


Review

Karst Brackish Springs of Albania

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Abstract: The territory of Albania presents wide outcrops of soluble rocks, with typical karst landforms and the presence of remarkable carbonate aquifers. Many karst areas are located near the coasts, which results in a variety of environmental problems, mostly related to marine intrusion. This paper focuses on the brackish springs of Albania, which exhibit temperatures approximately equal to the yearly air temperature at their location. Total dissolved solids of the springs are higher than 1000 mg/L, their waters are not drinkable, and they are rarely used for other purposes. The groundwater of the alluvial aquifers of Albania, particularly those of Pre-Adriatic Lowland, are often brackish too, but these will not be addressed here. Brackish springs of Albania are mainly of karst origin and can be classified into two groups: springs in evaporitic rock, mainly gypsum, and springs in carbonate rock. The hydro-chemical facies of the first group are usually Ca-SO₄, locally with increased concentrations of Na-Cl, whereas springs belonging to the second group usually exhibit Na-Cl facies. The largest brackish springs of Albania are described in detail, including their hydro-chemical correlations.

Keywords: brackish springs; karst; gypsum springs; coastal springs; Albania



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1. Introduction

Karst aquifers are among the richest and purest on Earth [1–4], and are heavily threatened by a variety of dangers, including anthropogenic impacts and marine intrusion [5–9]. The importance of karst waters has repeatedly been documented over the last few decades, up to the recent project World Karst Aquifer Map (WOKAM), which highlighted that the total surface area of carbonates and evaporites was estimated to be 20×10^6 km² (about 15% of the total ice-free land surface area on Earth [10,11]). The largest karst area is in Asia ($>7.5 \times 10^6$ km²), whereas Europe has the greatest percentage of karst, corresponding to 21.6% of its land surface area [3,4,11].

Karst aquifers currently supply about 10% of the global population with drinking water and, in some areas, are the only available water resource [12]. More than half the population in Albania, and in countries such as Bosnia and Herzegovina, Jordan, Austria, and Slovakia, drink karst water [13–15]. In Albania, every citizen consumes about 227 m³/s or 7.15×10^9 m³/year [16], thanks to the over 110 karst springs, with average discharge >100 l/s (17 springs exhibit discharge values >1 m³/s; [16,17]). During droughts, on several occasions in recent decades, there have been discussions about the possibility of using some Albanian springs to supply Italy with freshwater; this, for instance, was the case for Blue Eye spring in the Bistrica group (mean discharge 18.4 m³/s) [13,18].

In Albania, karst aquifers are hosted both by carbonate rocks occupying about 6490 km², and evaporites rocks with a surface area of about 260 km² [16,17]. These aquifers manifest very significant fluctuations in terms of water quantity and quality; they are related to hydrometeorological changes, as well as to variations in groundwater level, water flow velocity, spring discharge and water quality (chemical and physical parameters) [19–23].

Notwithstanding the data above, knowledge of the Albanian karsts, with particular regard to coastal springs, still needs further improvements. To provide an example, the review on submarine springs and coastal karst aquifers by Fleury et al. [24] did not include any information about Albania, thus testifying the lack of information about coastal karst in this country. Similarly, in the recent effort of the World Karst Spring hydrograph (WoKaS), the first global karst springs discharge database with over 400 spring observations worldwide [25], Albania is poorly represented. This highlights the need to improve our knowledge of Albanian karst, especially regarding data on spring discharge and hydrochemistry. In this sense, the present article contributes to providing basic data about the brackish springs in the country (without considering those present within alluvial aquifers), being a comprehensive collection of information and chemical measurements of the most significant karst brackish springs in Albania.

The use of karst springs for a water supply requires their in-depth quantitative and qualitative assessments. Previous studies on the quality of karst springs in Albania have demonstrated many of them to be brackish [17,26,27]; this paper focuses on these springs. Brackish cold springs are those at which total dissolved solids (TDSs) usually vary between 1000–10,000 mg/L, and the water temperature is approximately equal to the yearly air temperature at their location. These springs are non-potable, and usually not used for curative purposes; however, in special cases, some chemical components can be extracted from them. Albania's brackish springs, based on their origin, are ranked into two groups: (a) springs in evaporitic rock (mainly gypsum); and (b) springs in carbonate rock (Figure 1, Table 1).

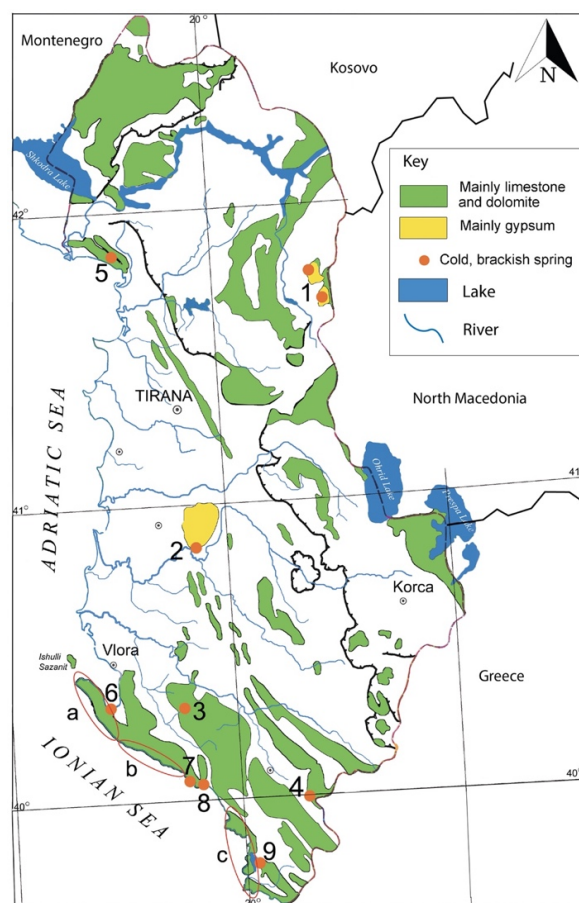


Figure 1. Location map of cold brackish springs in Albania. Springs in evaporitic deposits (halite-gypsum): 1, Korab; 2, Dumre; 3, Bashaj; 4, Glina. Springs in carbonate rocks: 5, Renci; 6, Marmiro; 7, Himare; 8, Qeparoi; 9, Butrint. Karst areas with diffusive drainage are bordered in red: (a) Karaburun; (b) Palase-Qeparoi; and (c) Ksamil-Gjuza (modified after [27,28]).

2. Springs in Evaporitic Deposits

Inland springs in evaporitic rocks (Figure 1) are mainly related to gypsum deposits cropping out in Korab Mountain and along the Ionian areas. At Korab, brackish springs emerge along the Banja River, near the city of Peshkopi, and along Gypsum River. In the Ionian area, the main springs emerge along the Thana Lake, near Lushnja municipality, and in Bashaj of Smokthina, Vlora. Other brackish springs are related to minor salt outcrops near Glina, Kolonja and Kardhiq in the Gjirokastra district, and at the former salt mine of Dhrovjan, Saranda.

2.1. Springs in Korab Area

Korab is an inner tectonic zone where, in its central sector, two tertiary gypsum tectonic windows are present [29–31]. The southern gypsum outcrop covers about 24 km², whereas the northern outcrop is about 66 km² (Figure 1). Both are surrounded by Paleogene shale-marl formations (Eocene-Oligocene), on which Cretaceous and Triassic-Jurassic flyschoid and limestone deposits overthrust. Gypsums are mostly massive, with a local presence of layering.

The active rise of Korab area during the Pliocene-Pleistocene was accompanied by strong erosion, as evidenced by the deep cutting stream valleys filled with solid deposits (>15 m thick), and by karstification processes. The largest streams are Banja River in the south, and Gypsum River, in the north (Figures 2 and 3). In the upper relief, karstic funnels and small valleys are present, hosting erosion-karst towers, caves and springs. In the Korab gypsum, there are two types of karst groundwater streams with very different physico-chemical qualities [32].

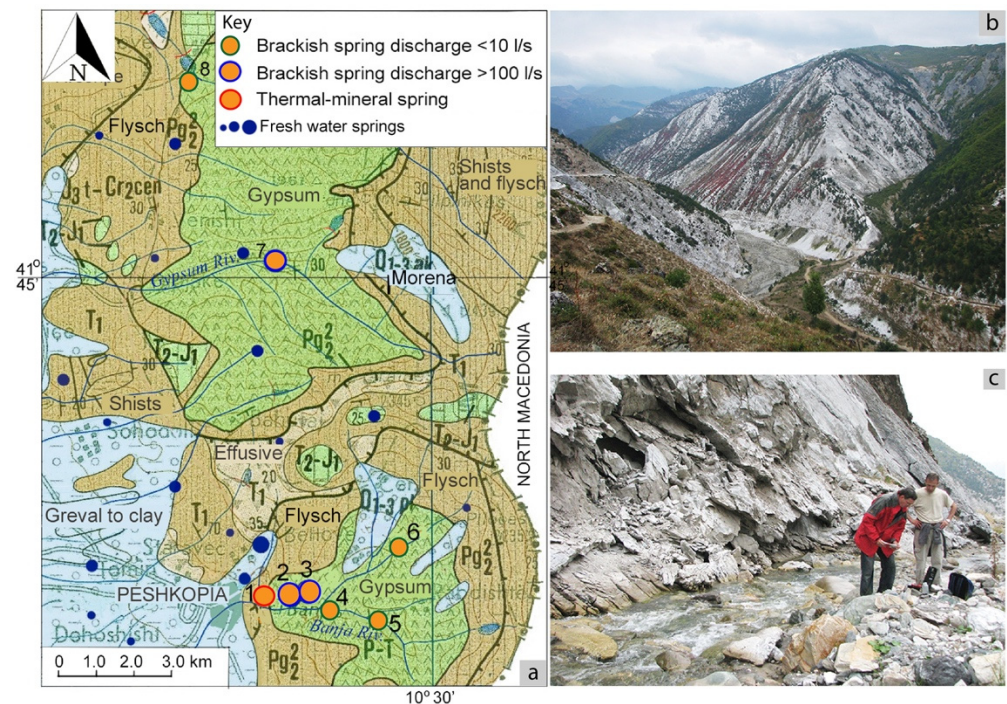


Figure 2. (a) Hydrogeological map of the Peshkopi area at Korab (modified after [33]) with the locations of springs: 1, Banya (thermal spring); 2, Brezhdani; 3, Konri; 4, Gypsum; 5, Rabdishta; 6, Bellova; 7, Gypsum River; and 8, Vlesha; (b) Gypsum River; (c) field hydro-chemical measurements in Gypsum River.



Figure 3. Brackish springs in the Peshkopia area: (a) Konri (no. 2 in Figure 2); (b) Brezhdani (no. 3 in Figure 2); (c) Gypsum (no. 4 in Figure 2); and (d) Vlesha (no. 8 in Figure 2).

Deep transient groundwater flow (H_2S -rich thermo-mineral water) and shallow groundwater flow feed cold karst springs with variable discharges (Table 1). The main cold springs of the Korab gypsum massif mainly emerge along the deep Gypsum and Banja valleys (Figure 2). In the Gypsum River valley there are small springs discharging 1–2 L/s, but important groundwater resources are drained in thick gravel deposits filling the wide riverbed. During the dry season, the Gypsum River flow (about 200 L/s) is fed mainly fed by drainage of the riverbed groundwater flow. Springs in the Banja River are larger, with discharges (Table 2) depending upon elevation. Smaller springs, often temporary, such as Gypsum, Rabdishta and Bellova, emerge in the upper Banja River. One spring only (Vlesha), discharging in the range of 4 to 35 L/s, is located in northwest Korab, far from the above-mentioned discharge areas of the rivers.

Cold springs at the Korab gypsum massif are characterized by temperatures around 10.8–13.7 °C, electrical conductivity fluctuating between 1852 and 2480 $\mu\text{S}/\text{cm}$, pH in the range 6.12–8.10, and with SO_4 -Ca hydro-chemical facies. They have very low contents of Cl and Na ions, which indicates that gypsum formations have not increased the salt content.

Table 1. Main Albanian cold brackish springs parameters. Analyses conducted by the Hydrochemical Laboratory of the former Hydrogeological Enterprise (Tirana) and the Hydrochemical Laboratory of Silesia University (Poland) [34]. Rock type: G, gypsum; H, halite; L, limestone; Q, discharge; T, temperature; EC, electrical conductivity.

Location	Spring Name	Rock Type	Q l/s	T °C	pH -	EC μ S/cm	TDS mg/L	Ca mg/L	Mg mg/L	Na+K mg/L	Cl mg/L	SO ₄ mg/L	HCO ₃ mg/L	Hydrochem. Facies	Mg/Ca -	Na/Cl -	
Springs in evaporitic rocks																	
Korab	Brezhdan	G	100	12.7	6.12	2480	2309	636	22.8	18.8	3.48	26.0	1491	180.0	SO ₄ -Ca	0.36	1.11
	Konri	G	70	10.8	7.11	2350	2127	614.0	1.2	4.45	1.13	5.0	1404	207.0	SO ₄ -Ca	0.03	1.36
	Gypsum River	G	250	13.7	8.10	1852	1470	474.0	0.0	2.2	0.71	7.6	902.0	153.0	SO ₄ -Ca	-	0.45
	Vlesha	G	9.0	13.2	7.52	2110	2376	704.2	6.44	1.13	0.10	0.16	1589.0	190.2	SO ₄ -Ca	-	-
Dumre	Thana lake	G	10.0	-	7.0	-	3286	663.3	48.0	268.6	329.8	592.1	308.6	SO ₄ -Cl-Ca-Na	0.12	1.25	
	Thana Leke	G	7.0	15.7	6.8	3410	2636	612.9	70.4	148.9	3.15	247.3	1313	377.2	SO ₄ -(Cl)-Ca-(Na)	0.19	0.94
Bashaj	Bashaj, Smokthinë	GH	20.0	12.0	7.4	-	11284	376.8	43.7	3812.5	37.9	5813.8	1083.2	158.6	Cl-Na	0.19	1.01
Springs in carbonate rocks																	
Renci structure	Nr 2, Shengjin	L	-	18.0	7.7	-	7058.8	317.4	275.3	1915.9	66.8	3867.8	557.2	154.9	Cl-Na	1.43	076
	Renci Structure	L	4.0	15.5	-	-	2650	123.5	91.6	741.0	1263.8	269.1	283.6	Cl-Na	1.2	0.9	
	Kakariq	L	7.0	15.5	-	-	2740	105.8	86.0	760.5	1249.6	263.4	286.7	Cl-Na	1.34	0.94	
	Gjok Gjini, Kakariq	L	1.0	15.5	-	-	4840	156.8	169.0	1429.0	2485.0	439.5	253.1	Cl-Na	1.7	0.89	
	Renc	L	8.0	15.0	-	-	3955	144.3	115.8	1193.9	1988.0	293.4	393.5	Cl-Na	1.3	0.93	
	Renci	L	7.0	17.2	-	-	1136	39.8	38.5	333.8	562.2	58.4	155.5	Cl-Na	1.6	0.91	
	1.2 km N to Lezha	L	20.0	-	-	-	1954	35.8	127.0	519.1	1002.9	138.3	222.6	Cl-Na	5.8	0.8	
	3 km W to Lezha	L	10.0	17.4	-	-	1830	71.6	60.6	534.7	891.0	144.8	225.7	Cl-Na	1.4	0.93	
Orikum	Marmiro	L	80	18.0	7.6	2270	3940	118.5	143.3	1196.0	2094.5	288.7	283.0	Cl-Na	2.00	0.88	
Himare	Potami	L	200.0	11.7	7.7	2170	1100	67.5	36.8	295.6	541.3	72.0	152.5	Cl-Na	0.9	0.84	
			50.0	12.0	7.8	1725	974	67.8	41.1	232.7	457.4	65.4	159.8	Cl-Na	1.0	0.78	
			0–350	12.0	7.8	2420	1530	73.7	42.3	434.0	660.3	225.5	167.1	Cl-Na	0.95	1.01	
	Filikur	L	7.0	13.0	-	-	1720.0	49.4	59.9	535.0	891.0	131.3	172.0	Cl-Na	2.0	0.93	
Qeparoi	Mulliri	L	350.0	15.1	7.55	8410	5276	140.5	191.3	1604.5	2840.0	395.0	262.3	Cl-Na	2.24	0.87	
	Hoston 1	L	6.0	14.0	7.8	3320	1990	84.50	63.18	571.10	994.0	139.91	203.74	Cl-Na	1.23	0.89	
	Hoston 2	L	4.0	14.2	7.85	3540	2055	95.50	53.64	581.2	994.0	146.08	207.4	Cl-Na	0.93	0.9	
	Hoston 3	L	0.7	16.7	7.4	2070	1324	88.42	36.36	363.40	560.90	112.75	306.22	Cl-Na	0.67	1.0	
Butrint	Bufi 1	L	15.0	15.6	7.5	11,120	7240	176.8	237.8	2231.7	3905.0	562.5	225.7	Cl-Na	2.21	0.88	
	Bufi 2	L	17.0	15.6	7.6	13,530	8386	212.2	293.8	2584.3	4881.2	287.2	215.9	Cl-Na	2.27	0.81	
	Bufi	L	600.0	15.3	7.6	9300	5658	161.13	190.12	1701.0	3014.1	444.83	208.62	Cl-Na	1.94	0.87	
KML threshold value							1500	100	50	Na: 175	25	250					

Table 2. Basic characteristics of brackish cold springs in Korab Mountain area (Figure 2).

Location	Spring Name	Elevation m a.s.l.	Q l/s	T °C	EC $\mu\text{S/cm}$	Hydrochem. Facies
Thermal spring	Nr 1	688	14	43.5	4060	SO ₄ -Ca
Banja River	Brezhdani	715	100–300	12.2–13.3	1550–2400	SO ₄ -Ca
Banja River	Konri	746	70–250	10.7–12.0	1500–2300	SO ₄ -Ca
Banja River	Gjipsi	830	0–250	9.7	1450–2150	SO ₄ -Ca
Banja River	Rabdishte	935	1–9	-	1560–1695	SO ₄ -Ca
Banja River	Bellova	950	1–12	-	1630–2160	SO ₄ -Ca
Gjipsi River	Përroi	970	200–3000	10–14	1500–1935	SO ₄ -Ca
Village Vleshë	Vlesha	880	4–35	12.2	2110	SO ₄ -Ca

Shallow circulation spring water is in equilibrium with gypsum deposits; the springs are saturated or close to calcium saturation [35]. The Korab gypsum springs are mainly used for irrigation, but they are also considered by local communities to have beneficial healing abilities.

2.2. Springs of Dumre Plateau

Dumre Plateau is in central Albania, in the Pre-Adriatic Lowlands. The main sector of the plateau is connected to the evaporitic dome of Dumre, situated along the transverse fault Vlore-Elbasan-Diber [36]. The age of evaporites is estimated to be Perm-Triassic [30,37]. The diapir evaporite deposit consists of gypsum, anhydrides, and other salts, and is 6000 m thick [38], with a carbonate caprock with well-cemented breccia and soil.

The Dumre dome covers an area of about 170 km², with a rolling landscape and average relief of 130 m a.s.l. It is surrounded by Paleogene flysch formations and Miocene-Pliocene molasses, all with low hydraulic permeability. Elevation of the massif decreases southwards until the bottom of the Thana artificial lake (15–25 m a.s.l.). The gypsum dome produces a karst relief filled with landforms such as sinkholes, funnels, endorheic basins and lakes. The density of sinkholes in the southern plateau is 15–20/km² [39–41], most of them being produced as collapse or solution sinkholes [42–44]. These processes at Dumre are still active today, locally representing a danger people's safety [45–47]. Sinkholes with an initial depth of a few meters can evolve to reach 15 m in depth, at the same time widening; often transformed into lakes, they are the most distinctive landform of the Dumre plateau, which hosts about 80 karst lakes (most of them being permanent), for a total area of 7.70 km². This is also typical of similar karst settings and poljes in other countries [48–52].

Reactivation of karst phenomena, related to transformation of anhydrides into gypsum, is well developed in Dumre. The resulting increase in volume closes the voids within the evaporites, thus reducing karstification in depth. As a result, karst phenomena are apparently closely related to the surface portion of evaporites, where gypsum predominates and water mainly flows in the epiphreatic zone [53]. The hydration of anhydrides in gypsum causes an increase in volume between 30% and 58% in the area near the surface [54]. Partial hydration, and the possible dissolution of saline bodies, leads to the formation of sulphate megabreccias, widely present at Dumre. The presence of salts in the Dumre evaporites distinguishes it from the gypsum at Korab, which is further confirmed by the groundwater chemical composition (Table 1): the contents of Na and Cl ions in spring water are 18.8 and 26.0 mg/L at Korab, whereas at Dumre, springs are up to 268.6 mg/L and 329.8 mg/L, respectively. In addition, the dissolution of salts in the Dumre plateau is the main cause of sinking processes and formation of vertical pits.

The aquifer at Dumre consists of the caprock basement and the upper karstified portion of anhydrite-gypsum. The top of the caprock formations in the topographically depressed areas, where the lakes are located, is isolated by the practically impermeable fine-granular materials, which prevents the lakes from communicating with the aquifer [39,47,55,56].

Thus, the lakes are mostly fed by precipitation, and generally they have good hydro-chemical quality.

Until 25 years ago, Lake Belsh was used as a drinking supply [41]. In recent decades, urban development, tourism, and the intensification of agriculture, have highly polluted the lake water with urban wastewater, herbicides, and pesticides [57].

Using the Turc formula at Dumre, the average air temperature is 15.1 °C, average annual rainfall is 1054 mm, and effective annual infiltration is estimated to be 469 mm/year (45% of the precipitation) or 2.53 m³/s. One-third of this amount (about 0.84 m³/s) is diffusely drained into numerous lakes [55], with the remaining part (approximately 1.69 m³/s) infiltrating in depth to recharge the saturated zone.

Natural water springs are rare in the Dumre plateau. The main regional direction of groundwater is north-south, towards Lake Thana where there are numerous springs (Figure 4), whose locations follows the lake level fluctuations:



Figure 4. Topographic map of Dumre plateau, marked with the red line.

- (a) The big linear springs, with the most important discharges, are located at the northernmost tip of Lake Thana (Figures 4 and 5), and emerge from fine-granular deposits. The flowing front of the springs is up to several hundred meters in length, with the total flow (Figure 6b) estimated to fluctuate from 10 to 20 L/s;

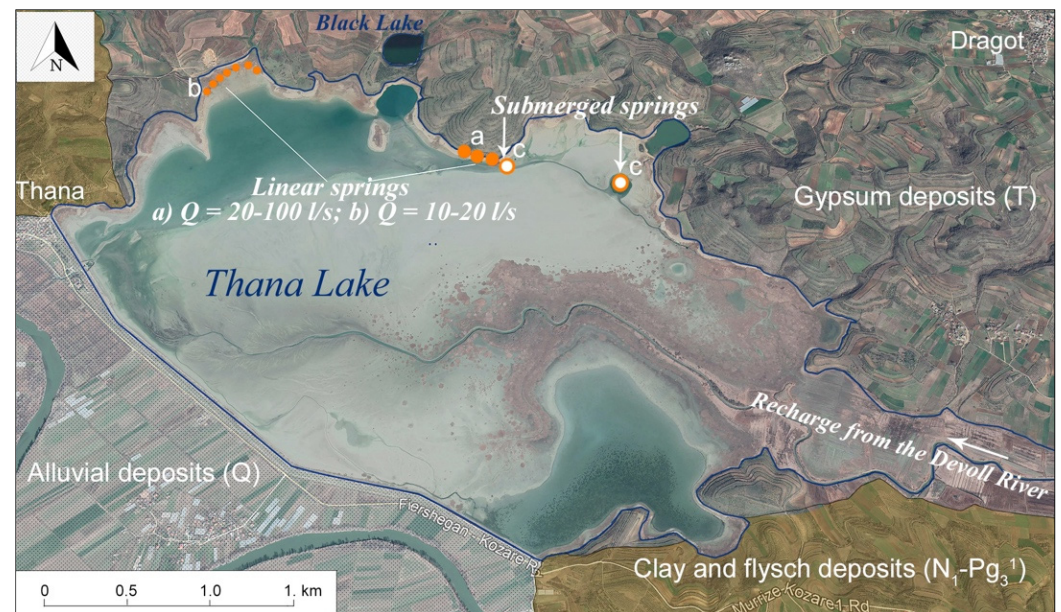


Figure 5. Gypsum springs in Thana artificial lake: (a) big linear springs; (b) small linear springs; (c) submerged springs.



Figure 6. (a) Big linear springs issuing from caprock (in the foreground) and a submerged spring just offshore; (b) small linear spring in the northern part of Thana Lake.

- (b) Small linear springs (Figures 4 and 5) emerge from the caprock, about 20–40 m thick near the springs; they become submerged during high lake water levels. Individual discharges range from 1 to about 10 L/s, and the total annual discharge is evaluated to be in the range of 20–100 L/s;
- (c) At two submerged springs (Figures 5 and 6) it was not possible to measure the discharge, which was estimated approximately to be 1300–1400 L/s.

According to non-systematic measurements, the electrical conductivity of point linear springs varies from 1900 to 3250 $\mu\text{S}/\text{cm}$; however, no data are available for the submerged springs. Based upon the chemical analyses, the hydro-chemical facies of gypsum karst springs along Thana shores is mainly $\text{SO}_4\text{-Ca}$ (Table 2), but high concentrations of ions Cl and Na are present (Table 1).

2.3. Bashaj Spring

Bashaj Spring is located at the western foothills of Griba Mountain, whose elevation decreases from 1850 m to 350 m a.s.l. toward the Smokthina River. It emerges at the bottom of the deep Kripur stream, 2 km east of Bashai. The right Smokthina Riverbank, where the spring emerges, is composed of Middle Jurassic limestones, partially covered by Lower Oligocene flysch; below, Perm-Triassic evaporites are present, in tectonic contact [29,30].

Bashaj Spring discharge is about 20 L/s, with a temperature of 12 °C. The spring has high mineralization: TDS is about 11.3 g/l, with Cl-Na hydro-chemical facies, and very high SO₄ content (1083 mg/L; Table 1). The concentrations of other elements are: NH₄-1.2 mg/L; K-37.9 mg/L; Fe-0.2 mg/L; Al-0.06 mg/L; Br-2.6 mg/L; moreover, the ratio of Na/Cl is 1.01, and Cl/Br is equal to 2236.

A distinctive hydro-chemical characteristics of Bashaj Spring is that although groundwater circulates in a gypsum environment, it is richer in NaCl than in CaSO₄. This can be explained by the presence of highly soluble salt within the gypsum formation, as for the large springs of Dumre. Despite the high salinity of spring water, the population of Basha area have used the underground resource for producing bread during crisis times, such as World War II, when salt was scarce.

3. Coastal Springs

Albanian coastlines are quite different between the Adriatic and Ionian seas [58]. The Adriatic coast is characterized by low elevation, plains and hill landscapes, which developed in recent Pliocene, Neogene, and Quaternary formations. The Quaternary gravel deposits filling the deltas of Rivers Mat, Ishmi, Erzen, Shkumbin and Vjosa are the most abundant in groundwater (Figure 1), and drain into the sea without forming any springs, with the only exception being the Renci structure. The Ionian coast generally consists of high, steep mountains in Mesozoic carbonates.

The drainage of karst aquifers on the Albanian coast occurs through natural springs with different discharges and hydrodynamic conditions. These can be classified, according to Stevanovic [12], into lithological contact springs, diffuse drainage areas, and submarine springs.

For the first group (lithological contact springs at sea level or above), the contact is created by carbonate rocks overthrusting the Paleogene-Neogene clay-sand/flysch formations. This type of contact is practically water-tight and prevents the sea-water intrusion. Usually, these springs are characterized by good hydro-chemical qualities, and are very important as water supply sources. This group includes springs Uji i Ftohtë near Vlora, the springs of Tragjasi, Borsh, and that of Sasaj-Piqeras [17,59].

Diffuse drainage areas consist of small, distributed discharge points. This type of drainage is characteristic of high-permeability karst aquifers [12,60], in direct contact with the sea, and is also typical of other Mediterranean settings [61–70]. In particular, along the Adriatic Sea several springs and sinkhole features associated with mixing between freshwater and sea water characterize the Apulian coastlines [71–76]. This is also the case in most of the southern rocky coast of Albania where distributed drainage is spread in the three areas of Karaburun, Palasë-Qeparoi, and Ksamil-Gjuza (Figure 1) [28,77,78].

Eventually, the group of submarine springs is related to deep karst conduits, inherited from the last period of glaciation when the sea level was about 100–150 m lower, creating conditions for the development of submarine karst [77–79]. Their formation is related to the topographic gradient greatly favoring the discharge of karst waters to the sea [80]. Underground water resources usually have considerable fluctuations in quantitative and qualitative indicators, aided by the pronounced changes in the Mediterranean climate [78]. According to an overall estimate, over 90% of the world's submarine resources are located along the Mediterranean coastlines [24].

3.1. Springs of the Renci Structure

The Renci structure mainly consists of limestones, with subordinate Upper Cretaceous dolomites (Figure 7), intensely fissured and karstified. Its central-western part borders the Adriatic Sea, whose water penetrates wide portions of the massif, thus causing many important sources to be brackish (Table 1). Only in the northern part of the Renci massif, the farthest from the sea, groundwater is drinkable. Plenty of springs are temporary, flowing only for a few days during the rainy season. The mean groundwater discharge is estimated to be at about 900 l/s. The inflows of permanent salt springs usually range from about 1 to 20 l/s (Table 1), but large amounts of groundwater, unfortunately with no available quantitative measurements, are drained into the Knalla swamp and the sea [81].

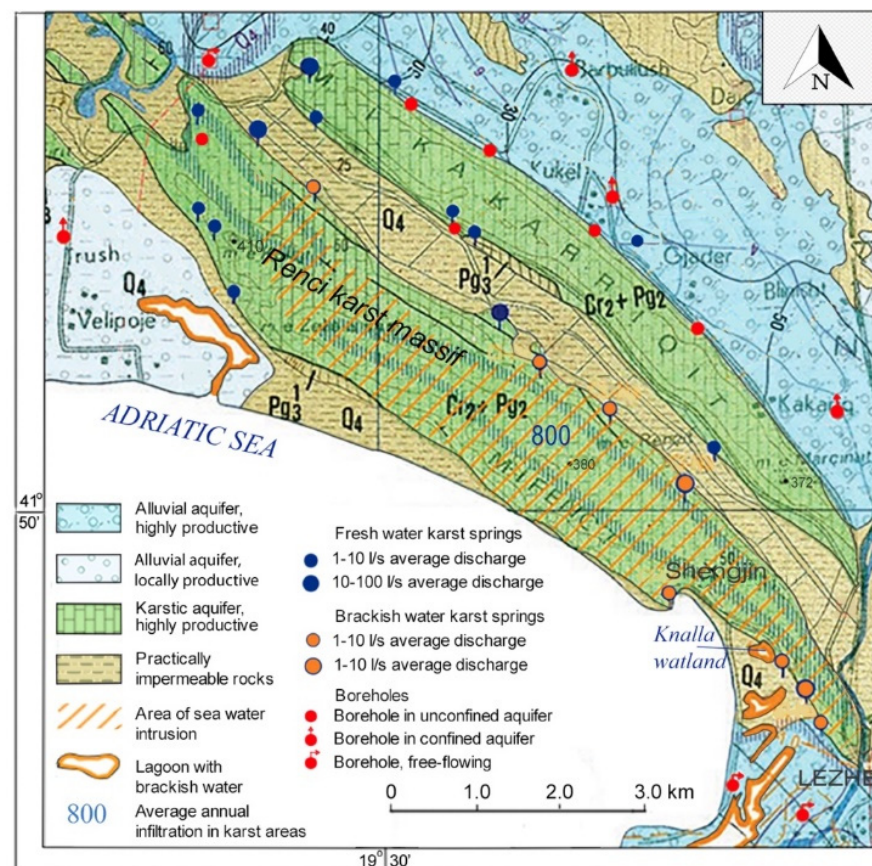


Figure 7. Hydrogeological map of the Renci structure (modified after [33]).

3.2. Springs of the Ionian Sea Rock Coast

The Albanian rock coastline, extending from the Karaburun peninsula to the Albanian—Greek border, is represented by karst aquifers composed of several Mesozoic to Eocene carbonate structures, overthrusting westward on the Upper Eocene—Oligocene flysch formations. Dense fissures and high karstification sensibly increase the permeability of carbonates and facilitate the karst groundwater flow towards the sea. The total karst water resources along the Ionian coast are estimated to be in the range of 1500–2000 Ls. Most of these waters are salty and, depending on the hydrogeological and hydrodynamic conditions, they are drained into the sea as: (a) diffuse drainage, (b) submarine resources, and (c) coastal resources.

Along the coast, the high permeability of carbonates causes the formation of a low water levels, with quite a thin freshwater body fluctuating on the denser sea salt water [82]. This is the case for the Karaburun Peninsula, and the Palase-Qeparoi and Saranda-Ksamil areas (Figure 1). Throughout the above-mentioned structures, rapid diffuse groundwater drainage occurs without producing any concentrated springs. Several attempts to tap

freshwater in the Karaburun Peninsula, Dhermi area, and in Kakome Bay by drilling wells located 100–300 m far from the sea, were not successful, due to the presence of salty water.

The level of carbonate rocks karstification is influenced by the Pleistocene Sea level movements, at the origin of the formation of submarine springs [1,27,83–86].

Submarine springs have been identified along the Himare coastal area, as well as in the bay of Spile, where springs with unknown discharge are present. The largest is Lera Pas, with a presumed flow of 1000–1500 L/s.

The largest brackish springs of the Albanian coastline are those emerging at sea, which represents the present base level of drainage and karstification. They are located along the coastline from the Vlora Bay in the north to the Butrint lagoon in the south (Figures 8–10, Table 3).

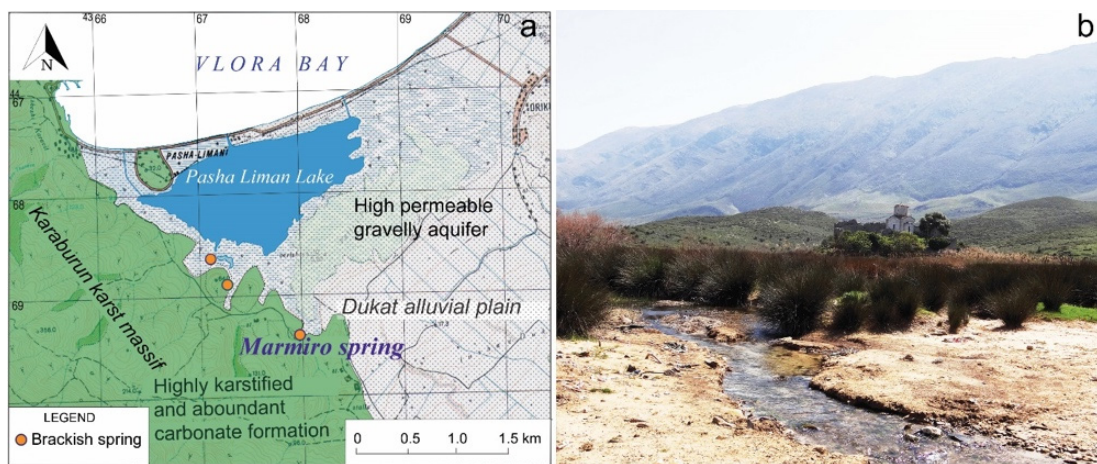


Figure 8. (a) Location of Marmiro Spring; (b) Marmiro Spring near the Marmiro church.

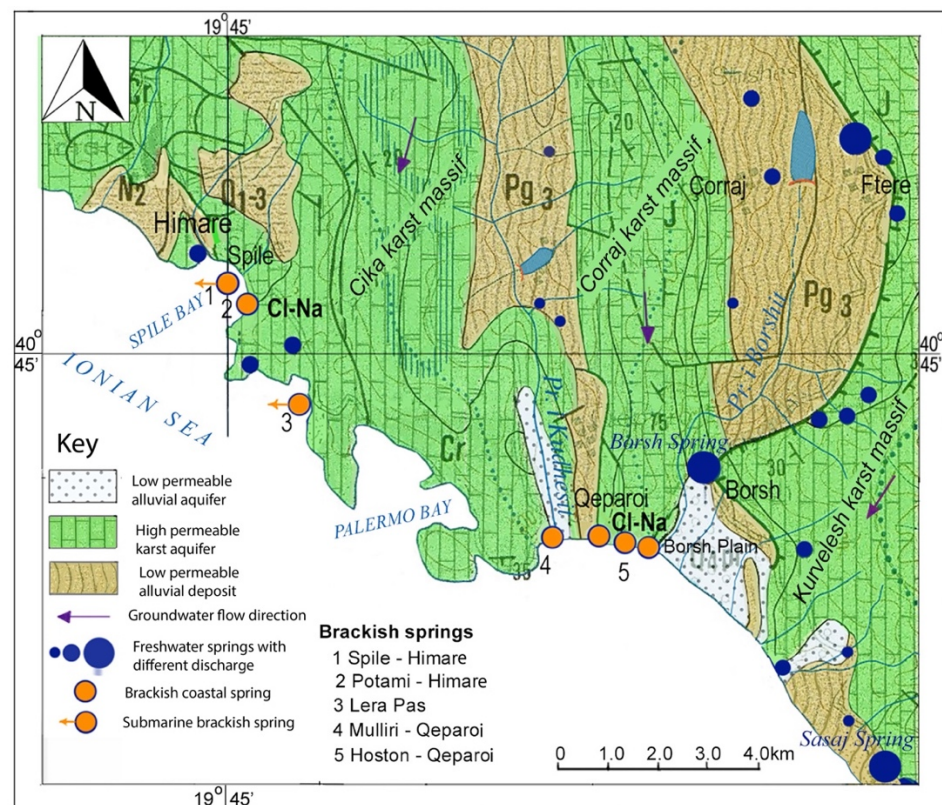


Figure 9. Hydrogeological map of Himare-Qeparoi (modified after [33]).

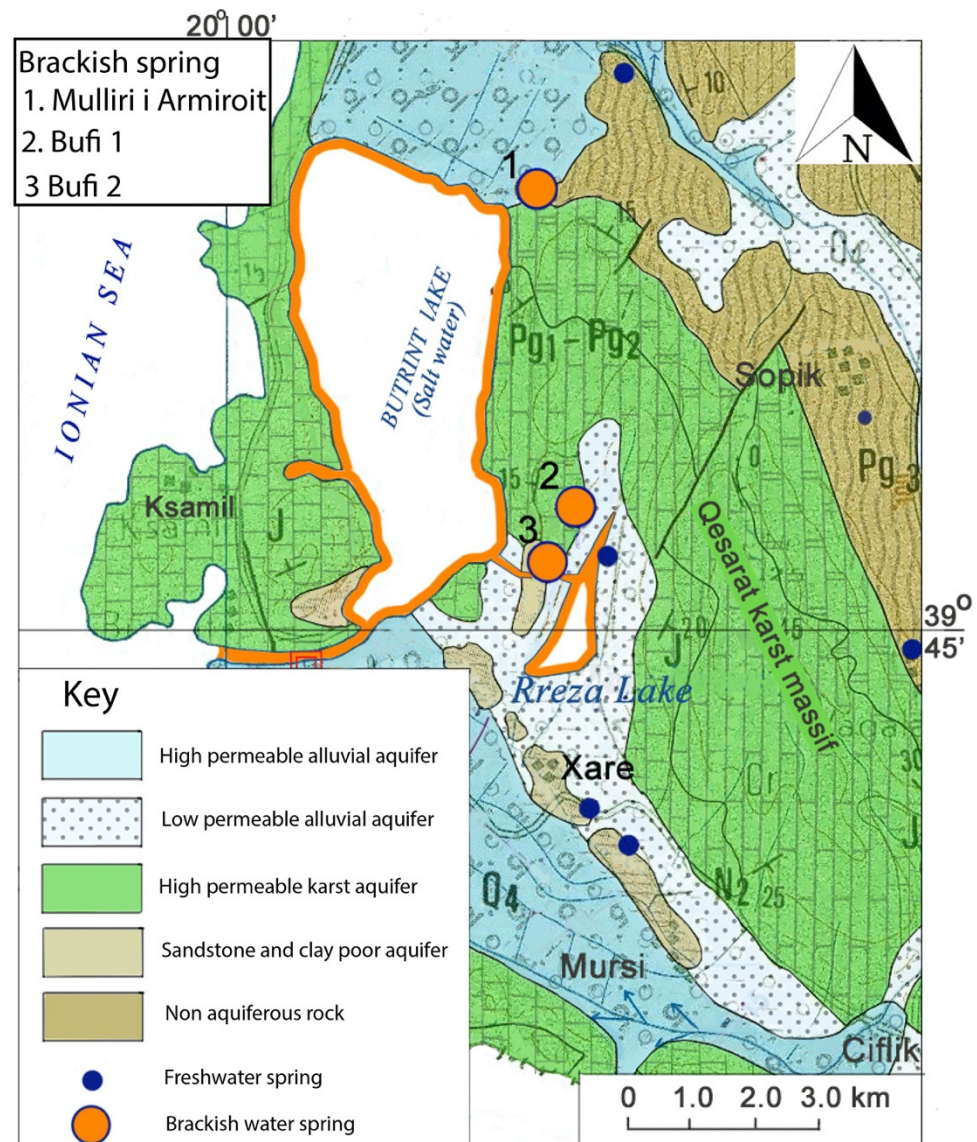


Figure 10. Hydrogeological map of the Butrint area (modified after [33]).

Table 3. Main characteristics of brackish cold karst springs of the Ionian coastal areas of Albania.

Location	Spring	Hydraulic Type	Elevation m a.s.l.	Q		EC ³ S/cm	Cl mg/L
				Min	Max		
Orikum	Marmiro	Free flow	2.0	0.07	1.0	2270–6650	-
Himare	Potami	Free flow	0.4–1.0	0.1–0.5	0.18	1700–2300	450–660
Qeparoi	Mulliri	Free flow	1.0	0.06	0.3	8400	2840
Qeparoi	Hoston	Free flow	0.0–0.4	?	1.0–1.5	3000–10,000	-
Butrint	Bufi	Free flow	4.0–5.0	150		-	-
Butrint	Bufi 1	Free flow	2.0–4.0	1.5–4.7	2.5	9000–13,000	3000–4900

3.3. Marmiro Spring

Marmiro spring, at an elevation of 1.5–2.0 m a.s.l. to the southwest of Pasha-Liman Lake (Vlora Bay), is recharged by the Karaburun massif, whose groundwater mixes with the intruding salty water. It consists of many issuing points around the Marmiro church, feeding a small stream flowing to the Pasha-Liman Lake (Figure 8b). The discharge is quite variable, from about 0.07 l/s to more than 1000 l/s, and is conditioned by the water salinity. According to non-systematic measurements, electrical conductivity ranges from 2270 to 6650 $\mu\text{S}/\text{cm}$. Notably, at the Pasha Liman Lake, there are numerous other groundwater venues which have not been studied so far, and which would be worthy of further research.

3.4. Himare Springs

Himare springs (several submarine springs and Potami) are recharged by the Cika carbonate structure (Figure 9). The first emerge at Spile Bay in Himare and is clearly visible in calm sea conditions. The largest submarine spring of the area (Lera Pas) is about 2.0 km southeast of Spile Bay (Figure 9). The strong groundwater flow emerges from a depth of about 7–8 m, with estimated discharge of 1000–1500 L/s.

The Potami spring (no. 2 in Figure 9) is the most important in the Himare area, being the only coastal spring used for water supply. It is located at the southern Spile beach, in the southern periphery of the Cika Mountain anticline structure, mainly comprising thick-layer Upper Cretaceous limestone. The spring emerges at 1.0 m a.s.l., is collected through a concrete channel about 200 m long, and then discharged into the sea. Both spring discharge and the chemical composition of water exhibit considerable seasonal variations: the first varies from about 50 L/s to more than 350 L/s, whereas TDSs are in the range of 1000–1500 mg/L, according to available surveys.

A comparison of the chemical analysis with the spring discharge (Table 1) indicates an unusual inverse relation of discharge with salinization, but the data are insufficient to come to reasonable conclusions. Concerning the possibility of using the spring as a drinking resource, it appears that some chemical parameters exceed the maximum permissible limit (KML) for drinking water: in detail, KML for Cl is 250 mg/L, whereas at the spring it fluctuates around 460–660 mg/L, and KML for Na is 200 mg/L, whereas at the spring it ranges from 200 to > 400 mg/L. Nevertheless, even though the Potami spring does not meet the drinking water standards, it continues to be used for the centralized public water supply of Himare, and for irrigation.

3.5. Qeparoi Springs

Under the Qeparoi springs name, the Mulliri spring and the Hoston group of coastal springs, near the village Qeparoi, are described (Figure 9). The first is in the northern sector of the beach, where alluvial deposits of the Qeparoi plain cover the Upper Cretaceous carbonates rocks. This spring represents the southernmost drainage of the Cika carbonate structure. The farthest emergence, with respect to the sea (“head of the spring”), consists of a karstic pit several meters in diameter, with the water front in the direction of flow being about 170 m long. The seasonal spring flow is in the range of 70–80 to >400 L/s. The water is salty; according to measurements in different seasons, electrical conductivity varies from 8000 to 10000 $\mu\text{S}/\text{cm}$, and water temperature fluctuates around 15.1–15.5 °C.

The Hoston group of springs is located along the rock shoreline separating the Qeparoi beaches to the north and Borsh to the south, representing the southern pericline of the Kudhes carbonate structure, whose total groundwater resources, estimated in about 890 l/s [87], are drained along a 600–700 m long spring-line. Along the Hoston coastline there are dozens of springs at elevations from sea level to 2 m a.s.l., whose discharges vary between 1 and 20 L/s. An exception is a spring emerging in the southernmost part of the coast, near the Borsh plain (discharge 0.5–0.6 m³/s, temperature 14 °C, electrical conductivity 4630 $\mu\text{S}/\text{cm}$).

3.6. Butrint Springs

The Butrint springs are located at the eastern corner of the homonymous lake (Figure 10): they are the Mulliri Armiro (discharge 100–200 L/s) at the northeast corner, and the Bufi springs (Bufi 1 and 2 in Figure 10), emerging near Rreza Lake. Bufi springs are connected by a canal about 500 m-long, flowing into the Butrint Lake. They are recharged from the Jurassic plate siliceous limestone formations, and have a total discharge of 600–700 L/s, temperature of 15.3–15.6 °C, and electrical conductivity of about 11,000–13,500 $\mu\text{S}/\text{cm}$, with a Cl-Na hydro-chemical facies (Table 1). These springs result by the mixing of karst freshwater with the seawater, as unequivocally supported by the values of ionic ratios, with particular regard to Na/Cl (0.88, typical value for marine water).

4. Hydrochemistry of Brackish Springs

The Piper diagram (Figure 11h), as well as the correlation plots in Figure 11e–g, show that the karst brackish spring of Albania belong to three hydro-chemical facies; (a) SO_4 -Ca for evaporitic springs; (b) Cl-Na for the Bashaj spring, related to the presence of halite; and (c) Cl-Na for coastal springs affected by seawater intrusion.

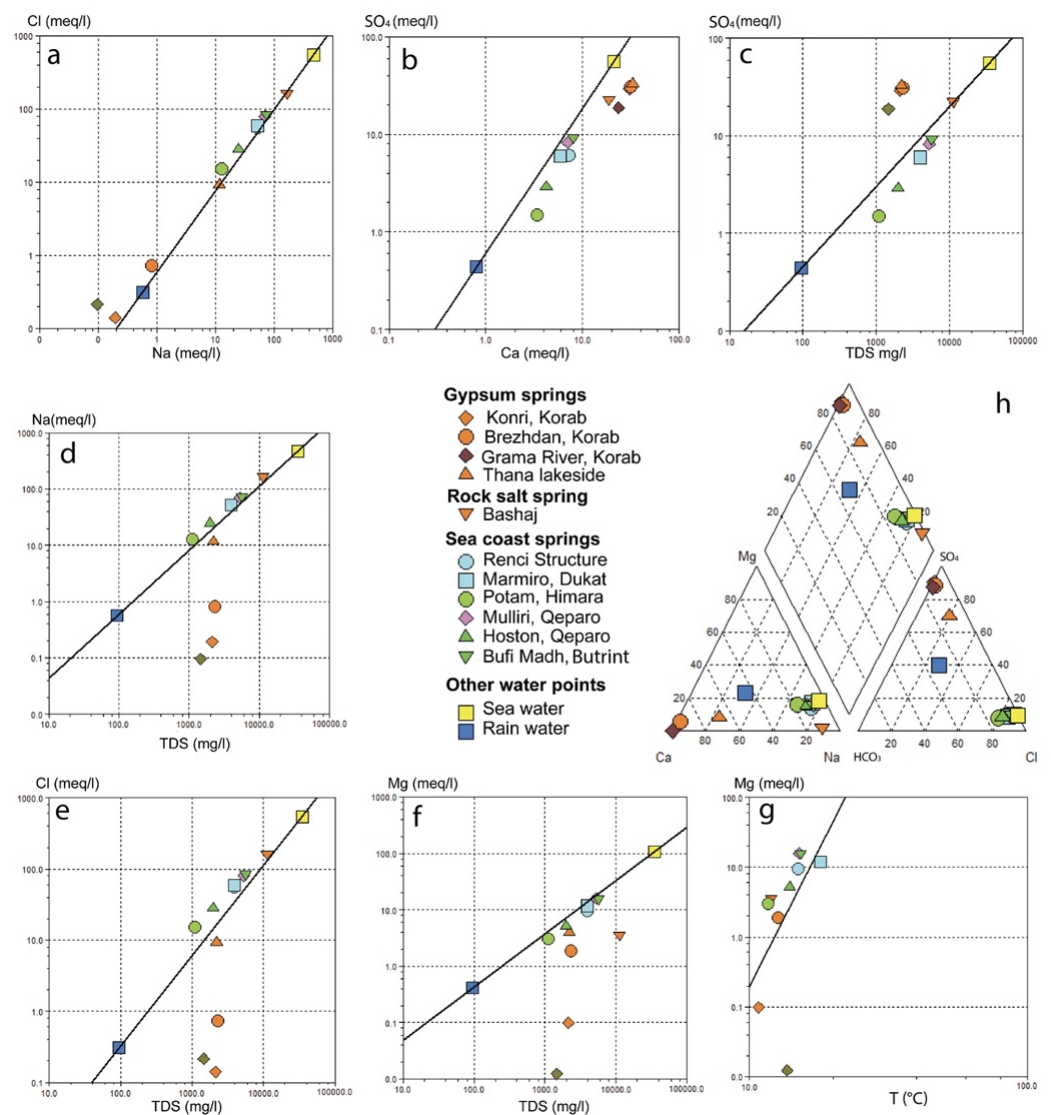


Figure 11. Plots showing the correlations between: (a) Cl and Na; (b) SO_4 and Ca; (c) SO_4 and TDSs; (d) Na and TDSs; (e) Cl and TDSs; (f) Mg and TDSs; (g) Mg and T; (h) a Piper diagram.

The springs of Dumre present intermediate hydro-chemical facies; they issue from gypsum rocks, but with high halite (NaCl) contents.

The evaporitic springs (facies $\text{SO}_4\text{-Ca}$) are characterized by very low concentrations of Na and Cl (Figure 11a), whereas the concentrations of Ca and SO_4 (Figure 11b) are very high, which shows that the gypsum deposits of Korab are relatively “clean”, consisting of gypsum but without salt.

The main factor controlling the chemical composition of coastal brackish springs is the mixing with varying degrees of freshwater of karst origin with marine waters. The mixing rate is highest at Butrint Spring no. 1 (about 30% seawater) and lowest at the Renci 2 spring (about 2–3% seawater).

Chemical compositions of the five evaporitic springs are quite different. The main reaction controlling their chemical composition is the dissolution of salts such as gypsum and halite [88]. In most of the figures presented here (Figure 11a,d,e,h) the Bashaj spring stands far from the Korab springs, due to higher TDS values and the different ion relationship. According to Cl, SO_4 and Na ion contents, Bashaj Spring appears to be a coastal spring: it has high TDS, Cl, and Na contents, although water circulates in the gypsum formation, cropping out along the overthrust tectonic fault of the Kurvelesh massif.

As already pointed out by Avgustinski et al. [34], water qualities at Bashaj are characteristic of groundwater circulating at great depths; near the surface, groundwater coming from the depths mixes with fresh shallow water, with consequent decreases in temperature and salinity. However, if water was actually circulating at depths, it would surely contain dissolved gases even in small quantities, but this is not the case. Furthermore, it could also have higher temperatures. Apparently, Bashaj is the spring with shallow groundwater circulation in evaporites. What is striking in the case of this spring is that groundwater circulating in a gypsum environment is richer in Cl-Na than in CaSO_4 . This is explained by the presence of halite, which exhibits a much higher solubility than gypsum [89].

Among the other gypsum springs, those at Dumre emerging at the Thana lakeside are distinguished for their relatively high content of NaCl, which indicates that halite deposits may also be present in the Dumre evaporites.

5. Conclusions

The available data about karst brackish springs of Albania, collected and presented in this contribution, allowed us to distinguish two types of hydro-chemical facies, characterizing the groups of evaporitic (mainly gypsum) springs and coastal sea springs, respectively. The only exception is the Bashaj Spring, with a discharge of about 20 L/s: it emerges from a small outcrop of evaporites with a high content of halite, along a tectonic contact between the Mesozoic limestones and the Oligocene flysch deposits. The spring is characterized by very high content of Cl (5813 mg/L) and Na (3812 mg/L).

For the first group (evaporitic springs), two main areas can be identified. The first is Korab Mountain (areal extension 90 km²), located in the center of the homonymous tectonic zone. At Korab, the springs discharge from some l/s to about 200–300 L/s, and are characterized by a $\text{SO}_4\text{-Ca}$ hydro-chemical facies, total dissolved solids in the range of 1500–2300 mg/L, and electrical conductivity of 1800 $\mu\text{S}/\text{cm}$. As indicated by the concentrations of Cl and Na ions, the content of salts is very low.

The second area is represented by the Dumre gypsum plateau, with a surface of 170 km², outcropping in the Ionian outer tectonic zone. This plateau is characterized by very developed karstification, documented by the high number of sinkholes which also host more than 80 karst lakes. The total groundwater resources of Dumre, as recharged by the effective infiltration, are estimated to be about 1.7 m³/s (5.35×10^7 m³/year), and are totally drained within the Thana artificial lake, at the southern edge of the plateau. The water is characterized by $\text{SO}_4\text{-Cl-Ca-Na}$ hydro-chemical facies, total dissolved solids in the range 2600–3300 mg/L, and electrical conductivity of 3400 $\mu\text{S}/\text{cm}$; notably, the concentrations of Cl and Na ions at the Dumre springs are about tenfold higher than those

in the Korab area. This is likely due to presence of halite in the gypsum deposits at Dumre, whose high solubility also explains the intensive karstification processes therein.

Concerning the coastal springs, these are mainly distributed at the Ionian coastal line, along a 147 km-long stretch from Vlora to the Albanian-Greek border. This is a mountainous karst area, intensively karstified, with total karst water resources estimated to be about 21.5 m³/s or 67.7 × 10⁷ m³/year. A significant amount of this (67% of the total karst water resources, corresponding to 14.5 m³/s) is brackish, and only 33% (7.0 m³/s) has a good quality, and is usable for drinking purposes. Most of the brackish water is drained mainly as diffuse flow, and only approximately 1.9 m³/s is drained as concentrated brackish coastal springs.

All brackish coastal springs are characterized by Cl-Na hydro-chemical facies, with total dissolved solids in the range of 1100 to 8390 mg/L.

Given the above values, karst brackish springs of Albania cannot be used as potable water sources. For irrigation purposes, the SAR (sodium adsorption ratio) coefficient should be taken into account, which is in direct correlation with the adsorption of sodium by soil. If the SAR is less than 10 meq/l, the water can be used for irrigation [90].

In the case of Korab, the SAR value is below the threshold limit, and actually the waters can be used to irrigate the fields. The situation at Dumre is quite different, because the SAR is close to 150 meq/l, which is potentially not suitable for irrigation. However, the springs at Dumre discharge into the Thana artificial lake, which is also supplied by the Devoll River. The resulting mixed water brings the SAR value below the threshold, thus making it useful for intensive application in the Central Albanian plains.

The Albanian karst is certainly among the most remarkable areas in the Dinarides for importance and quality of carbonate aquifers and the hydric resources contained therein. Nevertheless, scientific knowledge about many karst aspects of Albania still deserves attention from researchers, and needs much work in order to fully understand the dynamics of groundwater flow. With the goal of contributing to improve such knowledge, the present article provides significant information and data about the main brackish springs in Albania, which were previously scattered across local publications and reports. These are of particular importance, especially concerning coastal environments in karst settings [91–95], and are becoming some of the main priorities in times of climate change regarding the safeguarding and protection of very delicate natural ecosystems.

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