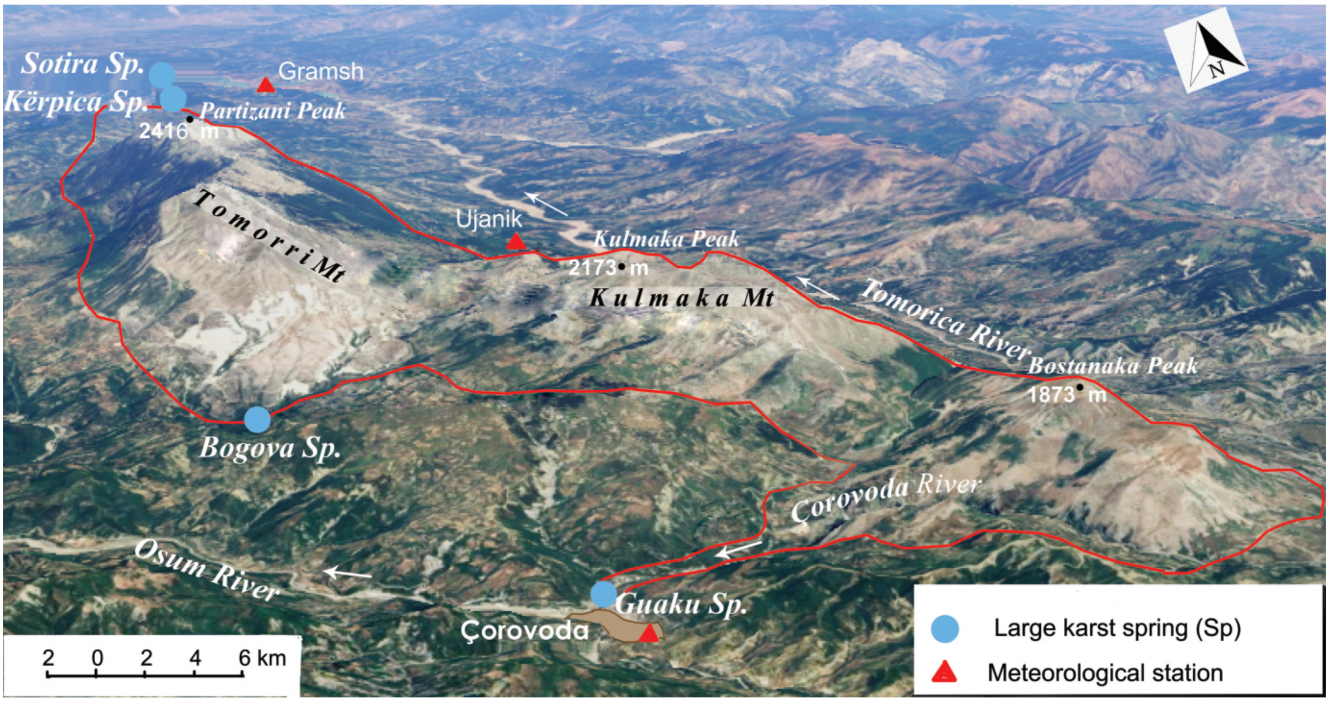


**Fig. 2. Digital Terrain Model of the Tomorri karst massif and main karst springs**

The red line marks the boundary of the carbonate rock of the Tomorri karst massif

position was determined using volumetric, spectrophotometric, colorimetric, and endpoint titration methods. During sampling, key parameters, including pH, temperature, and electrical conductivity (EC), were measured in the field.

The AHS, in collaboration with the Institute of Nuclear Physics in Tirana, conducted an O-18 sampling campaign across all significant and minor springs in the study area during May–June 1990. Recognizing the crucial importance of karst water in the Tomorri massif, the adverse effects of intensive quarrying in this area are monitored, and its consequences discussed (Eftimi and Zojer, 2015).

## CLIMATE AND HYDROLOGY

According to the Hydrometeorological Institute of Tirana (Anonymous, 2020), the climate of the Tomorri massif is classified as Mediterranean mountainous, with cold, rainy winters and cool to warm, relatively dry summers. Three meteorological stations operate in the area, located on the outskirts of the study zone (Fig. 2). Only the Ujanik station, at 1150 m a.s.l., represents a reasonably representative climate for the Tomorri karst massif (Fig. 2 and Table 1). Figure 3 shows the average monthly precipitation and temperature data. Based on the Ujanik station, the average annual temperature is ~8.6°C, with January averaging 0.9°C and August averaging 17.4°C. The annual precipitation averages 1,401 mm, with ~58% falling between October and April. Temperatures drop below freezing for ~40 days each year, resulting in snow cover on the karst plateaus, averaging ~40 mm in thickness.

As is typical of a karst massif, the Tomorri massif's surface hydrographic network is poorly developed, whereas the underground network is extensive (Bakalowicz, 2005; Worthington and Ford, 2009; Stevanović, 2015). The only permanent river passing through the Tomorri massif is the Çorovoda River, which forms the Gradec Canyon, over 100 m deep, cutting the southern part of the massif (Fig. 4). The average annual flow of the Çorovoda River at the canyon's mouth is 15.6 $m^3/s$. During the rainy season (October–May), it increases to 20.8 $m^3/s$, and during the dry season (June–November), it decreases to 3.57 $m^3/s$ (Pano, 2008). Several temporary high-energy streams, such as the Lubesha, Kapinova, Bogova

Table 1

**Basic data of the meteorological stations located in the periphery of the Tomorri karst massif**

| Meteostation | Elevation [m a.s.l.] | Mean air temperature [°C] | | | Precipitation [mm] | | |
|---|---|---|---|---|---|---|---|
| | | May–October | November–April | Yearly | May–October | November–April | Yearly |
| Ujanik | 1150 | 14.0 | 6.7 | 8.6 | 592 | 809 | 1401 |
| Çorovoda | 410 | 20.8 | 9.3 | 14.6 | 352.4 | 718.1 | 1070 |
| Gramsh | 200 | 20.4 | 9.1 | 14.7 | 432 | 696.2 | 1128 |

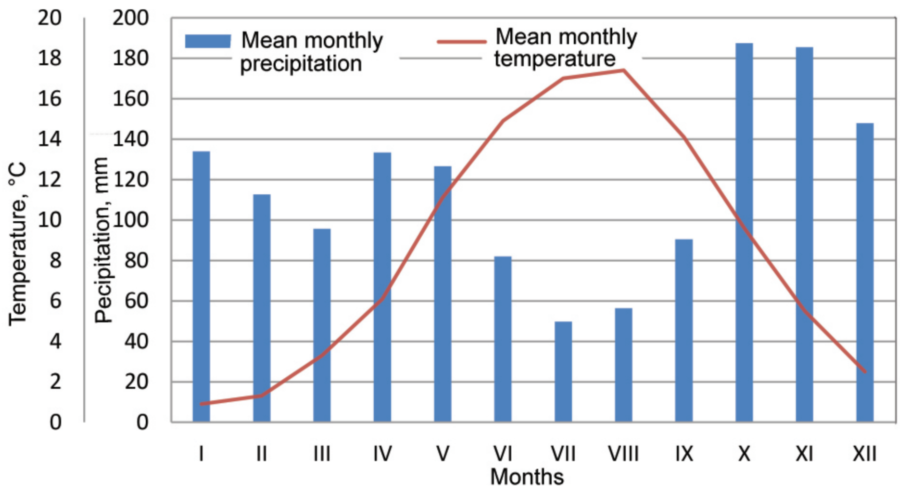


**Fig. 3. Mean monthly discharges of precipitation vs mean monthly temperatures for Ujanik meteorological station**

and Ujanik, flow from Mount Tomorri into the Osumi and Tomorica rivers (Fig. 4). The flow rate measurements of the springs as well as climatic data, are taken from publications of the Institute of Hydrometeorology of Tirana.

## GEOLOGY AND GEOMORPHOLOGY

The Tomorri Mountain is an anticlinal structure located in the Kruja tectonic zone, part of the Outer Albanides (Meço and Aliaj, 2000; Xhomo et al., 2002). It consists of limestone and minor dolomite deposits of Upper Cretaceous to Upper Eocene age ($Cr_2$-$Pg_2$; Fig. 4). The Upper Eocene deposits overlie the Upper Cretaceous and are dominated by biogenic limestones. Oligocene flysch ($Pg_3$) surrounds the carbonate formations of the Tomorri massif, the contact being at higher levels in the eastern than in the western part (Melo et al., 1987; Meço and Aliaj, 2000). Along the entire western side of Mount Tomorri, at the foothills of the carbonate rocks, thick Pleistocene ($Q_{1-3}$) colluvial breccia and moraine deposits are present (Fig. 5).

On the eastern side, near Ujanik village, a series of hills made up of Pleistocene slope debris and moraines can be found. According to the Geological Map of Albania, scale 1:200,000 (Xhomo et al., 2002), these hills are labeled as slope breaches, although they appear to be typical frontal glacial moraine deposits (Fig. 5B). Structurally, the Tomorri karst massif includes the Tomorri and Kulmaka anticlines, with the Siraka syncline situated between them (Fig. 4).

Tomorri's anticline is asymmetrical; on the eastern side, the deposits dip at angles of 25 to 50°, while the western flank has been tectonically shifted by 2–3 km and is nearly vertical (Melo et al., 1987). The northern periclinal part of Tomorri is complex; it is dissected by numerous east-west-trending tectonic faults (Fig. 4), which create a step-like block structure that slopes northwards, while its southern periclinal part dips more gradually (Aliaj, 2012).

As in other parts of Albania, karst relief features are generally well developed in the Tomorri anticline (Kristo, 1973; Qiriazi, 2019; Andreychouk et al., 2022). Among these features is a karst plateau covering ~3–4 km² and featuring a high concentration of karren, karren fields, dolines, and uvalas (Fig. 5B) on Kulmaka Mountain. Additionally, 20 caves have been discovered there, along with some vertical shafts ranging from ~120 to 209 m in depth (Uvlen shaft; Fig. 4) (Savino et al., 2003). Notably, glacial cirques with diameters of up to ~100 m develop along mountain ridges at elevations of 1800–1900 m (Fig. 5C). Among the most remarkable karst features are undoubtedly the Piro Goshi Cave and Proseku Shaft (Fig. 6A), the locations of which are also shown in Figure 4. Pirro Goshi has a predominantly horizontal extent and a length of 1500 m (Denneborg, 1993). It is located on the right river-slope of the Gradec Canyon, ~80 m above the Çorovoda River bed (Fig. 4).

## HYDROGEOLOGY

The Tomorri massif consists of a karst aquifer of Upper Cretaceous to Eocene age, of massive limestone and less commonly dolomite, which is overthrusted to the west over Oligocene flysch strata. On the west and east, there are extensive outcrops of unconsolidated Pleistocene moraines and slope debris (Fig. 4). The carbonate rocks are intensely fissured and karstified, forming an aquifer recharged by abundant precipitation of ~1550 mm/y. The karst water basin functions as a unique water body in which factors influencing groundwater flow and drainage, similar to those in other karst regions (Bakalowicz, 2005; Worthington and Ford, 2009; Stevanović et al., 2015), are determined by the hypsometric features of its boundary with the surrounding low-permeability flysch strata. Each of the large springs, namely Uji Zi (black water), Bogova Kerpica and Sotira, emerges at the lowest points of the limestone outcrop. As the aquifer has very high permeability and the elevation difference between recharge and discharge areas (springs) exceeds 750 m, the springs' regime is highly variable.

Across wide areas of the eastern and western peripheries, the karst aquifer is overlain by porous, unconsolidated and moderately permeable moraine and slope debris deposits, forming an aquifer with significant resources for the local population.

### SPRINGS AND THEIR REGIME

Two types of spring issue from the Tomorri massif and are associated with different aquifers: karst springs in carbonate

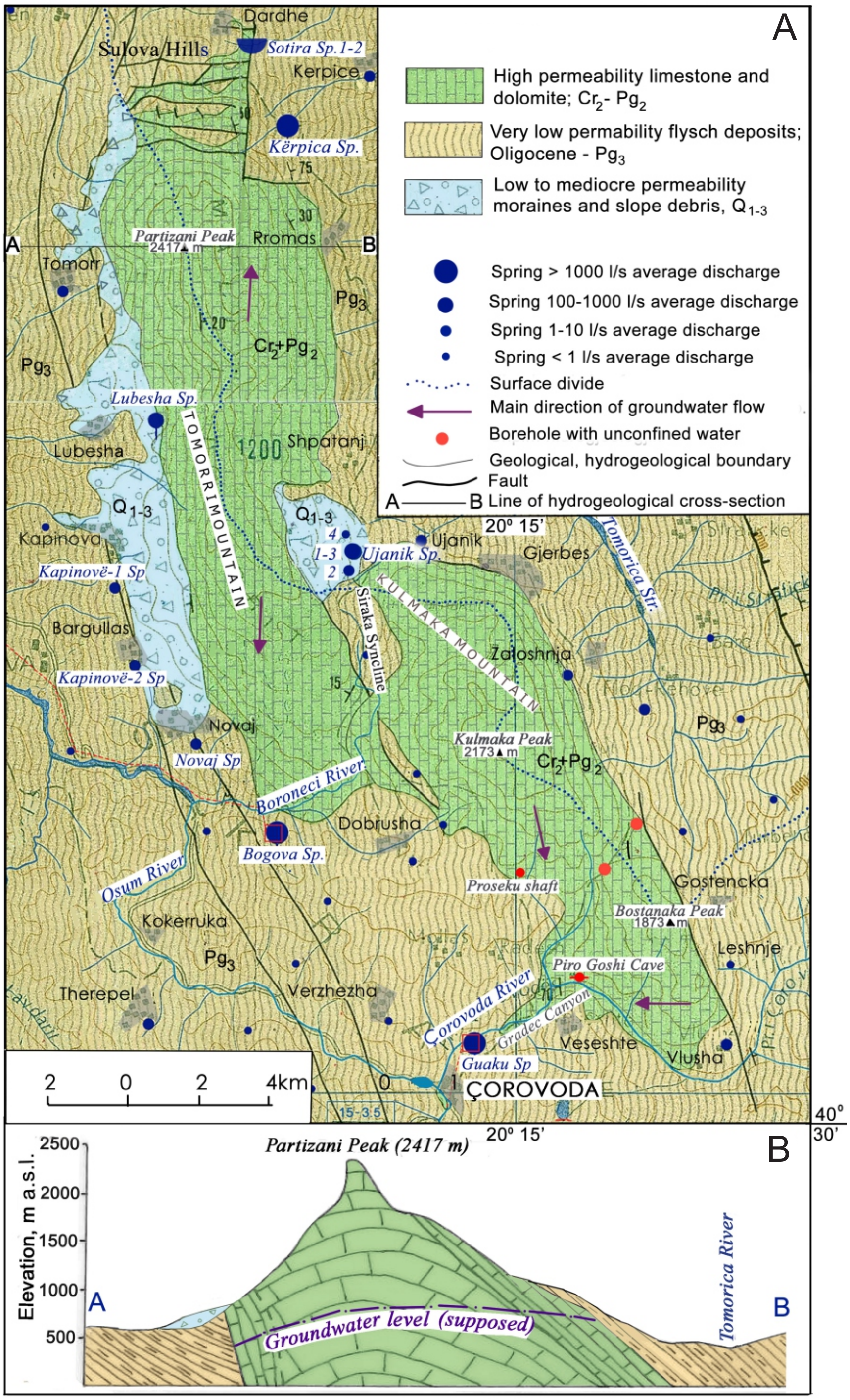


**Fig. 4A – hydrogeological map of the Tomorri karst massif (after Eftimi et al., 1985); B – geological cross-sections A–B (after Melo et al., 1987)**

rocks and springs in moraines and slope debris. Four large karst springs, Kërpica, Bogova, Guaku, and Sotira (Fig. 7), emerge from the carbonate formations of the study massif (Figs. 2 and 3). Systematic measurements of spring flow have not been conducted; however, for each of the four main springs, the Institute of Hydrometeorology of Tirana has taken between 8 and 92 measurements, mainly during the period 1980–2000, and these are summarized in Table 2.

**Kerpica spring** (Fig. 7B) originates from a single point roughly 3 km south-west of Kerpica village. Spring flow ranges from ~350 to 2500 l/s, averaging ~750 l/s. This spring supplies the town of Gramsh with nearly 100 l/s, and the remaining water is used for irrigation and electricity production.

**Bogova Spring** (Fig. 7C) is located ~2 km east of the village of the same name, at the edge of the Boronec River. It originates at the contact between Eocene ($Pg_2$) limestone and Lower Oligocene ($Pg_{3-1}$) flysch deposits. The spring's average flow is estimated at 1350 litres per second. Approximately


**Fig. 5A – Tomorri Mountain karst massif; general view from the north; B – Uvala in the central-eastern part of the massif; C – glacial cirques on the northern part of the mountain ridge (photos P. Qiriazi)**

350–500 litres per second from this spring are used for water supplies for the cities of Poliçan, Berat and Kuçova, with the remaining flow used for electricity generation.

**Guaku Spring** (Fig. 7D) is located ~1.5 km north-east of the town of Çorovoda, in the Çorovoda riverbed. The connection between the river water and the karst waters of the Tommori massif has not been studied. The average flow of this spring is ~1,500 litres per second. About 100 litres per second are used for Çorovoda city's water supply, while the remainder is used for electricity generation.

**Sotira Spring** (Fig. 7A), known locally as Curugje, is located in the northernmost part of the Tomorri massif, ~1.5 km west of Sotira village. This spring issues from a large block of carbonate rock, disconnected from the main body of the Tomorri massif and lowered at about. This block most probably has no hydraulic connection with the Tomorri massif; if it was, the spring would not be intermittent. Water emerges from a horizontal, stratified fissure in Eocene ($Pg_2$) limestone, 5–6 metres long and ~20 metres above the Leshnica River level, forming a beautiful waterfall. The spring's flow varies greatly; during the rainy season, it exceeds 3.5 m³/sec, but from June to November, it completely dries up.

The discharge of the springs is closely related to effective infiltration of precipitation, which depends mainly on annual precipitation and its seasonal distribution (Kessler, 1967). As shown in Figure 3, the monthly rainfall pattern in the Tomorri massif varies significantly: during the six-month cold season (October–February), ~62% of the annual rainfall occurs, while during the warm season (April–August), 38% occurs. Additionally, because evapotranspiration is much greater during the warm months, effective infiltration occurs mainly during the cold season (Kessler, 1967). As a result, high flows occur from October to early May, and low flows occur during the summer. This pattern is also reflected in the large fluctuations in flow in the karst springs of the Tomorri massif, where the $Q_{max}/Q_{min}$ ratio ranges from 8 to 16, indicating a highly variable flow regime (Stevanović et al., 2015). To evaluate water discharge data for each of these two springs, the data were compared with synchronous water discharge data from the Selita Spring, Albania's karst spring with the longest daily measurement period (Eftimi and Malik, 2019). The resulting correlation coefficients were $R^2$ = 0.61 for the Bogova spring and $R^2$ = 0.66 for the Guaku spring. The relatively strong correlation indicates that the springs have similar flow regimes due to relatively similar climate and hydrogeological characteristics of the recharging karst masses.

Some relatively important springs also emerge from moraines and slope debris developed on the eastern and western slopes of the Tomor Mount (Fig. 4). On the eastern slopes, the springs are located near the village of Ujanik, while on the western slope, the springs issue in a wider area between villages from Lubesha in the north to Novaj in the south. The

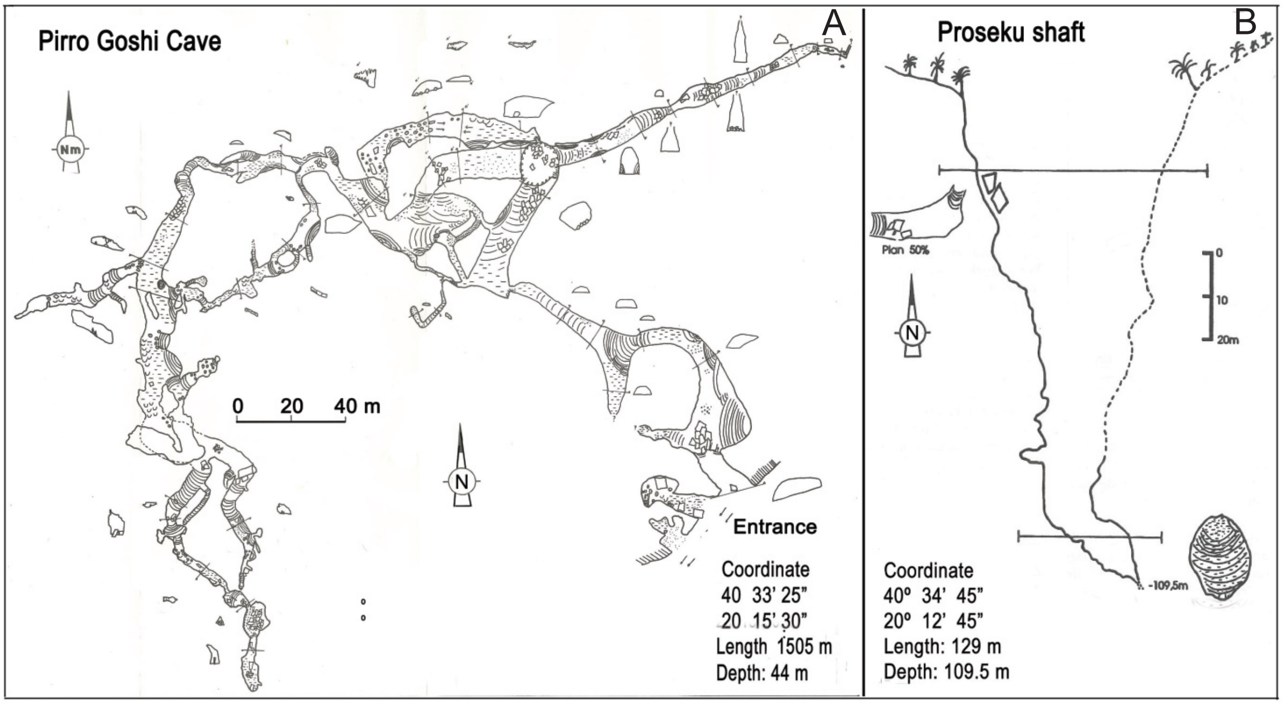


**Fig. 6. Tomorri massif: A – Pirrogoshi Cave; B – Proseku Karst Shaft (after Denneborg, 1993)**

discharge from these springs varies from ~1 to ~70 litres per second (Table 2) and is used to supply water to the villages.

## RENEWABLE KARST WATER RESOURCES

Estimating renewable karst water resources relies on the karst aquifer water balance, which requires determining the rate at which precipitation infiltrates the aquifer. The most reliable way to assess karst natural water resources is through discharge measurements of all the springs (Kresić and Stevanovič, 2010). However, this approach could not be applied to the Tomorri karst massif due to insufficient discharge data from the springs. To estimate the water balance, the Turc (1954) empirical method is used. According to Turc (1954), the most important parameter for estimating karst water resources is the rate of precipitation infiltration into karst aquifers. Empirical methods are widely used in engineering practice (Boni et al., 1982; Bonacci and Ljubenkov, 2005). According to the Turc empirical method, the mean annual precipitation and mean annual air temperature of the karst massif's recharge area are used to calculate effective infiltration. This parameter represents the part of precipitation that reaches the aquifer and recharges groundwater.

For this calculation, average annual precipitation data characteristic of the recharge area is used. Therefore, the meteorological stations providing data must be at roughly the same elevation as the massif's recharge area. According to the 1:25,000 scale topographic map of the Tomorri massif, its average elevation ranges from 1500 to 1600 m a.s.l. The highest-elevation meteorological station in this massif is Ujanik, at 1150 m a.s.l.; therefore, data from this station are not representative for calculating effective infiltration in this massif.

To determine the altitude of the recharge zone for karst water in the study massif, an $^{18}O$ sampling campaign was conducted in May–June 1990, and the water samples were analysed at the IAEA Isotope Laboratory in Vienna. Figure 8 shows the relationship between spring elevation and $\delta^{18}O$ (‰). The correlation graph (Fig. 8) is based on $^{18}O$ from small, local springs used to assess the altitude effect. It is assumed that their physical (measurable) elevation matches the elevation of the recharge area (Gat and Dansgaard, 1970; Bradley et al., 1972; Clark and Fritz, 1997). Using equation [1], the average elevation of the recharge area (Mra) of the larger springs (Table 3) is calculated.

$$\text{Mra [m]} = -612.82 \times \delta^{18}O - 4204.5 \quad [1]$$

The following formula expresses the mean annual water balance of a karst massif:

$$P = Ie + E + F \quad [2]$$

where: P – precipitation [mm]; Ie – effective infiltration [mm]; E – evapotranspiration [mm]

If the surface flow is missing (F = 0), formula [1] is simplified to:

$$P = Ie + E \quad [3]$$

Coefficient of infiltration = Infiltration / P

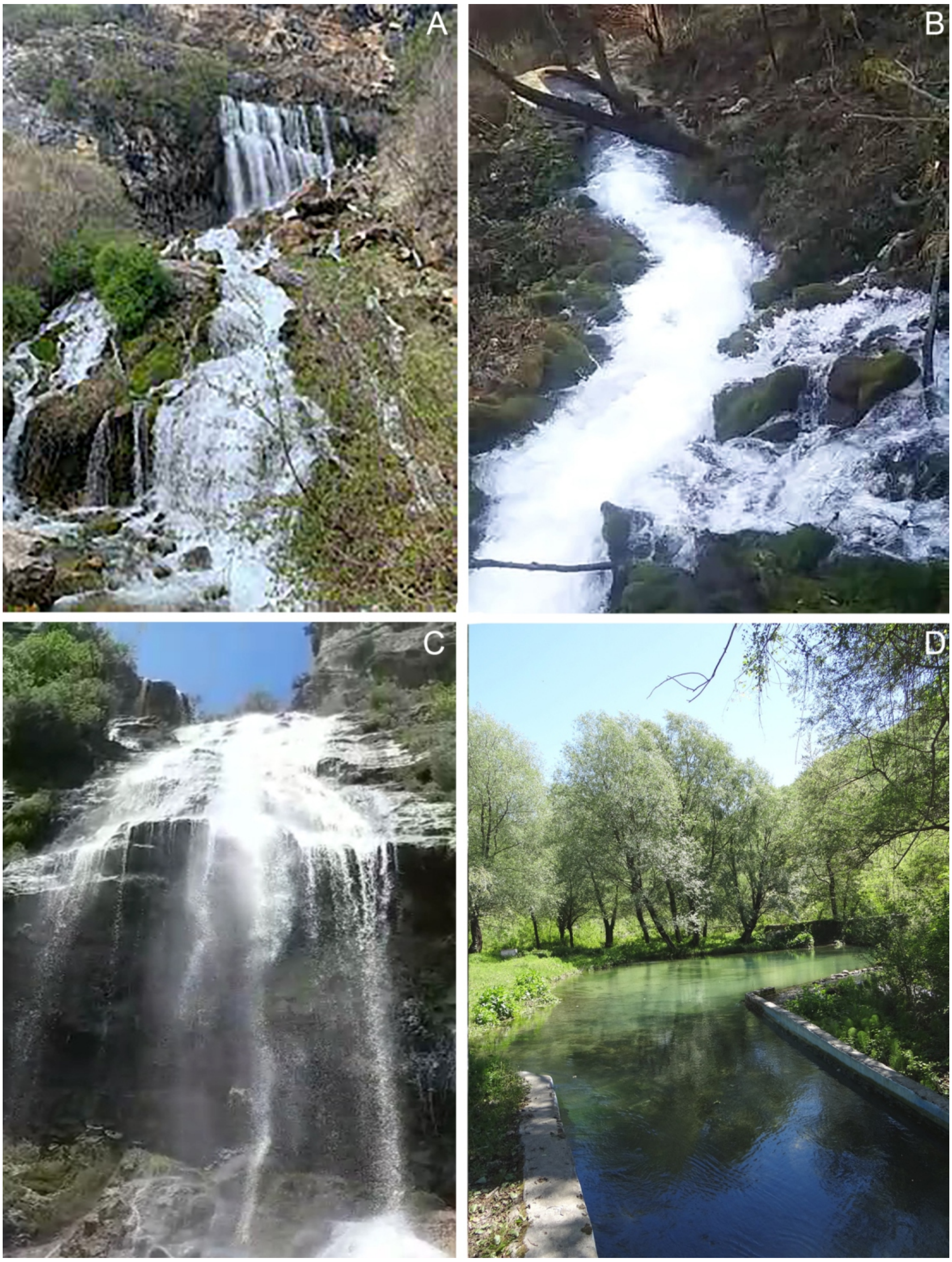


**Fig. 7. The largest karst springs of the Tomorri massif**

**A** – Sotira temporary spring; **B** – Kërpica;
**C** – Bogova during the rainy season; **D** – Guaku (photos by R. Eftimi)

In Table 3, the water temperatures of large springs are notably high, ranging from 8.5 to 11.5°C. The temperature of spring water also reflects the elevation of the recharge area (Schoeller, 1962; Eftimi, 1969). For small springs, the temperature fluctuates around the average air temperature at their elevation, whereas for large springs, it varies around the average air temperature of their recharge zone. However, the temperature of spring water is also affected by various natural factors, such as recharge from surface water, discharge and exposure of the spring, vegetation cover of the massif, rainfall amount, and of the air temperature (Schoeller, 1962). For the calculation of the recharge area elevation, we should rely more on the more trustworthy data from the large springs of Kërpica and Bogova.

The average elevation of the Tomorri massif, observed on the topographic maps, is ~1,550 m a.s.l. Using data from the Ujanik Meteorological Station, the average annual rainfall and temperature at this elevation were calculated based on rec-

Table 2

**Main hydrogeological data of the springs of the Tomorri karst massif**

| Springs | Rocks and age | Elevation [m a.s.l.] | Measurements | $Q_{mean}$ [l/s] | $Q_{min}$ [l/s] | $Q_{max}$ [l/s] | $Q_{max}/Q_{min}$ | Use of the spring |
|---|---|---|---|---|---|---|---|---|
| Kerpica | carbonate, $Pg_2$ | 715 | 15 | 725 | 350 | 2500 | 8.0 | Gramsh city water supply – 100 l/s, electricity production |
| Bogova | carbonate, $Pg_2$ | 344 | 60 | 1350 | 250 | 4000 | 16 | Poliçan and Berat city water supply – 250 l/s, electricity production |
| Guaku | carbonate, $Cr_2$ | 315 | 92 | 1400 | 450 | >3000 | 11 | Çorovoda city water supply – 120 l/s, electricity production |
| Sotira | carbonate, $Pg_2$ | 496 | 8 | ? | 0 | >3500 | – | tourist attraction |
| Ujanik, | moraine $Q_{1-3}$ | 1.470 | 21 | ≈70 | 30 | 250 | ~8 | village water supply |
| Kapinova-1 | slope debris, $Q_{1-3}$ | 630 | 10 | ≈3 | ≈1 | ≈6 | ~6 | village water supply |
| Lubesh | slope debris, $Q_{1-3}$ | 700 | 4 | ≈15 | ≈60 | ≈200 | ~13 | village water supply |

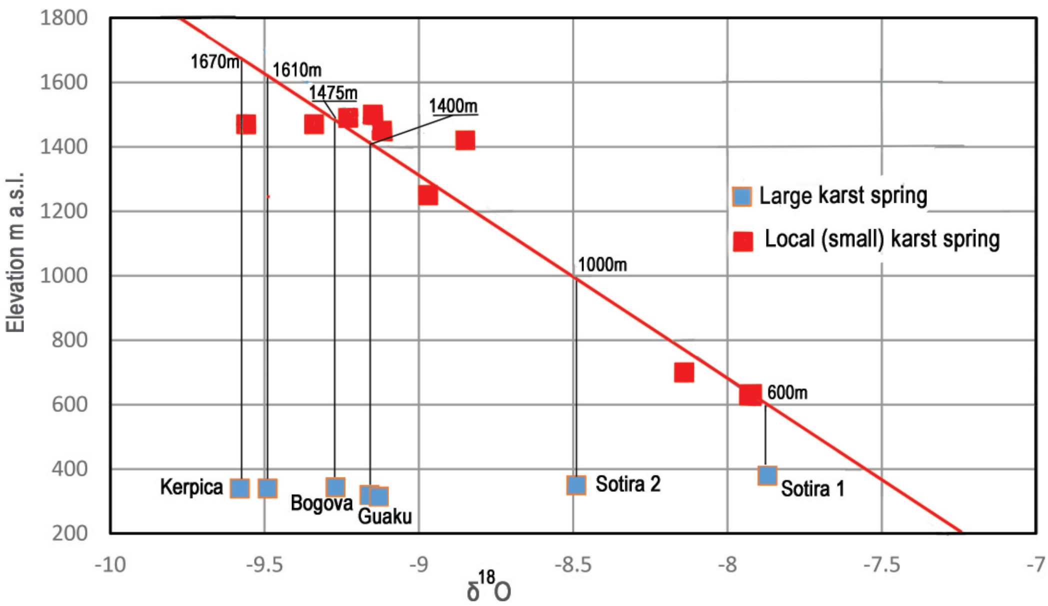


**Fig. 8. Correlation graphic of the springs' elevation vs $\delta^{18}O$ of the Tomorri karst massif**

ommendations for vertical reduction gradients (Anonymous, 2020). The results of the water balance calculations are shown in Table 4. The renewable resources of karst waters total 5.5 $m^3/s$, and the underground runoff module is 39.3 $l/s/km^2$ (Table 4), which is comparable to values reported for other karst regions in Albania (Eftimi, 2010, 2020); the average spring flow measured is nearly 3.7 $m^3/s$. The difference between total renewable reserves and the average spring flow is 1.8 $m^3/s$ (Table 2), which likely includes the uncertainties of the spring flow measurements and unknown karst water discharging into the Çorovoda River within the Gradec Canyon.

## CHEMICAL CHARACTERISTICS OF THE KARST WATER

The water samples were analysed for the major ionic constituents ($Ca^{2+}$, $Mg^{2+}$, $Na^+ + K^+$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$) in the AHS laboratory, and the main physical parameters (pH, EC, and T) were measured in the field at 13 karst springs. Volumetric, spectrophotometric, and colorimetric methods were used for the analyses. Also calculated were the ionic ratios rCa/rMg and $rSO_4$/rMg, the $CO_2$ pressure, and the saturation indices for calcite (SIc) and dolomite (SId).

Table 3

**Some physical data of the springs of Tomorri karst massif and the calculated elevation of the recharge area of the large springs based on $\delta^{18}O$ of the small springs**

| No. | Spring | Rocks | Elevation [m a.s.l.] | Data | Temp. [°C] | $\delta^{18}O$ [‰] | Calculated elevation [m a.s.l] |
|---|---|---|---|---|---|---|---|
| 1 | Kërpica | limestone – $Pg_2$ | 715 | 08.06.1990 | 8.9 | –9.49 | 1610 |
| | | | | 29.06.1990 | 8.5 | –9.58 | 1670 |
| 2 | Bogova-1 | limestone – $Pg_2$ | 344 | 30.05.1990 | 9.4 | –9.27 | 1475 |
| 3 | Bogova-2 | limestone – $Pg_2$ | 320 | 30.05.1990 | 9.6 | –9.16 | 1400 |
| 4 | Guaku | dolomite and limestone – $Cr_2$ | 315 | 30.05.1990 | 11.5 | –9.13 | 1400 |
| 5 | Sotira-1 | limestone – P $g_2$ | 380 | 29.06.1990 | 9.3 | –7.87 | 1000 |
| 6 | Sotira-2 | limestone – $Pg_2$ | 350 | 29.06.1990 | 9.3 | –8.49 | 600 |
| 7 | Ujanik-1 | slope debris moraine – $Q_{1-3}$ | 1470 | 31.05.1990 | 6.0 | –9.56 | |
| 8 | Ujanik-2 | slope debris, moraine – $Q_{1-3}$ | 1500 | 31.05.1990 | 6.1 | –9.15 | |
| 9 | Ujanik-3 | slope debris, moraine – $Q_{1-3}$ | 1470 | 31.05.1990 | 6.5 | –9.34 | |
| 10 | Ujanik-4 | slope debris, moraine – $Q_{1-3}$ | 1450 | 31.05.1990 | 7.1 | –9.12 | |
| 11 | Kapinova-1 | slope debris - $Q_{1-3}$ | 630 | 01.06.1990 | 10.9 | –7.93 | |
| 12 | Kapinova-2 | slope debris – $Q_{1-3}$ | 632 | 01.06.1990 | 10.7 | –7.92 | |
| 13 | Lubesha | cone of deposits- $Q_3$ | 700 | 01/06/1990 | 10.1 | –8.14 | |
| 14 | Prosek-1 | flysch – Pg | 1420 | 29.05.1990 | 9.2 | –8.85 | |
| 15 | Prosek-2 | flysch – Pg | 1250 | 29.05.1990 | – | –8.97 | |
| 16 | Kulmaka | flysch – Pg | 1490 | 31.05.1990 | 6.9 | –9.23 | |

Tables 5–8 show chemical analyses; graphs (Fig. 9) were completed using *AquaChem* software. Water temperatures range from 8.9 to 11.3°C, depending on the springs' elevation. The higher temperature of the Uji Zi Spring suggests possible recharge from the Çorovoda River in the Gradec Canyon. The electrical conductivity and total dissolved solids (TDS) of all the springs are generally low. The lowest average conductivity, ~250 μS/cm, occurs in moraine springs, followed by karst springs at ~271 μS/cm, with the highest, ~360 μS/cm, in slope-debris sources. TDS shows the same pattern as electrical conductivity: its average value is lower in moraine springs (158 mg/L), higher in carbonate rock springs (168 mg/L), and highest in karst springs (213 mg/L).

Saturation indices of the water with calcite (Sic) and dolomite (Sid) are also very similar; the water of the springs is, in general, saturated in calcite and near to saturation with dolomite. Although most springs are undersaturated with respect to calcite and dolomite, the undersaturation with dolomite is significantly greater than with calcite, given the higher solubility kinetics of calcite compared to dolomite (Jacobson and Langmuir, 1974; White, 2010). These findings align with the results from karst areas in Albania (Eftimi, 2005; Eftimi et al., 2025). In general, the concentrations of chemical parameters do not vary widely across the entire extent of the karst massif. In general, the chemical parameters of the moraine springs are slightly higher than those of the springs in the slope debris and carbonate rocks, as evidenced by the hydrochemical correlation graphics (Fig. 9).

The water chemical type of the investigated springs taking into consideration the concentration of the ions higher than 25% eqv/l, is of the $HCO_3$-Ca facies, and the ionic ratios are as follows:

$$Ca^{2+} > Mg^{2+} > (Na^{+}+K^{+}) \qquad HCO_3^{-} > Cl^{-} > SO_4^{2-}$$

The values of the hydrochemical parameters discussed and their relationships indicate that the water recharging all the springs studied flows through a carbonate rock environment (Jacobson and Langmuir, 1974; White, 2010)

Table 4

**The results of the water balance calculation of the Tomorri karst massif applying the Turc method**

| Meteorological station | Surface of karst massif [km²] | Mean elevation [m a.s.l.] | Mean air temperature [°C] | Mean yearly precipitation [mm/year] | Infiltration [mm/year] | Coeff. of infiltration [%] | Renewable resources [m³/s] | Module of underground flow [l/s/km²} |
|---|---|---|---|---|---|---|---|---|
| Ujanik | 140 | 1150 | 8.6 | 1400 | 887 | 63 | 4.32 | 28 |
| Ujanik, corrected | 140 | 1550 | 6.6 | 1700 | 1237 | 73 | 5.5 | 39.3 |

Data from the Ujanik meteorological station, the corrected data based on measurement

Table 5

**Chemical analyses of the springs of Tomorri karst massif; springs of carbonate rocks**

| No. | Spring location | Date [d/m/y] | Q [l/s] | T [°C] | pH | EC [µS/cm] | TDS [mg/l] | $Ca^{2+}$ [mg/l] | $Mg^{2+}$ [mg/l] | $Na^{+}$+ $K^{+}$ [mg/l] | $Cl^{-}$ [mg/l] | $SO_4^{2-}$ [mg/l] | $HCO_3^{2-}$ [mg/l] | SI Sic | SI Sid | Hydrochemical type | $rCa^{2+}$+ $rMg^{2+}$ | $rCa^{2+}/rMg^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Kërpica | 18/10/1989 | 600 | 8.9 | 7.74 | 277 | 170 | 52.0 | 5.3 | 6.99 | 3.6 | 8.2 | 185 | –0.09 | –0.36 | $HCO_3$-Ca | 3.02 | 6.02 |
| | | 8/06/1990 | 766 | 8.5 | 8.72 | 224 | 135 | 43.2 | 3.0 | 1.4 | 8.9 | 5.8 | 139 | +0.28 | –0.26 | $HCO_3$-Ca | 2.40 | 9.00 |
| | | 29/06/1990 | 850 | 8.5 | 8.13 | 218 | 144 | 35.4 | 9.5 | 5.53 | 8.9 | 9.9 | 142 | +0.20 | –0.04 | $HCO_3$-Ca-Mg | 2.54 | 2.26 |
| 2 | Bogova 1 | 30/05/1990 | 1700 | 9.4 | 7.89 | 237 | 152 | 43.2 | 4.7 | 1.8 | 7.1 | 7.0 | 160 | +0.11 | –0.32 | $HCO_3$-Ca | 2.54 | 5.68 |
| 3 | Bogova 2 | 30/05/1990 | 12 | 9.6 | 7.94 | 244 | 154 | 43.2 | 4.7 | 1.7 | 7.1 | 5.8 | 161 | +0.16 | –0.27 | $HCO_3$-Ca | 2.54 | 5.68 |
| 4 | Guaku | 15/03/1991 | 1700 | 11.5 | 7.78 | 309 | 189 | 57.0 | 4.2 | 11.06 | 16.0 | 11.1 | 181 | –0.05 | 0.56 | $HCO_3$-Ca | 3.18 | 8.35 |
| 5 | Sotira 1 | 29/06/1990 | 20 | 9.3 | 7.64 | 391 | 234 | 58.9 | 14.3 | 6.99 | 16.0 | 26.3 | 207 | +0.08 | 0.18 | $HCO_3$-Ca-Mg | 4.11 | 2.51 |
| 6 | Sotira 2 | 29/06/1990 | 4 | 9.3 | 7.43 | 240 | 151 | 40.3 | 10.1 | 2.92 | 8.9 | 9.1 | 154 | –0.41 | 0.65 | $HCO_3$-Ca-Mg | 2.84 | 2.42 |
| Average | | | | | 7.98 | 271 | 168 | 47.6 | 6.5 | 4.9 | 9.7 | 10.6 | 168 | +0.10 | –0.28 | – | 2.90 | 5.64 |
| Standard deviation | | | | | 0.34 | 57 | 31.4 | 7.9 | 3.7 | 3.2 | 4.3 | 6.7 | 22.7 | 0.12 | 0.15 | – | 0.56 | 2.39 |
| Standard error | | | | | 0.13 | 22 | 11.9 | 3.0 | 1.4 | 1.2 | 1.6 | 25 | 8.6 | 0.04 | 0.06 | – | 0.21 | 0.9 |
| Coefficient of variation [%] | | | | | 4 | 21 | 19 | 17 | 57 | 65 | 45 | 63 | 14 | 122 | 53 | – | 19 | 42 |

Q – discharge; T – temperature; EC – electrical conductivity; TDS – total dissolved solids; ions in “r” are in Eqv/l

Table 6

**Chemical analyses of the springs of Tomorri karst massif; springs of moraine deposits**

| No. | Spring | Date [d/m/y] | Q [l/s] | T [°C] | pH | EC [µS/cm] | TDS [mg/l] | $Ca^{2+}$ [mg/l] | $Mg^{2+}$ [mg/l] | $Na^{+}$+ $K^{+}$ [mg/l] | $Cl^{-}$ [mg/l] | $SO_4^{2-}$ [mg/l] | $HCO_3^{2-}$ [mg/l] | SI Sic | SI Sid | Hydrochemical type | $rCa^{2+}$+ $rMg^{2+}$ | $rCa^{2+}/rMg^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Ujanik 1 | 31/05/1990 | 20 | 6.0 | 7.91 | 224 | 142 | 46.2 | 1.2 | 1.2 | 7.1 | 5.4 | 153 | –0.086 | –0.67 | $HCO_3$-Ca | 2.40 | 23.0 |
| 8 | Ujanik 2 | 31/05/1990 | 5 | 6.1 | 7.81 | 254 | 156 | 50.1 | 2.3 | 2.1 | 7.1 | 2.5 | 167 | –0.058 | –0.57 | $HCO_3$-Ca | 2.69 | 13.16 |
| 9 | Ujanik 3 | 31/05/1990 | 6 | 6.5 | 7.67 | 244 | 161 | 50.1 | 1.7 | 1.6 | 7.1 | 12.8 | 165 | –0.085 | –0.79 | $HCO_3$-Ca | 2.64 | 17.8 |
| 10 | Ujanik 4 | 31/05/1990 | 0.7 | 7.1 | 7.78 | 278 | 174 | 58.0 | 1.2 | 1.7 | 8.9 | 5.4 | 192 | +0.16 | –0.65 | $HCO_3$-Ca | 2.99 | 28.9 |

Explanation as in Table 5

Table 7

**Chemical analyses of the springs of Tomorri karst massif; springs of slope debris deposits**

| No. | Spring | Date [d/m/y] | Q [l/s] | T [°C] | pH | EC [µS/cm] | TDS [mg/l] | $Ca^{2+}$ [mg/l] | $Mg^{2+}$ [mg/l] | $Na^{+}$+ $K^{+}$ [mg/l] | $Cl^{-}$ [mg/l] | $SO_4^{2-}$ [mg/l] | $HCO_3^{2-}$ [mg/l] | Si Sic | Si Sid | Hydrochemical type | $rCa^{2+}$+ $rMg^{2+}$ | $rCa^{2+}/rMg^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Kapinova-1 | 1/06/1990 | 4.5 | 10.9 | 7.65 | 346 | 223 | 52.1 | 15.1 | 2.3 | 8.9 | 16.9 | 226 | +0.09 | –0.12 | $HCO_3$-Ca-Mg | 3.84 | 2.10 |
| 12 | Kapinova-2 | 1/06/1990 | 2.5 | 10.7 | 7.69 | 325 | 203 | 51.1 | 13.0 | 2.4 | 7.8 | 7.0 | 217 | +0.11 | –0.13 | $HCO_3$-Ca-Mg | 3.62 | 3.38 |
| 13 | Lubesha | 1/06/1990 | 30.0 | 10.1 | 7.55 | 410 | 214 | 61.9 | 19.7 | 3.29 | 8.9 | 7.2 | 270 | - | - | $HCO_3$-Ca-Mg | 4.71 | 1.91 |

Explanation as in Table 5

## ANTHROPOGENIC IMPACT ON GROUNDWATER

Due to their high permeability, extreme heterogeneity, and many direct connections between surface water and groundwater, karst aquifers are highly sensitive to anthropogenic impacts (Drew and Hötzl, 1999; Bakalowicz, 2005; Gutiérrez et al., 2014). This sensitivity is driven not only by their physical traits but also by the community’s limited understanding of these features (Ravbar and Šebela, 2015). These impacts often stem from business pressures on community interests. Several experiences in Albania have shown that the main human negative impacts on karst water are related to: (a) urbanized areas; (b) agricultural activities; and (c) quarrying (Eftimi

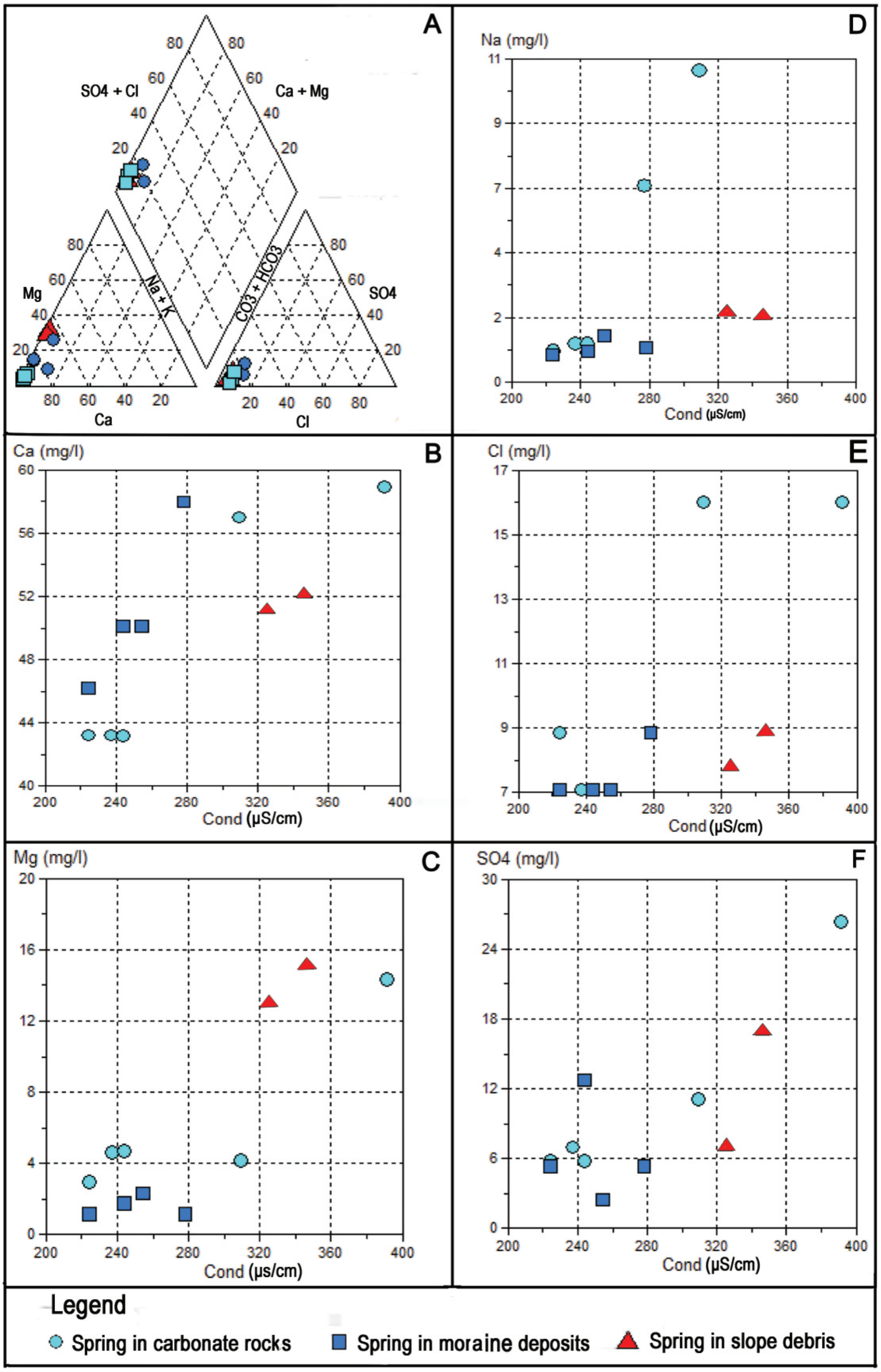


**Fig. 9A – Piper diagram showing hydrochemical signatures of the sampled springs of the Tomorri massif and hydrochemical correlations: B – Ca vs Cond; C – Mg vs Cond; D – Na vs Cond; E – Cl vs Cond; F – $SO_4$ vs Cond**

Table 8

**Generalized values of the main physical and chemical parameters of the springs**

| | Carbonate rocks | | Moraine deposits | | Slope debris | |
|---|---|---|---|---|---|---|
| | Amplitude | Mean | Range | Mean | Amplitude | Mean |
| T [°C] | 8.5–11.4 | 9.4 | 6.0–7.1 | 6.4 | 10.7–10.9 | 10.8 |
| CE [μS/cm] | 218–391 | 271 | 224–278 | 250 | 325–346 | 335 |
| TDS [mg/l] | 135–234 | 168 | 142–174 | 158 | 203–223 | 213 |
| $rCa^{2+} + rMg^{2+}$ | 2.40–4.11 | 2.9 | 2.4–2.99 | 2.68 | 3.63–3.84 | 3.73 |
| $rCa^{2+}/rMg^{2+}$ | 2.26–9.00 | 5.64 | 13.8–28.9 | 20.7 | 2.1–2.4 | 2.25 |
| pH | 7.64–8.72 | 7.98 | 7.67–7.91 | 7.79 | 7.65–7.69 | 7.67 |
| $P_{CO2}$ [bar] | $10^{-2.4}$–$10^{-3.06}$ | $10^{-2.8}$ | $10^{-2.55}$–$10^{-2.83}$ | $10^{-2.65}$ | $10^{-2.38}$–$10^{-2.44}$ | $10^{-2.4}$ |
| $SI_k$ | –0.09–+0.28 | 0.10 | –0.086–+0.16 | 0.017 | 0.09–0.11 | 0.10 |
| $Si_d$ | –0.3 6–0.04 | –0.28 | –0.79–(–0.57) | –0.67 | –0.12–0.13 | 0.125 |

and Zojer, 2015). Limestone quarrying is the primary extractive industry in Albania. The process of extracting limestone through quarrying has several significant impacts: (a) pollution and other negative effects on groundwater; (b) destruction of the environment in areas with high scenic value, including damage to surface and underground karst landforms.

As described above, Bogova Karst Spring supplies water to the cities of Poliçan, Berat and Kuçova; Kerpica Spring supplies the city of Gramsh; and Uji I Zi supplies the city of Çorovoda, serving a total population of ~150,000. Under natural conditions, the recharge area of Bogova Spring is a clean limestone region with significant natural and touristic value. This changed dramatically after 1995, when quarrying intensified due to rising demand for limestone from the construction sector. The first impression upon entering the quarrying zone is that the subcutaneous layer has been stripped away and the ecosystem destroyed, with no effort to reclaim the quarry areas (Fig. 10).

This intensive quarrying also contributes to pollution in Bogova Spring; occasionally, the spring water becomes turbid. The turbidity is allochthonous, originating from soil and surface runoff, and is exacerbated by the sparse or absent red clay across large parts of the Tomorri massif. This allows rock particles generated by explosions to quickly reach the aquifer after heavy rainfall. Supported by the well-developed conduit network of the karst aquifer, the turbidity disperses rapidly over large areas and affects the springs.

The sanitary authorities monitor the turbidity of Bogova Spring and disconnect the spring water from the water supply system when turbidity exceeds acceptable levels (Eftimi and Zojer, 2015). Brief contamination episodes interrupt longer or shorter periods of clean spring water, and measured turbidity in Berat's water distribution system far exceeds the specifications of the European guidelines (Council Directive 98/83/EC, 1998). Turbidity, especially the finest particles, is strongly correlated with *E. coli* (Goldscheider et al., 2010), but no such study has yet been conducted for Bogova Spring. The recommendation to stop quarrying within the spring's immediate protection area, with a 1 km perimeter upstream, has not yet been implemented.

## DISCUSSIONS AND CONCLUSIONS

This paper provides a systematic overview of the hydrogeological features of the Tomorri karst massif in south-central Albania, comprising two mountains, Tomorri and Kulmaka, and covering an area of 140 km². This massif stands out as a prominent block rising above the surrounding hilly terrain. Morphologically, the Tomorri massif is a ridge ~5 to 5.5 km wide and ~35 km long, with an average elevation between 1,500 and 2,000 m a.s.l. It consists of massive limestone and, less commonly, dolomite of Upper Cretaceous to Eocene age and is

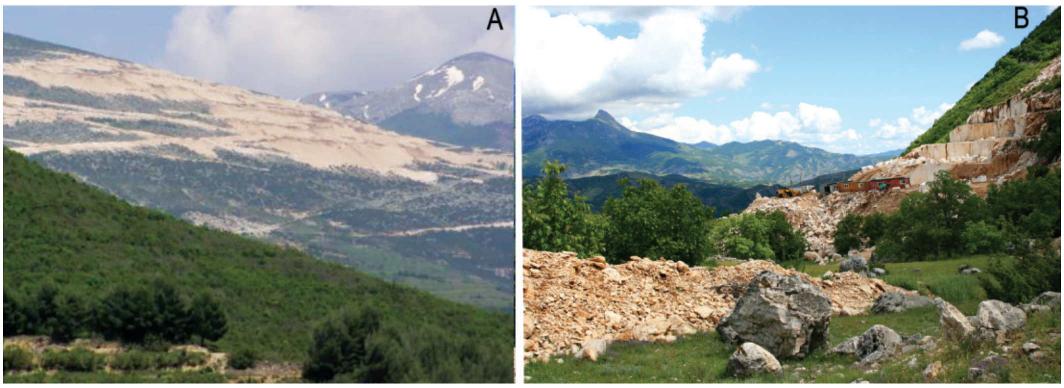


**Fig. 10. Large quarries developed in the recharge area of Bogova Spring (A), and of Uji Zi (B) (photo R. Eftimi)**

surrounded by an extensive area of Oligocene flysch deposits. The carbonate rocks form a karst water basin that functions as a unique water body. Each of the large springs, namely Uji Zi (black water), Bogova, Kerpica, and Sotira, emerges at the lowest points of limestone outcrops. Because the aquifer has very high permeability and the elevation difference between recharge and discharge areas (springs) exceeds 750 m, the springs' regime is highly variable.

The main findings of this research include:

– a detailed description of the hydrogeological setting;
– using the Turc empirical water balance method, a fairly high mean effective infiltration of 1632.3 mm/year was obtained, corresponding to an infiltration coefficient of 73%;
– the total renewable karst water resources amount to 5.5 $m^3/s$ (173,25 × 106 $m^3/y$), with a module of karst water flow of 39.9 $l/s/km^2$;
– analysis of the hydrochemical data shows that the karst water has very low mineralization, with electric conductivity varying between ~150 and 200 μS/cm, and the karst water in general has very good drinkable quality;
– using O-18 isotope data, the elevation of the recharge area of the karst spring is calculated to be ~1550 m a.s.l.;
– the quality of the karst water is endangered by uncontrolled anthropogenic activity, mainly very intensive quarrying in the Tomorri massif.

This karst massif is one of Albania's most important karst structures because it lies within a large area of low-permeability flysch strata, which are very deficient in groundwater. High-quality groundwater resources of this massif provide water to >150,000 residents in Berat, Poliçan, Çorovoda, Gramsh, and several villages. Future research should focus on many phenomena that remain unexplored or unexplained. This is particularly true of the water circulation, its variability, and its relationship to the current and changing climate. Systematic, interdisciplinary, and detailed studies that use modern research technologies should be applied to the poorly understood processes underlying the sustainable development of this vulnerable environment.

**Acknowledgements.** The authors would like to thank the reviewers, A. Benderev and K. Jóźwiak, for their very insightful analyses of this manuscript. Their suggestions were very valuable and contributed to a significant improvement of this paper.

**Author contributions.** RE: conceptualization, methodology, data analysis, and writing-original draft. TO: regime of springs, corrections of Abstract and Conclusions. PQ: geology and geomorphology.

**Funding.** The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

**Declarations**

**Conflict of interest.** No conflict of interest is declared for this article.

**Ethical approval.** All authors kept to the "Ethical Responsibilities of Authors".

**Consent to participate.** All the authors gave explicit consent to participate in this study.

**Consent to publish.** All the authors gave explicit consent to publish the manuscript.

## REFERENCES

**Anonymous, 1992**. Geomorphological map of Albania. Center of Geographical Studies, Academy of Science of Albania. Topographic Institute, Tirana.

**Anonymous, 2020**. Yearly Books of the Hydrology Data of Albania. Hydrometeorological Institute, Tirana.

**Andreychouk, V., Eftimi, R., Nita, J., Klimchouk, A., 2022**. Karst relief of the Mali me Gropa Massif, Central Albania. Geological Quarterly, **66**, 6; https://doi.org/10.7306/gq.1638

**Bakalowicz, M., 2005**. Karst groundwater: a challenge for new resources. Hydrogeology Journal, **13**: 148–160; https://doi.org/10.1007/s10040-004-0402-9

**Bakalowicz, M., 2015**. Karst and karst groundwater resources in the Mediterranean. Environmental Earth Sciences, **74**: 5–14; https://doi.org/10.1007/s10040-004-0402-9

**Bonacci, O., Ljubenkov, J., 2005**. Karst river Keka hydrology. Proceedings of the International Conference and Field Seminars, Belgrade and Kotor (eds. Z. Stevanović and P. Milanović): 397–404.

**Boni, C., Bono, P., Capelli, G., 1982**. Valutazione quantitativa dell'infiltrazione efficace in un bacino carsico dell'Italia centrale: confronto con analoghi bacini di litologia diversa (in Italian). Estratto da: Atti del II° Simposio Internazionale sulla "Utilizzazione delle aree carsiche" Bari – Castellane Grotte, 20–22 Maggio 1982.

**Bradley, M., Brown, R.M., Gonfiantini, R., Payne, B.R., Przewlocki, K., Sauzay, G., Yen, C.K., Yurtsever, Y., 1972**. Nuclear techniques in groundwater hydrology. In: Groundwater Studies, Chap. 10. UNESCO, Paris.

**Clark ID and Fritz, P., 1997.** Environmental Isotopes in Hydrogeology, Lewis Publishers. New York.

**Dansgaard, W., 1964**. Stable isotopes in precipitation. Tallus, **16**: 436–468.

**Denneborg, M., 1993**. Albanien-Expedition 1992 und 1993. Mitteilungen des Verbandes der deutschen Höhlen- und Karstforscher, **39**: 64–73.

**Drew, D., Hötzl, H., 1999**. Karst Hydrogeology and Human Activities: Impact, Consequences, and Implications. International Contributions to Hydrogeology, **20**. Balkema, Rotterdam.

**Eftimi, R., 1969.** The water temperature of the natural springs (in Albanian). Përmbledhje Studimesh, (12): 85–88.

**Eftimi, R., 2005**. Hydrochemical characteristics of some lithologically different karst massifs of Albania. In: Water Resources & Environmental Problems in Karst (eds. Z. Stevanović and P. Milanović): 499–504. Proceedings of the International Conference and Field Seminars 13–19 September, Belgrade 2005.

**Eftimi, R., 2010**. Hydrogeological characteristics of Albania. AQUAmundi Am01012: 79–92; https://doi.org/10.4409/Am-007-10-0012

**Eftimi, R., 2020**. Karst and karst water resources in Albania: their management. Carbonates and Evaporites, **35**: 1–14; https://doi.org/10.1007/s13146-020-00599-0

**Eftimi, R., Malík, P., 2019**. Assessment of regional flow type and groundwater sensitivity to pollution using hydrograph analyses and hydrochemical data of the Selita and Blue Eye karst springs, Albania. Hydrogeology Journal, **27**: 2045–2059; https://doi.org/10.1007/s10040-019-01974-5

**Eftimi, R., Zojer, H., 2015**. Human impact on karst aquifers of Albania. Environmental Earth Sciences, **74**: 57–70; https://doi.org/10.1007/s/12665-015-4309-7

**Eftimi, R., Bisha, G., Tafilaj, I., Sheganaku, Xh., 1985**. Hydrogeological Map of Albania, scale 1:200 000, Tirana. Mjeteve Mësimore H. Shijaku, Tirana-Albania.

**Eftimi, R., Andreychouk, V., Malík, P., Orehova, T., Nita, M., Qiriazi, P., 2025**. Factors influencing the groundwater circulation in Mali me Gropa karst massif, Central Albania. Acta Carsologica, **54**: 155–172; https://doi.org/10.3986/ac.v54i2.14389

**Gat, J.R., Dansgaard, W., 1970**. Stable isotope survey of freshwater occurrences in the Israel and Jordan Rift Valleys. Journal of Hydrology, **16**: 177–212; https://doi.org/10.1016/j.earscirev.2014.08.002

**Goldscheider, N., Pronk, M., Zopfi, J., 2010**. New insight into the transport of sediments and microorganisms in karst groundwater by continuous monitoring of particle-size distribution. Geologia Croatica, **63**: 157–166.

**Gutiérrez, F., Parise, M., De Waele, J., Jourde, H., 2014**. A review of natural and human-induced geohazards and impacts in karst. Earth-Science Reviews, **138**: 61–88; https://doi.org/10.1016/j.earscirev.2014.08.002

**Jacobson, R.L., Langmuir, D., 1974**. Controls on the quality variations of some carbonate spring water. Journal of Hydrology, **23**: 247–265; https://doi.org/ 10.1016/0022-1694(74)90006-7

**Kessler, H., 1967**. Water balance investigations in the karst regions of Hungary. Act Coll Dubrovnik. Proceedings AIHS-UNESCO, Paris: 91–105.

**Kresić, N., Stevanović, Z. (eds.), 2010**. Hydrology of Springs: engineering, theory, management, and sustainability. Elsevier, Burlington.

**Kristo, V., 1973**. Some aspects of karst in Albania (in Albanian). Collection of Studies, **1**: 67–79.

**Liso, I.S., Parise, M., 2020**. Apulian karst springs: a review. Journal of Environmental Science and Engineering Technology, **8**: 63–83; https://doi.org/10.12974/2311-8741.20.20.08.7

**Margat, J., 1998**. Les eaux souterraines dans le bassin méditerranéen. Ressources et utilisations. Documents BRGM, **282**.

**Meço, S., Aliaj, Sh., 2000.** Geology of Albania. Gebrüder Borntraeger, Berlin.

**Melo, V., Çili, P., Gjenerali, Dh., 1987**. Structural Geology – Geotechnics (in Albanian). Tirana University.

**Pano, N., 2008**. Albania's Water Resources (in Albanian). Academy of Science of Albania, Tirana.

**Parise, M., Qijiazi, P., Sala, S., 2004**. Natural and anthropogenic hazards in karst areas of Albania. Natural Hazards Earth System Science, **4**: 560–581.

**Ravbar, N., Šebela, S., 2015**. The effectiveness of protection policies and the legislative framework, with special regard to karst landscapes: Insights from Slovenia. Environmental Science Policy, **51**: 106–116; https://doi.org/10.1016/j.envscl.2015.02.013

**Qiriazi, P., 2019**. Physical Geography of Albania (in Albanian). Mediaprint, Tirana.

**Savino, G., Didona, F., Parise, M., Sgobba, D., 2003**. Le ricerce speleo-carsica in Albania: risultati e prospettive (in Italian). Gruppo Puglia Grotte, c/o Politecnico di Bari, Thalass Salentina, **26**: 33–40

**Schoeller, H., 1962**. Les Eaux Souterraines. Masson & Cie Éditeurs, Paris.

**Stevanović, Z. (ed.), 2015**. Karst Aquifers: Characterization and Engineering. Springer. https://doi.org/10.1007/978-3-319-12850-4

**Stevanović, Z., 2019**. Kast water in potable water supply: a global scale overview. Environmental Earth Sciences, **78**, 662; https://doi.org/10.1007/s12665-019-8670-9

**Stevanović, Z., Eftimi, R., 2010**. Karstic sources of water supply for large consumers in south-eastern Europe – sustainability, disputes and advantages. Proceedings International Interdisciplinary Scientific Conference "Sustainability of the Karst Environment. Dinaric Karst and Other Karst Regions", September 2009, Plitvice Lakes, Croatia: 23–26; https://doi.org/104154/gc.2010.15

**Turc, L., 1954**. Le bilan d'eau des sols. Relations entre les precipitations, l'évaporaton et l'écoulement. Annuar Agronomique, **5**: 491–595.

**White, W.B., 2010**. Springwater geochemistry. In: Groundwater Hydrology of Springs (eds. N. Kresić and Z. Stevanović): 231–268. Heinemann, Burlington.

**Worthington, S.R.H., Ford, D.C., 2009**. Self-organization permeability in carbonate aquifers. Groundwater, **47**: 326–336; https://doi.org/10.1111/j.1745-6584.2009.00551.x

**Zhalov, A.K., 2015**. Bulgarian speleological studies, Albania, 1991–2013. Berliner Höhlenkundliche Berichte, **58**.

**Xhomo, A., Kodra, A., Xhafa, Z., Shallo, M., 2002**. Geology of Albania. Notes of Geological Map of Albania, scale 1:200.000 (in Albanian). Albanian Geological Service, Tirana.