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Article

Hydrogeological Aspects of the Municipal Water Supply of Albania: Situation and Problems

Romeo Eftimi [1,*], Kastriot Shehu [2] and Franko Sara [3]

1 Independent Researcher, Rr. Rreshit Çollaku, Pll. Kl. Konst., Nr. 43, 1000 Tirana, Albania
2 Independent Researcher, HUK Projekt, Bulevardi Zogu 1, Pll.135, Nr. 9, 1000 Tirana, Albania; hukprojekt18@yahoo.com
3 Hydrogeological Service of Albania, Rr. Kavaja, Nr. 153, 1000 Tirana, Albania; frankosara@yahoo.com
* Correspondence: eftimiromeo@gmail.com

Abstract: The municipal water supply, related mainly to the cities of Albania, began to develop in the second half of the 19th century and very intensively after 1945. Today, the reported mean water production for the cities, on average, is about 300 l/capita/d, including drinking and industrial water supplies. The territory of Albania has an uneven distribution of very heterogeneous aquifers conditioning often the difficulty of municipal water supply solutions. In this article, are analyzed and classified the hydrogeological aspects of the water supply sources of the settlements, which are summarized in five groups: (a) wells in alluvial intergranular aquifers; (b) karst springs; (c) wells in karst aquifers; (d) springs in fissured rocks; and (e) mixed water sources. For each group of the water supply sources, the main concerns regarding the quantity and quality problems are analyzed, facilitated by the description of a variety of representative examples of different situations. Based on the gained experience, important recommendations are given for the better understanding of hydrogeological aspects of water supply systems, related to the river water recharge areas, the seawater intrusion in coastal aquifers, and the high vulnerability of karst aquifers, as well as trans-boundary aquifers. However, the main problem of public water supply of Albania remains the poor management of water supply systems, which is reflected in the significant water losses, as well as the low public awareness of requests for sustainable use.

Keywords: municipal water supply; intergranular aquifers; karstic springs; groundwater contamination; Albania

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1. Introduction

The construction of city water supply systems is a very ancient activity, testifying to the culture level and engineering knowledge of the early civilizations. A large part of these systems is still perfectly functioning nowadays, and there are uncounted examples, such as the water supply of ancient Rome. This consists of 11 aqueducts carrying more than 13 m^3/s of karst spring water to the city of old Rome from a distance of 16 to 91 km [1]. Generally, many cities continue to be supplied by karst springs today in the world, with diverse examples in south-eastern Europe, including Albania as well.

The Illyrians, the ancient people living in the territory of Albania, constructed the first cities during the IV–III centuries BC, and different contemporary techniques for that time were used for water supply [2]. The archaeological data testify to the high level of the ancient intake structures and water supply system of Apolonia [3], Durrahy (Durres), Buthrot (Butrinti) and Tepelena [2]; some are shown in Figure 1.

Albania's modern cities have no long history; they began to be built in the second half of the 19th century. Their water supply was initially based on the use of water resources within the settlement's territories, such as natural springs, or groundwater of the intergranular aquifers, captured by big-diameter dug wells. In some cases, such as in Gjirokaster City in South Albania, the population collected the rain water in "steras" (cisterns), built in house cellars. The first modern water supply systems of Albania's cities began to be built after 1920. The end of World War II found Albania with seven water supply systems, five recharged by springs and two by diverted river waters, with a total capacity of 160 L/s. The population served by the water supply in 2010 was 2.65 million people, corresponding to 80.3% of the total population in the jurisdictional areas of all water utilities in Albania (3.31 million people). The first important hydrogeological investigation realized by the Albanian Hydrogeological Service (AHS), started after 1960, initially focused mainly on the intergranular aquifers. Later, it organized the hydrogeological prospecting of the entire territory of Albania, which was finalized with the Hydrogeological Map of Albania sc. 1:200,000 [4]. This map was the starting point for understanding all different aquifers of the country. At the same time, mass construction of the water works for the water supply of Albanian cities and industries began. The term "potable" was used for water distributed to the consumers through the water works, without distinction between water for drinking and that for other communal and industrial needs. As a result of the dynamic development of the cities and the growth of the economy, the water demands changed very often, making it difficult to manage the water supply problems. However, a great deal of experience was gained in solving water supply problems related to various hydrogeological situations.

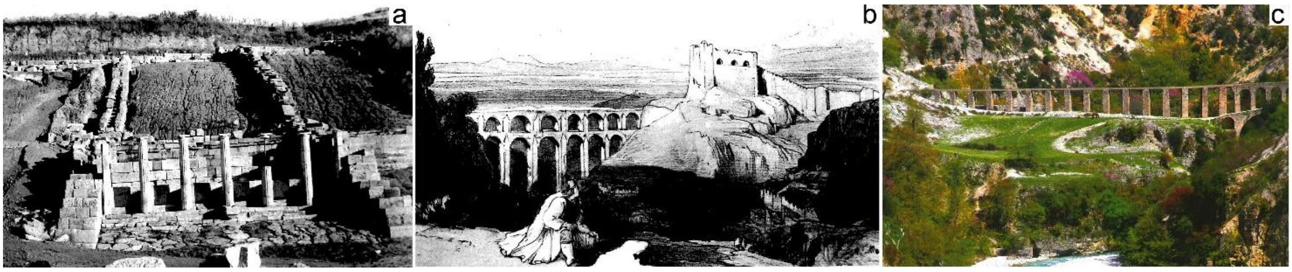

Figure 1. (**a**) The Monumental Fontana of Apolonia, IV century BC [3]; (**b**) aqueduct of Gjirokaster (gravure of XIX century); (**c**) aqueduct of the city of Tepelena (**b**,**c**), from [2].

The intergranular gravelly–sandy aquifers are situated mainly in the Near-Adriatic Plain and along the river valleys where the most important cities of Albania are situated. The location of the water supply wells in these aquifers should respect some contradictory principles [5]. Pumping wells should be placed near the recharge area in order to ensure sustainability and to increase the pumping capacity of the wells through induced infiltration [6–11]. However, near the recharge area, the pumped groundwater can be easily contaminated by polluted river water recharging the aquifer. Thus, a compromise between benefits and undesirable consequences should be respected when determining the location of the water wells [12–14]. Another concern for the intergranular aquifers is the polluting activities such as quarrying at the riverbed recharge areas [15], likely facilitating, in turn, seawater intrusion as a result of the decrease in aquifer hydraulic pressure [16]. Further, rapid and uncontrolled urbanization has a marked impact on groundwater quality too [17–19]. The hydrogeological investigations performed in Albania have already documented several examples of groundwater quality deterioration by pumping near the recharge areas of intergranular aquifers [20–24].

As in many Mediterranean countries [25–27], in Albania, the karst springs are also a very important source of potable water supply [4,28]. Experience in the use of karst springs as potable water sources has repeatedly demonstrated the problems of high variability of their discharge, often causing water shortages in the cities [25,29–31], and their easy pollution in areas of demographic growth and industrial development [32–37]. The main factors contributing to deterioration of the good quality in karst areas of Albania are, therefore: uncontrolled urban sewage, effluent and industrial discharges in lakes and rivers, quarrying in karst areas, use of karst landforms for illegal dumping and developing intensive agriculture activities in karst areas [15,38,39].

The magmatic rocks and molasses contain relatively restricted groundwater resources and are used for the water supply of small towns and villages. During the last 10 years, the increase in water demands for human and industrial water supplies has constricted the use of surface water. The available geological [40] and hydrogeological maps [4], and a variety of other data, have been collected and analyzed for this study. Most of these sources represent archive materials such as reports, chemical analyses and historical non-systematic monitoring by the AHS. The existing data have been compared to recent field observations by the authors. The article analyzes the hydrogeological aspects and experience of groundwater exploitation of different aquifers. To facilitate the analyses, the water supply sources of Albanian cities are classified into five groups, mainly related to the aquifers or to the applied solution of the problems. The analysis is illustrated with typical negative and positive examples of the solutions of the problems.

2. Hydrogeological Characteristics of Albania

Although geographically a small country, Albania has a great geological variety. Rocks vary in age from Ordovician to Quaternary, while, according to their origin, they are sedimentary, magmatic and metamorphic [40,41]. As seen in the simplified hydrogeological map of Albania (Figure 2a), due to uneven areal distribution of different rocks, the hydrogeological characteristics of the country's territory are highly variable also [4,10,28].

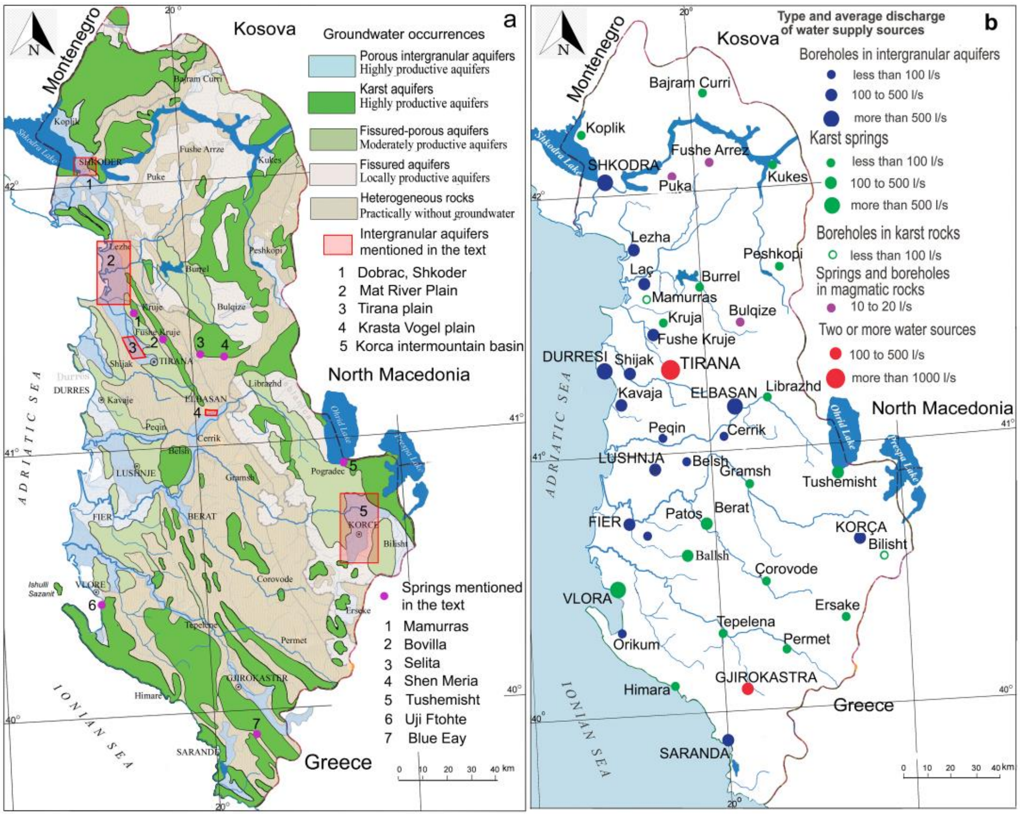

Figure 2. (**a**) Map of groundwater occurrences of Albania (modified from [42]), (**b**) map of water supply sources of the cities of Albania.

As shown in Figure 2, two different classes of rocks are the most abundant aquifers: (a) the porous, intergranular, mainly fluvial gravelly aquifers (blue color), exploitable mainly by drilling wells, and (b) the karstic aquifers (dark-green color), consisting usually of high-elevation carbonate structures recharging strong karst springs. The other fissured–porous aquifers, such as sandstone–conglomerate aquifers, and fissured magmatic rocks, are generally considered as moderate- to low-productive aquifers. The group of rocks, shown on the map with dark-brown color (Figure 2), occupies about 40% of

Albania's territory, consisting of low-productive to very low sedimentary and metamorphic rocks. This fact undoubtedly represents an aggravating factor for the water supply of the settlements and, in general, of the whole country. Table 1 shows the estimated total natural (renewable) and exploitable groundwater resources of Albania.

Table 1. Total natural and exploitable groundwater resources of Albania [28].

Aquifers Related to:	**Natural Resources**		**Exploitable Resources**	
	m^3/year	**m^3/s**	**m^3/Year**	**m^3/s**
Intergranular aquifers	0.47×10^9	15	0.945×10^9	30
Carbonate karst aquifer	7.15×10^9	227	2.84×10^9	90
Molasse rocks aquifers	0.45×10^9	14	0.22×10^9	7
Magmatic intrusive rocks aquifers	1.00×10^9	32	0.41×10^9	13
Total groundwater resources	9.07×10^9	288	4.4×10^9	140

The natural groundwater resources of Albania are estimated at about 288 m^3/s, while exploitable groundwater resources consist about 140 m^3/s, which, in most of the aquifers, corresponds to 50% of the total calculated natural groundwater resources. Exceptionally, in intergranular aquifers, the groundwater exploitable resources can be larger than the natural ones as a result of induced infiltration when pumping at the recharge areas. According to an approximate estimation, in Albania, urban and industrial water supply from the groundwater currently accounts for about 12 m^3/s, while rural water supply uses about 2.0 m^3/s, amounting to a total of about 14 m^3/s. Only Tirana has an additional water supply source of about 1.5–2 m^3/s, from the surface water of an artificial lake.

3. Hydrogeological Characteristics of the Water Supply of the Cities of Albania

Water supply sources of the Albanian cities can be summarized into five groups (Figure 2b):

- Drilling wells in intergranular aquifers;
- Karst springs;
- Drilling wells in karst aquifers;
- Drilling wells and springs in fissured rocks;
- Two or more different water supply sources, including surface water.

3.1. Water Supply from Intergranular Aquifers

The groundwater intake structures in intergranular aquifers of Albania consist mainly of pumped wells. As shown in Figure 2b, according to their total capacity, the groundwater intakes are classified in three groups: (a) less than 100 L/s, (b) from 100 to 500 L/s and (c) more than 500 L/s. Only in three cities (namely Shkoder, Durres and Elbasan) is the actual pumped capacity more than 500 L/s; in the others, the capacity is smaller.

The intergranular gravelly–sandy aquifers of Albania [4] generally consist of Quaternary fluvial deposits, with maximum thickness from about 50 to 200 m, representing mainly a multi-layered gravelly aquifer system.

The techniques of groundwater resource evaluation require an understanding of the concept of groundwater yield. The primary objective of most groundwater studies is the determination of the maximum possible pumping rates that are compatible with the hydrogeological environment from which the water will be taken. The known aquifer characteristics enable one to respect and harmonize two important principles when determining the location of pumping wells [5,12,13,43,44]: (a) the water supply wells preferably are located as close as possible to the recharge areas, thus ensuring sustainability of the groundwater flow and the possibility of increasing the pumping capacity of wells through induced infiltration [6,8–10], and (b) the water wells preferably are placed in areas with the highest aquifer transmissibility, ensuring higher pumping rates of the wells and, consequently, a reduction in their number.

The intergranular aquifers of Albania differ in their high filtration parameters; usually, the aquifer transmissibility varies from about 1000 to over 10,000 m^2/day, and, accordingly, the specific capacity of the pumped wells varies from 10 to more than 100 L/s/m [10,45], while, in some cases, the maximum total capacities of the wells exceed 200 L/s [24]. For evaluating the aquifer filtration parameters in Albania, the Thiem–Dupuit method for steady-state flow is widely used [46], together with different formulas representing the solution for non-steady-state flow. Special solutions are used for aquifers limited by one or more straight recharge boundaries [7–9].

In the following, four problematic examples of groundwater exploitation in intergranular aquifers of Albania are discussed: the Fushe Kuqe Plain, Krasta Vogel Plain, Shkodra Plain and Korça intermountain basin.

Fushe Kuqe Plain. This plain is situated south of the Mat River (Figure 3). It is one of the most abundant and most heavily pumped among the intergranular aquifers of Albania. The total surface of the Fushe Kuqe Plain is about 100 km^2 and is filled up by fluvial deposits of the Mat River with a maximum thickness of 200 m. Transmissivity of the gravel aquifer in the central area varies from about 4000 to 8000 m^2/day, and, accordingly, the specific capacity of the wells often exceeds 40 L/s/m [10,20]. The pumped groundwater is used for the water supply of the cities Durres, Lezhë, Milot and Laç, and for dozens of villages as well, with a total population of about 350,000 people (Figure 2).

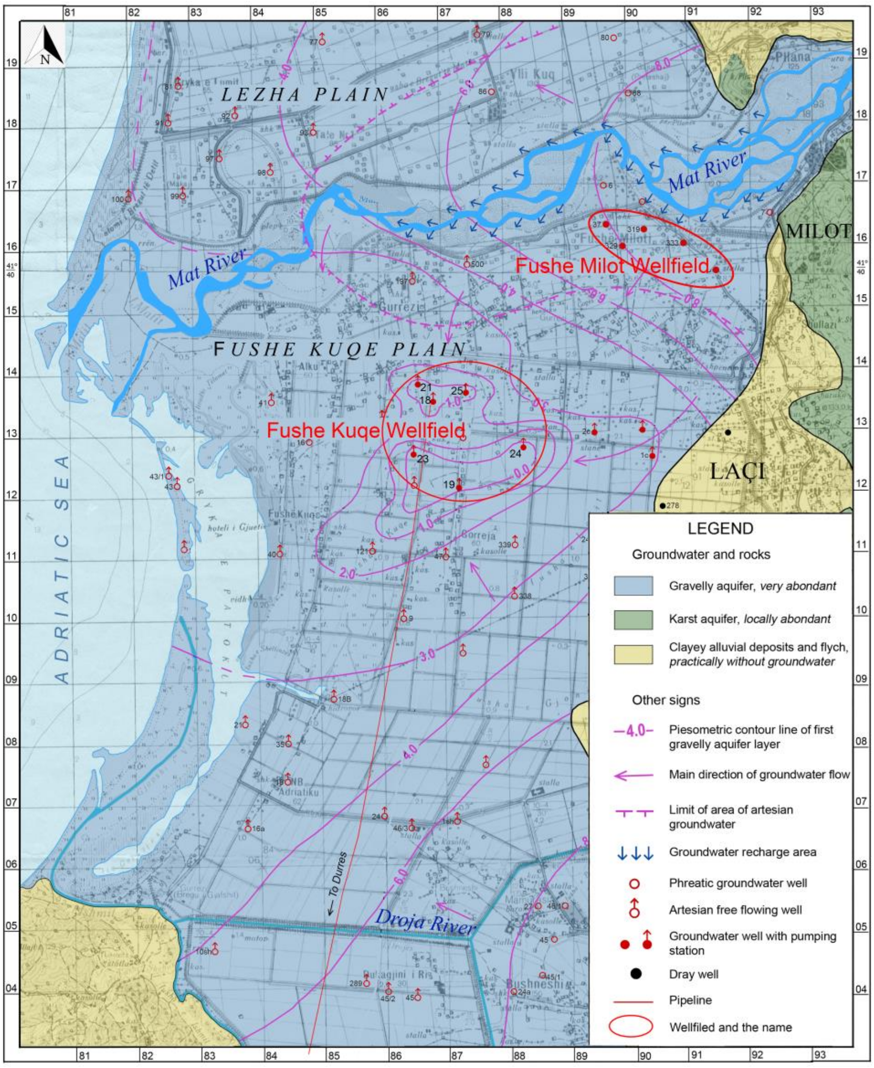

Figure 3. Hydrogeological map of intergranular alluvial aquifer of Mat River Plain, sc. 1:50,000 (modified from [20]).

The recharge source of this aquifer is the Mat River. The most important wellfields in this aquifer are those of Fushe Kuqe, with a capacity of 720 L/s, functioning since 1972, and Fushe Milot, with a capacity of 625 L/s, functioning since 2021 (Figure 3). Fushe Kuqe wellfield is located at similar distances from the Mat River (recharge area) and the Adriatic Sea (discharge area). Before starting intensive pumping of the groundwater (around 1972), the piezometric level in the wellfield area was stabilized about 4–5 m above the ground surface, corresponding to the absolute elevation of about 6 m. At present, the groundwater level is decreased and, in the center of the wellfield, is stabilized at an absolute elevation of around 0.0 m (Figure 3). This created a threat of sea water intrusion into the gravel aquifer.

As shown by environmental hydrochemical and isotope investigations, the occurrence of brackish water in the periphery areas is related to the exchange processes between the Ca^{2+} ions of the groundwater and the Na^{+} ions of clay intercalating layers, remnants of the Holocene Sea transgression [20,23,47].

Additionally, the hydrochemical observations [22] do not indicate a current risk of seawater intrusion in the studied aquifer. After more than 40 years of groundwater pumping in the Fushe Kuqe wellfield, the Cl and Na contents do not show any significant increase; marine water intrusion is thus still not yet considered a problem [5]. Nevertheless, the second big wellfield in Fushe Kuqe Plain, the Fushe Milot, is located near the Mat River recharging the aquifer (Figure 3). It has been calculated that the total influence of the pumping in the new wellfield of Fushe Milot should be less than 1 m in the center of the existing wellfield of Fushe Kuqe, and no intensification of the sea water intrusion will happen. This is supported by observation of the groundwater level and chemical analyses [20,23].

A big concern is the groundwater contamination by infiltration into the aquifer of polluted river water [5,12,48] since most of the Albanian rivers are polluted by untreated urban sewage waters discharged along the rivers [23]. In addition, the intensified quarrying at the riverbed recharge areas represents another serious concern [20,22]. The decrease in thickness of the gravel aquifers at the recharge areas causes reduction in the aquifer hydraulic pressure, which, in turn, facilitates seawater intrusion in the coastal areas [20,49].

Using the Ghyben–Herzberg equation, it is calculated that, actually, a groundwater level lowering of about 1 m at the upper part of the Mat riverbed recharge area causes an aquifer level lowering at the seashore of about 0.1 m, corresponding roughly to a 4 m increase in the freshwater–seawater interface. Nevertheless, the investigations have shown that there is no current risk of seawater intrusion since the wells close to the seashore are artesian [20]. In addition to this, the riverbed quarrying activities are also a source of groundwater contamination [50–52] by oil leakage from machineries, but, so far, no quantitative data on this issue are available.

Krasta Vogel Plain. Rapid urbanization has a profound effect on groundwater recharge and a marked impact on groundwater quality [17,18,33,53]. The intergranular aquifer of Krasta Vogel Plain, located near the eastern suburbs of the city of Elbasan, in Central Albania (Figure 2), testifies to this statement.

The small Krasta Vogel Plain aquifer located along the Shkumbin River is filled with high-permeability gravel deposits, hydraulically connected with the river (Figure 4). For the water supply of the city of Elbasan, three pumped wells, with a total capacity of 245 L/s, have been drilled at a distance of about 200 m from the riverbanks. As a result of the uncontrolled urban expansion of Krasta Vogel village without sewage water collection infrastructure, which started about 20 years ago, the groundwater pumped by wells nos. 2 and 3 was contaminated, and new wells were drilled upstream.

Dobraç wellfield. A similar example, but of a larger scale, is the Dobraç wellfield, near Shkodra Lake, in North Albania (Figure 5), initially developed in a peripheral, undeveloped area. Shkodra Plain is filled by a 60–70 m thick intergranular aquifer, covered by a thin-grained soil, with a thickness of 5–10 m. The groundwater is recharged by rainfall infiltration in the Shkodra Plain and moves westward to Shkodra Lake. The aquifer transmissivity in wide areas is higher than 8000 m^2/day, and the capacity of the wells is about 100–120 L/s. In Dobraç wellfield, about 800 L/s for the water supply of Shkodra City is pumped, but the groundwater is threatened by infiltration of the untreated sewage water of the new urban area developed in the immediate vicinity of the pumped wells. Actually, two exploitable wells, the closest to the new urban area, each with a capacity of 100 L/s, are polluted and abandoned (Figure 5), and the same will likely happen in the future with the other pumping wells.

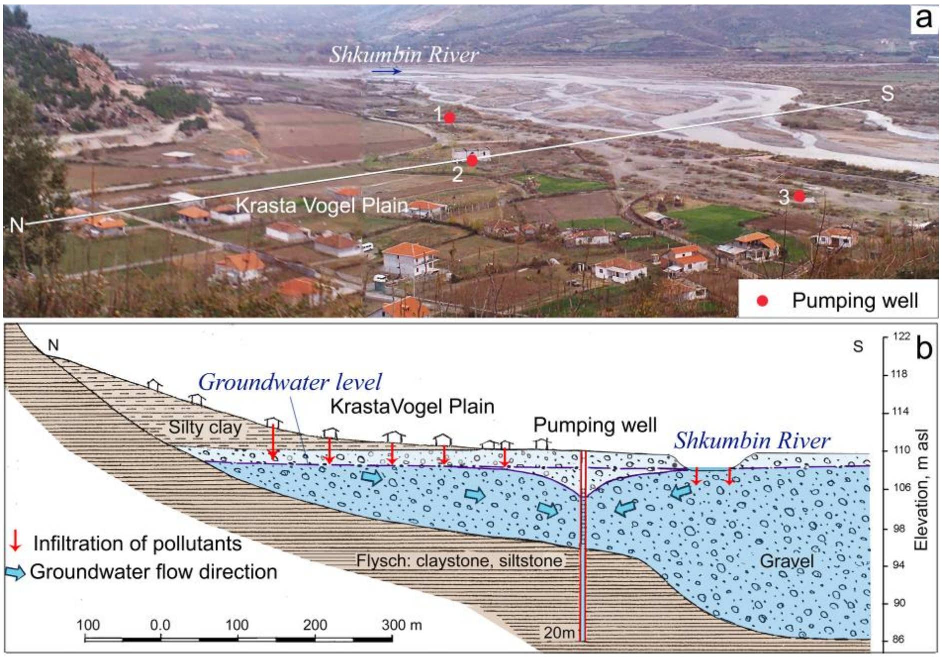

Figure 4. (**a**) General view of the intergranular aquifer in the Krasta Vogel Plain wellfield, (**b**) hydrogeological cross-section of the Krasta Vogel (modified from [24]).

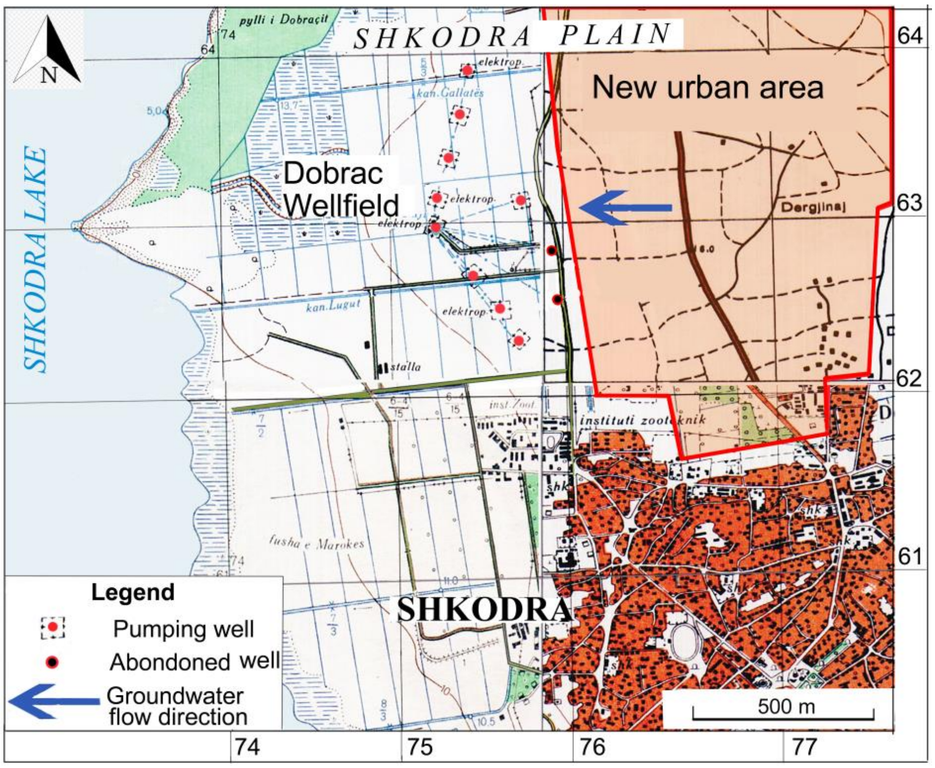

Figure 5. The new urban area is dividing threatening the Dobraç wellfield, with a capacity of about 800 L/s (improved from [10]).

Korça intermountain basin. This basin, located in south-eastern Albania (Figure 2), is the largest intermountain artesian basin of the country (Figure 6). It is filled with Pliocene–Holocene deposits (max. thickness of about 250 m), consisting of intercalation of the gravel intergranular aquifer with clayey layers. The main recharge sources of the basin are the small rivers flowing from the mountain gorges around the Korça plain. The intensive groundwater exploitation in the Korça basin started by the end of 1960s. The pumping intensification from the aquifers is always associated with the formation of a regional groundwater depression. Actually, in total, about 400 L/s is pumped in the Korça basin, used for the water supply of the city, creating in the center of the Turan wellfield a groundwater regional depression of about 14–16 m [45,54].

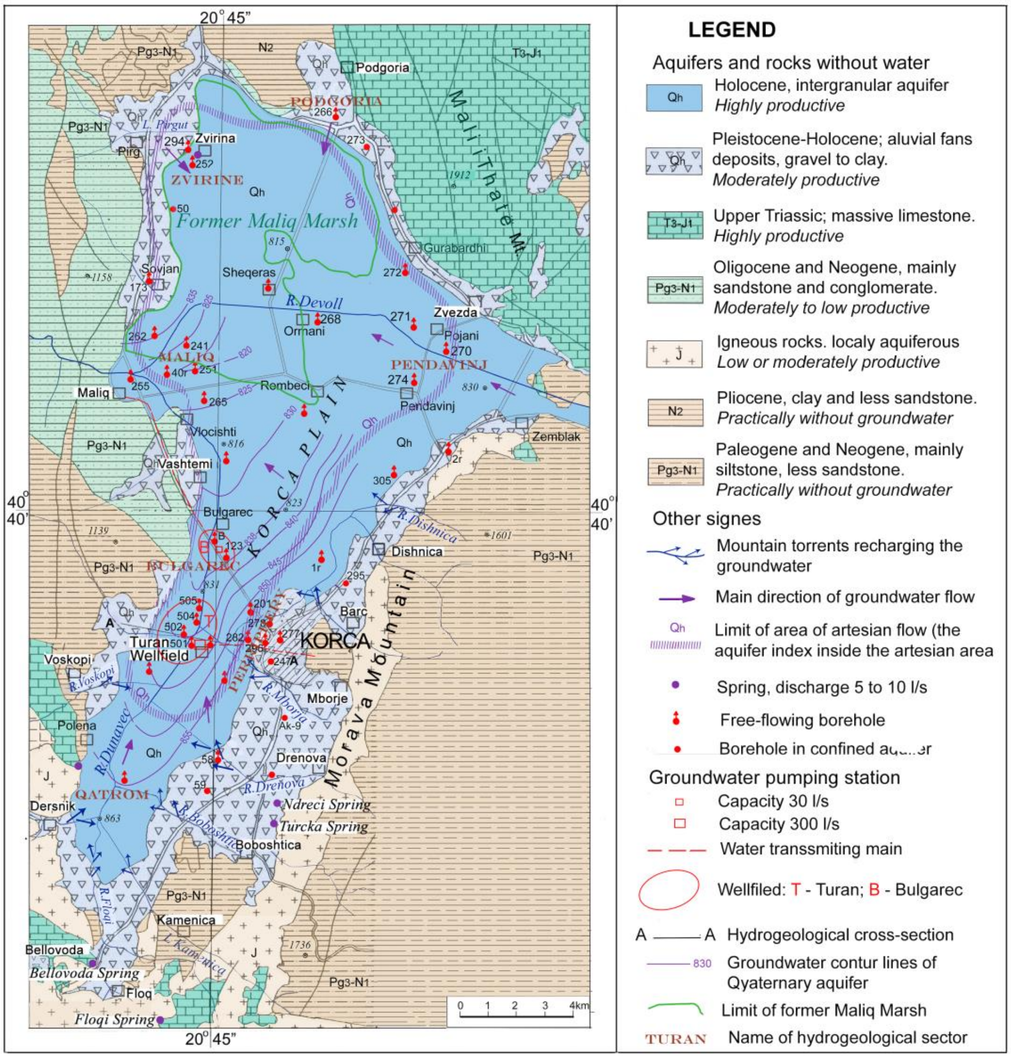

Figure 6. Hydrogeological map of Korça intermountain basin (modified from [45]).

The main problem regarding the intensification of the groundwater use in Korça basin is the sustainability which must be established between the quantity of pumped groundwater and eventual negative environmental impacts. Safe yield is traditionally defined as the attainment and maintenance of long-term balance between the amount of groundwater withdrawn annually and the annual amount of recharge [55]. However, the aquifer development, based upon the concept of safe yield, is not safe and sustainable [43,44,55–57]. If the groundwater pumping should be limited within the natural groundwater flow to respect the so-called "self-yield", it might be difficult, if not impossible, to face the constant increase in groundwater demands. Maybe it would be more appropriate to respect the "basin yield" concept, which can be sustained by the hydrogeological system of the groundwater basin without causing unacceptable changes in any environmental components of the basin. Respecting the "basin yield" concept means sustainable groundwater management of the Korça basin, which must be necessarily accompanied by observations and control of the aquifer, water conservation measures, water quality monitoring and observation of the possible negative impacts such as the drying up of the rivers, pronounced changes in wetlands, including in their habitats, etc.

3.2. Water Supply from Karst Springs

Karst rocks occupy an area of 6750 km^2, or 24% of Albania's territory [4]. In Albania, 100 karst springs have an average discharge exceeding 100 L/s. Among them, 17 outflows discharge more than 1000 L/s, and Blue Eye Spring (Figure 2), the biggest spring of the country, reaches 18.4 m^3/s. Total renewable karst groundwater resources of Albania are estimated at about 227 m^3/s and account for about 80% of all groundwater resources in the country [28,58]. Based on climatic data and using empirical methods [59,60], the yearly efficient infiltration of the precipitations is calculated to be from 1500 to 2000 mm in the Albanian Alps, in the north of the country, 1100–1750 in the central and southern part and about 450 in south-eastern Albania [58]. Karst groundwater represents the main source of potable water supply in many countries, and particularly in coastal areas [25,27], where urbanization is growing fast. The experience of utilization of karst water resources encountered two main problems: (a) the spring discharge regime and (b) water quality deterioration.

Since the regime of the recharging karst springs rainfalls is highly variable (about 70% of them are concentrated during the period of November–April), their discharge regime is too. This is the reason why many cities face water shortages, especially during the summer–autumn months, when karst springs significantly reduce their flows [26,31,61]. Karst waters often show significant variations in their physic-chemical and bacteriological characteristics, and experience has shown that the variations in water quality are more pronounced when there are also variations in the output of karst springs [58,62].

In the following, experiences related to three big karst springs of Albania (Uji Ftohte, Bogova and Tushemisht) used for urban water supply are presented.

Uji Ftohte springs. This spring, the largest in the southern coastal area of Albania, 147 km long (Figure 2), issues from the Tragjas karst massif, consisting of Triassic dolomite and Jurassic to Eocene limestone and thin-bedded cherts. In the area of the Uji Ftoht springs, a transgressive contact between carbonate rocks and Neogene clayey formations is present [40,41], and the formations work as a barrier preventing the intrusion of seawater into the karst aquifer (Figure 7). Uji Ftoht Spring is used for the water supply of the city of Vlora, which has a population of about 170,000 inhabitants (Figure 7). This spring consists of 32 springs emerging at sea level along a 1.7 km long stretch. Three horizontal galleries parallel to the coastline, excavated at a distance of 60–70 m from the coast, at an elevation of 0.2–0.5 m asl, collect inside the rocks most of the discharges into the sea karst water [63]. The mean annual discharge of the three draining tunnels is about 2.0 m^3/s, while the mean water supply discharge for Vlora city varies by about 0.8 m^3/s. Based on non-systematic water quality analyses, the levels of some chemical parameters measured at drainage tunnels are as follows: conductivity 400–700 µS/cm, TDS 250–540 mg/L, pH 7.2–7.7, Cl 20–150 mg/L, Na 20–90 mg/L, HCO_3 50–60 mg/L, NO_2 missing, and water hydro-chemical type is HCO_3–Ca–Mg.

However, the situation in the catchment areas of the Uji Ftohte springs is undergoing rapid changes; instead of fruit trees, brushwood and meadows on outcropping rocks, an uncontrolled urban area without a centralized waste water system is under development above the water collecting at an elevation from 20 to 250 m (Figure 7). Bacteriological analyses, performed at least since 2009, confirm that Uji Ftohte springs are heavily polluted. The values of some bacteriological indexes confirm the groundwater pollution: total coliform, 10–20, faecal coliforms (Escherichia coli), 10–17, and *faecal streptococcus*, 2–4, which indicate the possible presence of various pathogens [64].

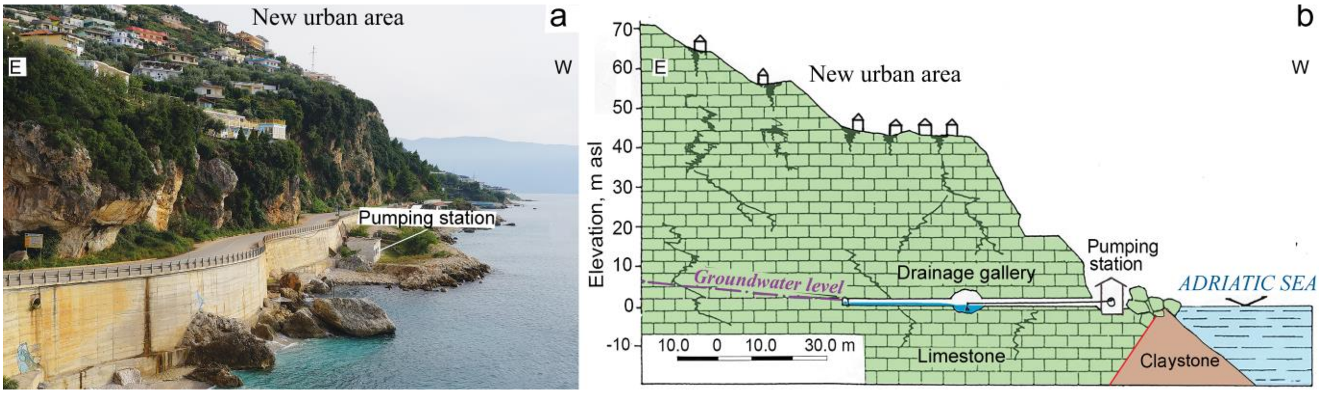

Figure 7. Uji Ftohte karst spring: (**a**) a new urban area is developing above the water collecting tunnels; (**b**) hydrogeological cross-section of the spring and the intake structure (modified from [38]).

With regard to the numerous possible hazards emanating from the urban area, the only mitigating element seems to be impervious "terra rossa" fillings of the cover sequences [32], which, in the Uji Ftohte spring area, have significant thickness. In case of a small thickness of the unsaturated zone, such as at Uji Ftohte, the purification process is also limited by the short time the water stays in the aquifer [65].

To protect the water quality of Uji Ftohte springs, the following measures are recommended: (a) to stop the development of the upstream urban area, (b) to ensure that water-impermeable septic tanks are constructed, (c) to construct the wastewater drainage system respecting the peculiar conditions in the considered area and (d) to monitor the water quality and establish protective areas of the groundwater catchment. So far, the only adopted measure is an increase in the dosage of chlorination.

Bogova Spring (Figure 2) is an example of the negative impact of limestone extraction through quarrying activity in a karst aquifer such as the mentioned similar examples [50–52,66]. The mentioned spring is one of three big karst springs issuing from Tomor karst massif, in Central Albania, and is located in its western part at 344 m asl. The water quality is excellent, the conductivity is about 224 μS/cm, the total hardness is 2.54 meq/L and the water type is HCO_3–Ca–Mg [38]. The average discharge of the spring is about 1350 L/s, and, by gravity, it is used for the water supply of the cities of Berat, Poliçan and Kuçove in Central Albania, with a total population of about 120,000 inhabitants.

The spring recharge area was a clean mountainous limestone area. This situation completely changed after 1995, when the quarrying activity accelerated, demanded by the construction industry. Quarrying is still particularly intensive upspring, at elevations of about 600–1000 m asl and distances of about 1.0–3.0 km north-east of the spring. This activity is responsible for the pollution of Bogova Spring, where, from time to time (mainly at the beginning of the rainy season), the spring water becomes turbid. The turbidity originates from the soil, favored by removal of the red clay in the subcutaneous zone [67], and rapidly spreads over large distances after every significant precipitation event, thus impacting the springs. Brief contamination episodes are interrupted by more or fewer long periods of clean spring water. In some events, the measured turbidity in the water distribution system of Berat varies from 2 to 4 NTU (nephelometric turbidity units), whilst the European guidelines indicate that turbidity values must not exceed 1.0 NTU [68]. The recommendation to stop quarrying within the spring's immediate protection area, with a 1 km buffer in the upstream direction, has not been respected.

Tushemisht spring. This spring is one of the St Naum–Tushemisht spring group, issuing from the Ohrid Lake coastal line, at the boundary between Albania and North Macedonia (Figure 2). The high karst mountain chain Mali Thatë–Galičica separates two lakes, Prespa Lake at elevation 849 m asl and the Ohrid Lake at elevation 693 m asl (Figure 8a). This massif is a transboundary karst aquifer shared by Albania, North Macedonia and Greece.

Water of Prespa Lake disappears in Zaver swallow hole and reappears at lower elevation as large karst springs along the Ohrid Lake coast [69]. The shorter transit water distance is about 17 km. The most important springs in the Ohrid Lake coastal line are the St Naum Spring, with an average discharge rate of 7.50 m^3/s issuing in North Macedonia, and Tushemisht spring, with an average discharge of 2.5 m^3/s, issuing in the Albanian territory (Figure 8a). As determined by the application of the environmental isotope methods, the total discharge of this spring group is recharged nearly 50% by the karst water of Mali Thatë–Galičica and about 50% by the Prespa Lake [38,70].

The city of Pogradec, located in the southern sector of Ohrid Lake (Figure 2), is an important, fast-developing tourist center in Albania. Since about 1980, Pogradec has been supplied with water by a gallery about 35 m long, excavated near the Tushemisht spring (Figure 8b). About 70 to 120 L/s water was pumped in a small collecting room. After detailed hydrogeological investigations in 2002, it was decided to enlarge the tapping structure, aimed at increasing the spring discharge to about 250 L/s. However, serious concerns have arisen about the possible pollution of the pumped karst water from the seepage of the eventually polluted Ohrid Lake water.

The practice of exploitation of karst springs offers many examples for the solution of similar problems, often consisting of the construction of special hydrotechnical structures, such as underground diaphragms [36,71,72]. Similarly, to avoid the infiltration of lake water into Tushemisht spring, a pumping shaft isolated by an impermeable diaphragm surrounding the waterworks was constructed (Figure 8b). The diaphragm consists of 74 alternated cemented and reinforced boring piles of diameter 600 mm and depth 5 to 10.5 m, tightly fixed on the karstified limestone basement. As proved by trace experiments, the concrete curtain is water tight, and even the groundwater level in the collecting room during the pumping of about 200 L/s is stabilized about 30 cm above the lake level.

Another important issue is the possibility of contamination of Tushemist spring by the polluted Prespa Lake water recharging the spring. This is facilitated by large karst conduits separating the lakes [73], enabling high flow velocities, shortening the transit and reducing the necessary time for micro-organisms to die [32]. The main reason for pollution of the Prespa Lake area seems to be the rapid increase in population and tourism and the intensified agriculture, with village waste disposal sites scattered along the coastal line of Lake Prespa which discharge into the lake untreated waste water [38]. The situation becomes more problematic due to the catastrophic decrease of about 10.5 m in the level of Lake Prespa during the last 50 years as a result of the climate changes [74], corresponding to about 25–30% of the total lake volume [75]. The dramatic drop in lake level is accompanied by increased eutrophication [76]. Nevertheless, until now, no significant pollution of the Tushemisht spring has been reported.

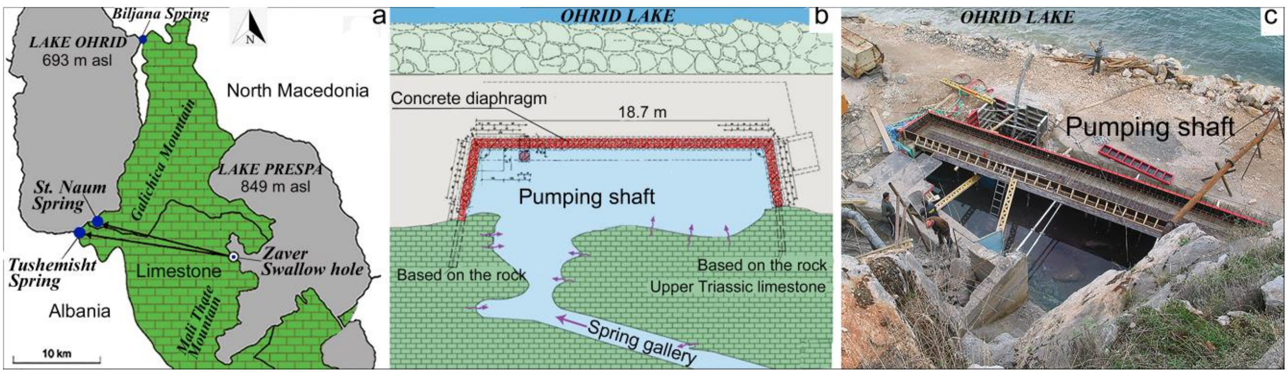

Figure 8. Tushemist spring: (**a**) hydrogeological scheme of the transboundary karst aquifer Mali Thatë–Galičica, (modified from [76]), (**b**) sketch of isolation diaphragm, (**c**) pumping shaft during the construction ((**b**,**c**) from ILF Construction Company, Innsbruck, Austria).

For managing and protection of the karst aquifers, it is important to know their hydrogeological character, which can be established using the discharge and chemical variability data. Springs with high discharge variability can indicate a high degree of groundwater transport; there are at least two end-member types of groundwater flow in karst aquifers: conduit flow (fast flow) and diffuse flow (slow flow) [77]. The analyses of hydrograph separation constructing the master curve enable identification of the fast flow, slow flow and intermediate flow, enhancing the estimation of groundwater vulnerability [78,79]. The hardness variation was used by [80] to classify the springs into diffuse flow and conduit flow, but the list of chemical parameters used for this purpose was elongated by [81]. Both mentioned methods of interpretation were used to evaluate the karst flow character of the springs Selita and Blue Eye in Albania, and the result fully agreed. Selita spring has a prevailing conduit karst flow and high vulnerability in terms of groundwater quality, while Blue Eye Spring is characterized as a diffuse-flow spring and has lower sensitivity to potential pollution [58].

3.3. Water Supply from Drilling Wells in Karst Aquifers

As explained in the above paragraph, the main problem in water supply, related to karst springs, is the water shortage during the recession period [25,36,58,62,82,83]. The intake structures usually tap the natural discharge of the springs, despite the fact that dynamic water resources in karst often surpass undoubtedly the used karst water resources [84]. Based on groundwater monitoring, the ratio between the maximum and minimum discharges for karst springs of Albania vary mostly from 3 to more than 6, but there are also karst springs with maximum discharges higher than tenths of m^3/s that dry up totally [28,58].

To face the water shortage of the springs, the most appropriate type of water intake is through pumping dynamic karst water reserves by application of large-diameter wells [31,36]. The hydrogeological conditions must allow the drilling wells, sited in karst aquifers, to pump the static reserves in a short time, which should be replenished during the next wet season [25,27]. Usually, the drilling wells are located upstream in the catchment. The karst conduit system may be very heterogenous, and the boreholes at small distances may have very different productivity.

In the following, two examples of successful water supply by drilling wells near shortage springs are shortly described. The small city of Mamurras, located in Central Albania, was initially supplied by a karst spring discharging about 20 L/s, quite insufficient for the normal water supply of the increasing population of the city. The spring issues from Makaresh karst massif, consisting of Upper Cretaceous dolomite and limestone, with calculated water resources of about 400 L/s. During 2002, two wells, 50 m deep, were drilled near to the spring (Figure 9a). The pumping tests confirmed that both wells were abundant; the free flow of well 1 was nearly 50 L/s (Figure 9b), while the pumping capacity of well 2 was 60 L/s. Since 2002, the city of Mamurras has normally been supplied with about 50 L/s by one single well.

A similar example is the small city of Bilisht in south-eastern Albania (Figure 2). The city was supplied by an ascending karst spring issuing from Upper Eocene conglomerate limestone and discharging about 12 L/s. To improve the water supply of Bilisht during 2008, two wells were drilled upspring, 150 m deep. The pumping capacity of the new wells, individually, is about 35 L/s.

Using drilling wells for the capture and pumping of the renewable karst static water resources could be applied also in other places in Albania, such as around the cities of Koplik in North Albania and Permet and Gjirokaster in South Albania. There are cases of ascending vaucluse springs where the pumps are installed into the siphon channels of very big temporary springs, such as in Viroi and Goranxi, in South Albania, and of the perennial spring Syri Sheganit in Northern Albania. In each case, the pumping capacity is about 2 to 3 m^3/s, and the pumped water is used for irrigation.

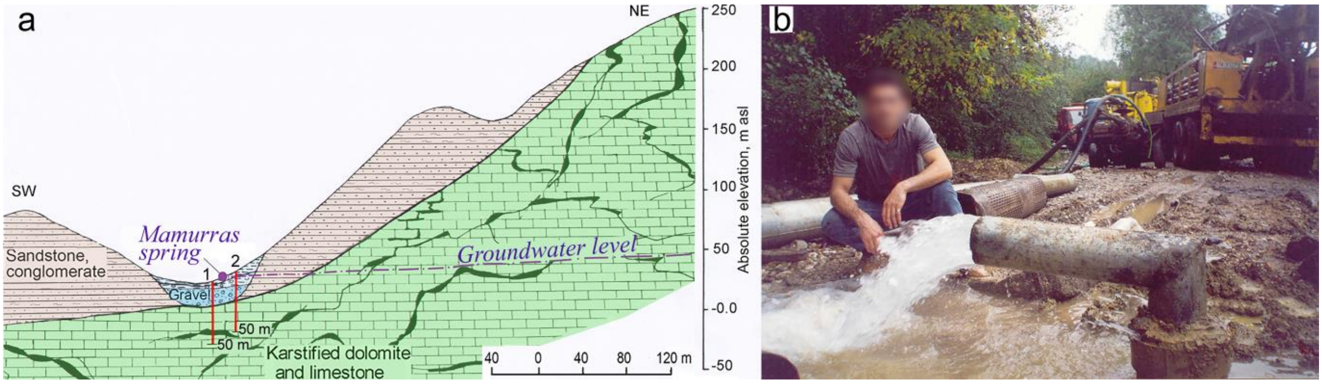

Figure 9. (**a**) Hydrogeological cross–section through two drilling wells used for Mamurras water supply; (**b**) drilling well no. 1, free flowing capacity of about 50 L/s.

3.4. Water Supply Wells in Fissured Rocks

There are two main fissured aquifers in Albania, one related to magmatic and the second to sandstone–conglomerate rocks (Figure 2a). The magmatic rocks crop out in inner Albania and occupy about 4200 km^2. They are mainly ultrabasic rocks, such as serpentine rocks, and less basic rocks such as gabbro. Generally, their water resources are related to two fissure zones distinguishable in the magmatic rocks [85]. The first zone develops close to the surface (down to about 30–40 m) and is represented by weathering joints, and the second is represented by faults. The groundwater of the first zone recharges small springs, usually discharging less than 1 L/s. The second zone, associated with faults, typically extends to a considerable depth of a hundred meters, or even more, containing usually pressurized (artesian) water. The drilling wells have a great diversity in output, reflecting the importance of the distribution of fracture systems and their frequency [28]. The free-flowing wells, tapping deep fault zones in intrusive rocks and placed at the low-elevation valley bottoms, vary from 1 to about 8 L/s. As for the ascending springs, related to well–developed fault zones, the maximum discharges vary from about 10 to 30 L/s.

Among the Albanian cities, only two small ones, Puka and Fushe-Arrza, are supplied with water from springs of magmatic rocks, their discharges varying in the range of 15–20 L/s. Since relatively larger springs issuing from magmatic rocks are missing, the increase in their water supply capacity still represents an unresolved problem. The encouraging results of the water wells drilled in magmatic rocks, mainly to investigate the mining hydrogeology of Albania [28,85], must serve as a support for intensifying the drilling of water supply wells for small cities located at such rocks.

The second fissured aquifer is of the sandstone–conglomerate (molasses) rocks, outcropping at about 4000 km^2 and consisting of intercalation of Neogene sandstone and clayey rocks; it has low permeability or is practically without water (Figure 2). The average transmissivity values and specific capacity of water wells are, respectively, about 3 to 15 m^2/day and about 0.03 to 0.2 L/s/m. The small groundwater resources of this aquifer are used only for family water supply. The Pliocene molasses deposits, represented by sandstone–conglomerate deposits known by the local name the Rrogozhina Formation, cover an area of 2300 km^2 and are located in the Near-Adriatic Plain. The average values of transmissivity and specific capacity have, respectively, values of about 80 m^2/day and about 0.4 L/s/m, while the maximum capacities of the wells are about 10 L/s [86]. The small cities of Kavaja and Roskovec, in Central Albania, are supplied from the Rrogozhina Formation aquifer with quantities of about 20 to 40 L/s. As the groundwater of this aquifer is usually hard, and the concentration of the iron often exceeds the drinking water limit of 0.3 mg/L, the use of this aquifer is constantly being reduced.

3.5. Water Supply from Two or More Different Water Supply Sources, Including Surface Waters

In Albania, only two cities, Tirana, the capital, and Gjirokaster, in Southern Albania, have mixed water supply systems consisting of two or more different water sources.

Tirana City. The water supply system of Tirana City consists of: (a) three karst springs; (b) four wellfields in intergranular aquifers; and (c) surface water of a reservoir (Figure 10).

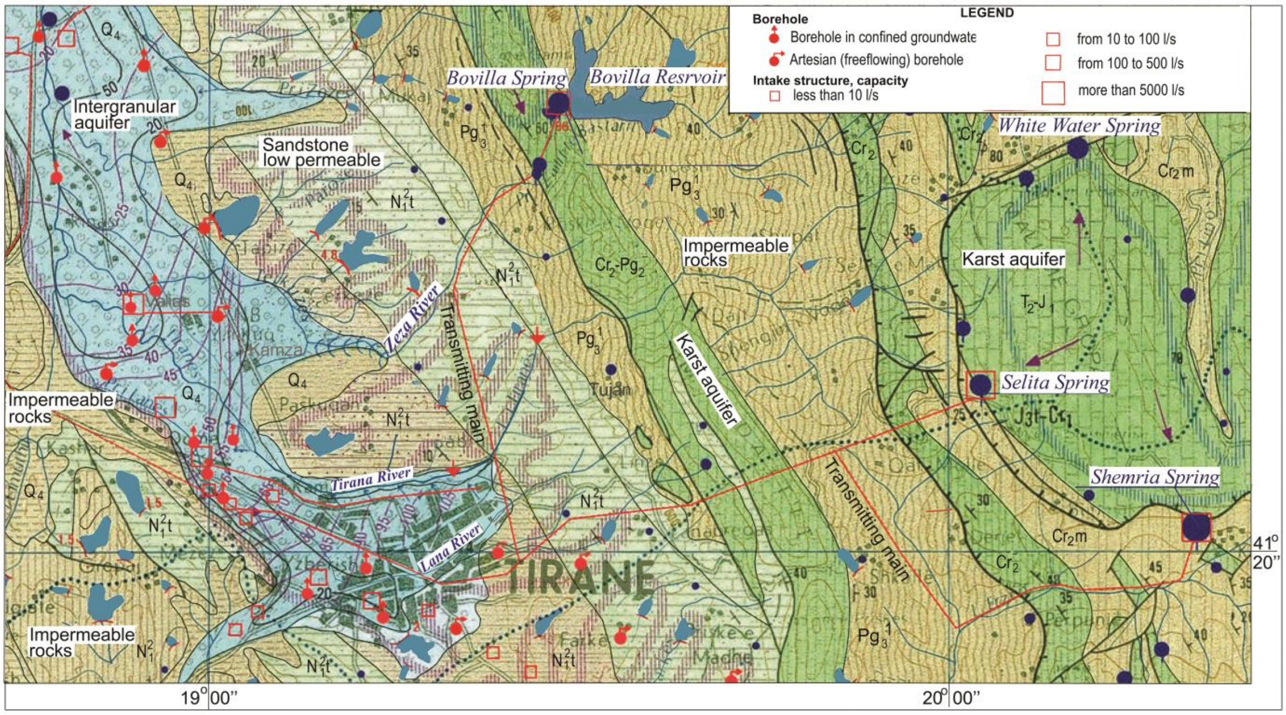

Figure 10. Hydrogeological map of Tirana area sc. 1:200,000 (modified from [4]).

The increase in water supply capacity for Tirana is related to the development of the city. The first centralized water supply system (capacity of 30 L/s) was constructed in 1940 and used the water of the Tirana River. In Tables 2 and 3 are summarized the main data of the karst springs and of water supply systems constructed after 1951 for Tirana water supply, also shown in Figure 10.

Table 2. Minimum, mean and maximum discharges of karst springs Selita, Shën Meria and Bovilla.

Spring	Qmin—L/s	Qmax—L/s	Qmean—L/s	Qmax/Qmin
Selita	230	1200	507	5.2
Shën Meria	613	>3000	894	>5.0
Bovilla	140	640	381	4.6
Total	983	>4840	1782	

Table 3. Average annual water quantity used for Tirana water supply.

Type of Water Resource	Water Supply System	Average Capacity of the Water Supply System, L/s
Karst springs	Selita Spring	439
	Shën Meria Spring	500
	Bovilla spring	381
Wellfields in the gravelly aquifer	Laknas, Berxull, Tirana	445
Surface	Bovilla Reservoir	2000–2500
Total		3765–4265

To balance the reduction in the spring's discharges during the summer–autumn season, as well as to face the necessity of additional water quantities during 1975–1990, some pumping wells, located in the Tirana plain, are included in the Tirana water supply system (Figure 10). The overall discharge of the pumped wells is about 300 L/s, a quantity that cannot satisfy but enables the water needs of the city. To face the needs of the high population increase in Tirana after the political changes of 1990, a large water supply system fed by the Bovilla Reservoir was constructed (Figure 10). Before the distribution, the water of the reservoir is treated physically and bacteriologically in a plant, initially constructed for the capacity 600–700 L/s and at present increased to about 2000 L/s.

Table 3 shows that the total water supply capacity of Tirana is equal to 4265 L/s. Unfortunately, performance of the water supply systems is deteriorated; the difference between System Input Volume and Billed Authorized Consumption, representing the water losses, is about 65%. In practice, the billed water quantity of Tirana is only 1493 L/s. Similarly to that of Tirana, the "water losses" in other urban water supply systems of Albania consist of about the same percentages.

Although different as regards the chemical composition, the quality of Tirana water sources respects the drinking water standard limit [21]. As concerns the bacteriological composition, there are constant problems, mostly with the groundwater pumped in the intergranular gravel aquifer of the Tirana plain. Generally, in these wellfields, the recommended groundwater protection measures are not respected; many buildings are constructed, even within the strong sanitary protection zone of the shallow pumped wells. Generally speaking, the rivers Lana and Tirana, representing the main recharge sources for the intergranular aquifer of Tirana, collect all the untreated sewages of the city and are heavily polluted [21]. Further, the water of Bovilla Reservoir is under constant threat of pollution by untreated sewerage of the rural centers (villages) situated in the lake watershed.

Gjirokaster city. Gjirokaster is the second city in Albania with a combined water supply system. Traditionally, the city was supplied with water from the "steras" (cisterns), situated in the cellars of the houses, where the rain water was collected, similarly to in other countries in the Mediterranean Basin [87–89]. The first centralized water supply system of the city was constructed in 1939, when the Tranoshisht karst spring water was diverted by gravity. The used capacity of this spring varied by about 15–40 L/s and soon was completely insufficient for the normal water supply of the city, particularly during the summer season. To compensate the summer water demands, during 1970, the water supply system of Hosi karst spring was built, with used capacity of about 40–60 L/s. However, the water quantity soon become problematic again, particularly during the summer. To compensate the needed water quantity demand, during 1985–1990, two big-diameter wells were drilled in the Drinos River valley, where 100 L/s is pumped from the intergranular aquifer filling the valley. As the hydraulic connection of the gravel aquifer with the Drinos River is very intensive and the distance from the recharging river to the pumped wells is only about 120 m, the contamination of the groundwater by the eventually polluted river water is a constant problem.

4. Discussion and Conclusions

Albania is a country rich in groundwater. The calculated renewable resources produce about 288 m^3/s, while the total exploitable resources produce about 140 m^3/s [28]. Groundwater in general is more desirable than the surface water as a water supply source for the following main reasons: (1) it is commonly free of pathogenic organisms; (2) temperature, color and chemical composition are nearly constant; (3) groundwater supplies are not seriously affected by short droughts; (4) the radiochemical and biological contamination of most groundwater is difficult [90]. Actually, the groundwater resources used for the water supply are estimated to produce about 14 m^3/s, consisting of only 10% of exploitable groundwater resources of Albania. Total capacity of the centralized water supply after 1944 was 160 L/s, of which about 63% was from karst springs and 37% from surface (river) water. In 2010, the total capacity of the centralized water supply systems was about 14 m^3/s and served about 2.65 million people. According to the type of water sources, the population is supplied as follows: 54% from intergranular aquifers using water wells, 37% from karst water, and about 13% of the population is served by surface water. It seems the proportion of surface water use to total water use should rise significantly.

This work demonstrates that the water supply of the cities, or of the settlements in general, depends mainly on the type of the aquifer. There are two more important aquifers widely used for the water supply of Albania's settlements: the intergranular gravel–sandy aquifers and the limestone–dolomite karst aquifers.

The main problem related to the intergranular gravel–sandy aquifers is the location of the pumping wells. Locating them near the recharge areas ensures the sustainability of the groundwater flow [6,8–10,91]. However, this increases the hydraulic gradient of the groundwater flow, as well as the groundwater flow velocity, and, consequently, shortens the transit time of the groundwater flow from the recharge area (mainly the rivers) to the pumped wells. A similar situation is undesirable in terms of the quality of the pumped water, particularly when the transit time from the river to the pumping wells becomes shorter than 50 days, which is the necessary length of time for viruses to completely disappear. This is the reason why some legislations, such as in Germany, use 50 days of water travel time to determine the limit of the groundwater protection zone [92]. Therefore, this principle is not applied when dimensioning the groundwater protection zones in Albania. The common main pollutants of groundwater are the untreated domestic waste water and industrial waste water and the uncontrolled use of pesticides in agriculture [32,48], which, in Albania, are usually discharged directly into the rivers.

Gravel abstraction from the riverbeds for construction purposes is another important pollution source, with pollution coming from the hydrocarbons or fuels used by the operating machines. In addition to this, a negative impact of the riverbed quarrying is also the groundwater level lowering as a result of the thickness reduction in the gravel deposits in the recharge area. This is transmitted also in the decrease in the hydraulic pressure of freshwater flow in seaside areas, facilitating the seawater intrusion [16,49]. As explained above, this is one of the concerns arising from the intensification of the groundwater pumping in the Fushe Kuqe intergranular aquifer.

Although often problematic, karst aquifers represent the main source of potable water supply in many countries [25,27]. There are two important problems when karst aquifers are used as a water supply source: (a) the significant decrease in spring flow during the recession period, (b) easy contamination of karst aquifers by urbanized areas, agricultural activity and quarrying [36,37,39,51]. In addition, the fragility of the karst environment, and diffuse problems and degradation deriving from anthropogenic activities in the Albanian karst, has to be taken into account too [15,38].

One of the most important aspects of groundwater protection, in general, is the determination of the three groundwater protection zones, as foreseen in the Water Law of Albania, in accordance with the National Standard of the Potable Water [93]. Regarding the actual situation in Albania, it can be said that: (a) most of water supply sources are determined without performing the necessary detailed special hydrogeological investigations; (b) the recommended measures for different protection zones in many cases are not respected; (c) dimensioning of the groundwater protection zones does not take into consideration the fifty-days transit time principle, and often it is made arbitrary or empirically.

For sustainable water resources management in Albania, a reasonable equilibrium between groundwater intensive exploitation and its protection from depletion and pollution should be realized. This could be achieved mandatorily by intensive monitoring and control of aquifer and water conservation measures. The existing monitoring network in Albania is quite incomplete as concerns the number of observation points and the observed parameters.

To face the situation of municipality water supply in Albania, it appears necessary to urgently undertake the following measures: intensification of basin-wide hydrogeological investigations; establishment of a wide groundwater monitoring network including hydrodynamic, hydrochemical and environmental isotopes; construction of detailed GIS hydrogeological maps at scale 1:25,000–1:50,000 and related mathematical models of the aquifers; compilation of the aquifer vulnerability maps; and establishment and respect of groundwater protection zones for each water supply source based on special hydrogeological investigation. Particularly, aimed at facing the problems dealing with transboundary aquifers, as a first step, there is the creation of active joint consultative bodies between transboundary countries for collecting, harmonizing and interchanging all available monitoring and geological–hydrogeological data. The sustainable water supply of settlements is linked with efficient governmental laws, with public education encouraging the maintenance of water supply systems and with a serious increase in the public interest in these problems, building up an environmental awareness in urban and rural areas.

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