Hydrogeological characteristics of Albania

Romeo Eftimi

Abstract: This paper provides a comprehensive description of the hydrogeology of Albania based on the hydraulic type of the rocks. They result in porous aquifers, karstic and fissured aquifers, porous and fissured rocks with low productivity or rocks practically without groundwater.

The porous aquifers are associated to gravelly deposits filling some plains of the Adriatic Basin, river valleys, as well as some intermountain lowlands. For these aquifers the description includes their geometry, filtration parameters, well capacity, water quality, regimen and groundwater use. The water supply of Albania's largest cities is totally based on groundwater wells in porous aquifers.

Karst aquifers crop out over an area of about 6,500 km^2. There are roughly 110 karst springs with average discharges exceeding 100 l/s. Of these, 17 have discharges exceeding 1,000 l/s. The average yearly discharge of the Blue Eye Spring, the biggest karst spring in Albania, is about 18.4 m^3/s. The paper summarises the main characteristics of karst aquifers like the karst morphology, surface and underground network, effective infiltration, karst water quality, filtration parameters, application of trace methods of investigation, and vulnerability of karst water.

Very important for the local water supply are the aquifers associated to some major basins filled with sedimentary molasses of different lithology, as well as the magmatic intrusive rocks. On both types of rocks the statistical treatment of short-term tests are used for characterising the aquifer filtration parameters and the capacity of wells.

Shortly are described in the paper also the thermomineral waters of Albania and are assessed the total natural groundwater resources of the country separately calculated for the main aquifers. During the past decade, tourist expansion and population density have been particularly evident in Albania, and the problem of water availability has become the main obstacle to further development.

Keywords: Albania, regional hydrogeology, gravelly aquifers, karst water, fractured rocks, groundwater resources

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Riassunto: L'Albania è situata nella parte orientale della Penisola Balcanica sulla costa est del mare Adriatico e Ionico. La superficie totale dell'Albania è 28.748 km^2 e la popolazione conta 3.2 milioni di abitanti. Questo lavoro dà una descrizione comprensiva della idrogeologia dell'Albania basata sulle caratteristiche idrauliche delle rocce. Queste si riscontrano negli acquiferi porosi, in quelli carsici e fessurati, nelle rocce porose e fessurate con una bassa produttività o in rocce praticamente prive di acque sotterranee. Gli acquiferi porosi sono associati ai depositi ghiaiosi che riempiono alcune pianure del Bacino Adriatico, le valli dei fiumi così come alcune pianure intermontane; Il loro spessore massimo arriva a circa 300 m. Per questi acquiferi la loro caratteristica comprende la loro geometria, i parametri di infiltrazione, la potenzialità del pozzo, la qualità delle acque, il regime e l'uso delle acque sotterranee. Valori di trasmissività di oltre i 2000 m^2/giorno riguardano ampie aree di acquiferi ghiaiosi e sono frequenti potenzialità dei pozzi di oltre 50 l/s. La chimica delle acque sotterranee indica con accuratezza le condizioni idrodinamiche generali dell'acquifero ghiaioso. In alcuni di essi è ampiamente sviluppato anche il fenomeno del "naturale addolcimento delle acque sotterranee". L'approvvigionamento idrico delle maggiori città dell'Albania è totalmente basato su pozzi di falde di acquiferi porosi. Gli acquiferi carsici affiorano su un area di circa 6.500 km^2. Ci sono approssimativamente 110 sorgenti carsiche con una portata media che supera i 100 l/s. Di queste, 17 hanno una portata che supera i 1000 l/s. La portata media annua della Sorgente Blue Eye, la più importatnte sorgente carsica albanese, è circa 1,8 m^3/s. L'articolo passa in rassegna le principali caratteristiche degli acquiferi carsici come la morfologia carsica, la rete superficiale e sotterranea, l'infiltrazione efficace, la qualità delle acque carsiche, i parametri di filtrazione, l'applicazione dei metodi di indagine con i traccianti, e la vulnerabilità delle acque carsiche. Le aree carsiche dell'Albania coincidono con le montagne più alte e la loro morfologia e particolarmente bella. La rete carsica viene controllata essenzialmente dalla realazione tra le aree di ricarica e quelle di deflusso e si sviluppano perfino perpendicolarmente ai piani di stratificazione. L'articolo mette in evidenza l'efficacia dell'applicazione degli isotopi ambientali e dei metodi idrochimici con lo scopo di capire meglio i pattner relativi alla circolazione dell'acqua carsica come "pirateria di sottosuolo" o la valutazione delle fonti di ricarica. Molto indicative per la caratterizzazione della chimica delle sorgenti carsiche risulta il grafico di rCa/rMg rispetto a quello di rCa+rMg, così come il grafico di Sic e Sid. Molto importanti per la fornitura locale di acqua sono gli acquiferi associati ad alcuni dei maggiori bacini riempiti da molasse sedimentarie di differenti litologie così come di rocce magmatiche intrusive. In entrambi i tipi di roccia i trattamenti statistici di tests a breve termine sono usati per la caratterizzazione dei parametri di filtrazione degli acquiferi e la potenzialità dei pozzi.
Vengono descritte brevemente anche le acque termominerali dell'Albania e sono valutate le risorse naturali complessive delle acque sotterranee del paese. Durante i dieci anni passati, l'espansione turistica e la densità della popolazione è diventata particolarmente evidente in Albania, e il problema della disponibilità delle acque è diventato il principale ostacolo ad un futuro sviluppo.

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Introduction

Albania is situated in the western part of the Balkan Peninsula, on the eastern coast of the Adriatic and Ionian Seas. The total surface of Albania is 28,748 km² and the population numbers 3.2 million. One of the most important natural resources in the country is groundwater.

This paper provides a comprehensive and relatively detailed description of the hydrogeology of Albania and incorporates much of the hydrogeological work carried out by the Hydrogeological Service of Albania and others throughout the country. The most intensive hydrogeological surveys in Albania were performed during the period 1960-1990, consisting in drilling thousands of test boreholes and water supply wells, which are mostly rotary-drilled small diameter wells usually to a maximum depth of about 300 m. Particularly valuable for the description of the hydrogeology of the alluvial basins of Albania are the results of the cable tool method, including pumping tests and water chemical analyses. Of importance is also the hydrogeological survey of Albania, which is a relatively thorough inventory of the springs. The above investigations have generally defined the different hydrogeological units, their geometry, groundwater resources and quality. Most of the data on the drilling wells and registered springs are listed in several hydrogeological reports which are kept in the Archives Office of the Albanian Geological Service. Based on the copious data the first hydrogeological map of Albania was published in 1985 at a scale of 1:200,000 (Eftimi et al. 1986). Since 1990 in Albania a large number of boreholes have been drilled by private companies, though regrettably retaining few records on the work performed.

Generally speaking, although Albania has abundant groundwater resources, the regional hydrogeological picture is very heterogeneous. The groundwater is related to rocks of different genesis and litho-stratigraphy forming very different aquifers in hydraulic terms; the complex geological-structural and geomorphologic conditions of Albania have resulted in aquifer heterogeneity concerning their resource, hydrodynamics and hydro-chemical characteristics. Due to uneven distribution of groundwater throughout the country, extensive seasonal fluctuation, limited public awareness and controlled management, the local population is affected periodically by water shortages.

Physiogeography and climate

Albania is situated in the western part of the Balkan Peninsula, on the eastern coast of the Adriatic and Ionian Seas (Fig. 1). The country is mainly mountainous with the mean elevation 764 m above sea level (asl); many peaks higher than 2000 m a.s.l. are situated in the northern, eastern and southern parts of Albania. The highest is Mt. Korab, reaching an elevation of 2,751 m. In the central western part of the country, along the Adriatic coast, is the Adriatic Depression composed of hills and plains with elevations below 200 m a.s.l.

Albania belongs to the Mediterranean climatic belt, which is characterised by hot dry summers and mild rainy winters (Inst. Hydromet. 1975). The moderating influence of the sea is encountered only in the western part of the country, and through valleys it penetrates well inland. Annual mean air temperatures in the coastal regions vary from 15 to 16°C, and about 10°C in mountainous areas.

Annual mean precipitation in Albania amounts to about 1450 mm, with more than 3,000 mm in the North Albanian Alps, and about 650-700 mm in the Eastern depressions of Korçe and Kolonje. The range of annual evapotranspiration is very wide; the maximum evaporation of about 700-750 mm/year is measured in the central Adriatic Depression and the Ionian coastal area, while values of about 300-400 mm/year are characteristic for the high mountains in north and north-east Albania.

The hydrographic basin of Albania with a total area of 43,305 km^2 is about 50% bigger than the state country territory; for this reason Albania has abundant water resources (Inst. Hydromet. 1984). Overall renewable resources amount to 41.7x109 m^3 or 13,300 m^3 per capita, of which 65% is generated within Albania and the remaining 35% from upstream countries (Inst. Hydrom. 1978). The chief rivers in Albania, namely the Drin, Mat, Shkumbin, Seman and Vjose, drain towards the Adriatic Sea. The southern rocky coasts of Albania drain directly to the Ionian Sea mainly as springs. The biggest lakes, namely Prespa, Ohrid and Shkodra, are transboundary and of tectonic origin; all of them belong to the Drin river system. In Albania, there are numerous lakes of different origin; many small lakes situated at high elevations originate in Quaternary glacial activity, or have karstic origin. Three high dams with large artificial lakes, all in the Drin river system, and about 620 smaller reservoirs totalling 5.60x109 m^3 of storage capacity have been built for flood protection, irrigation and production of hydroelectric power.

Geological settings

From a geological standpoint, Albania belongs to the southern branch of the Alpine orogenic system (Fig. 1). The Shkodra-Peje transversal fault divides the Dinarides from the Hellenides. Albanian geologists refer to the geological structure constituting Albania as Albanides. The Northern Albanides extend into the former Yugoslavia with Dinarides and the Southern Albanides continue southwards to Greece with the Hellenides (Meçe et al. 2002, Xhomo et al. 2003). The inland tectonic zones include the Korab Zone (Pelagonian) and Mirdita Zone (Subpelagonian), Albanian Alps Zone (High Karst Zone), Vermosh (Bosnian Zone) and Gash Zone (Durmitor Zone). The external tectonic zones include the Sazan and Ionian Zones (Paksos and Ionian), Kruja Zone (Gavrovo) and Krasta Zone (Pindos). Generally, the tectonic zones successively overthrust each other towards the west.

Though geographically small, Albania has a variety of geological formations of different periods. Among these are rocks ranging from Ordovician to Quaternary in age; they comprise sedimentary, and magmatic types together with rather less frequent metamorphic. The carbonate sedimentary rocks ranging from Devonian to Burdi-

Fig. 1: *The phreatic aquifer of Oued Guéniche*

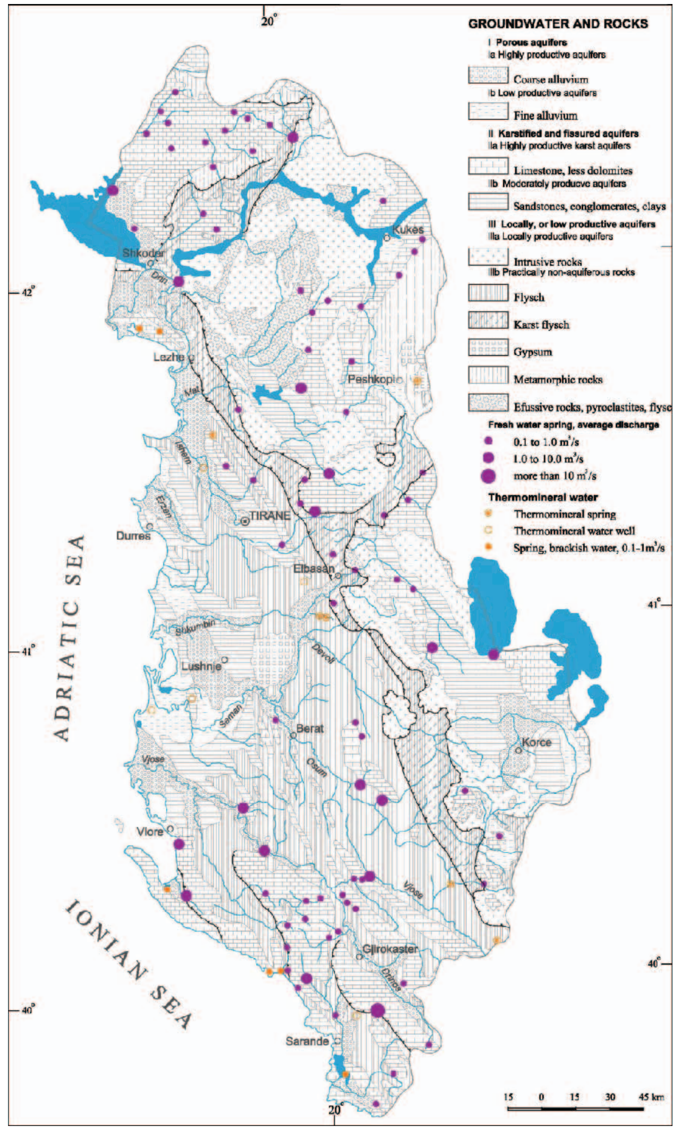

Fig. 2 *Simplified hydrogeological map of Albania*

galian in age constitute many large and small anticline and syncline structures found throughout tectonic zones. The Oligocene to Pliocene molasses sediments mainly consisting of heterogeneously intercalated sandstone, conglomerate, siltstone, claystone and clay layers mainly fill the Adriatic depression as well as some inland depressions like the Albanian-Thessaly which is the largest. Pleistocene-Holocene gravelly clayey deposits are the most widely distributed geological unit in the Adriatic Basin, as well as in some inland mountain plains and river valleys. Magmatic rocks are extensively developed mainly in inland tectonic zones. Most developed is the Jurassic ophiolitic magmatism of Mirdita (Subpelagonian) zone, which consists mostly of intrusive and less of volcanic rocks.

Groundwater and rocks

The basic element responsible for the water-bearing capacity of the rocks is their hydraulic type: this may result in porous aquifers, karstic and fissured aquifers, porous and fissured rocks with low productivity or rocks practically without groundwater (Fig. 2).

Porous rocks

Porous rocks are related mainly to the Quaternary deposits, and according to their productivity are divisible into high and low productive aquifers.

Highly productive porous aquifers. These aquifers are associated to gravelly deposits filling some plains of the Adriatic Basin, river valleys, as well as some intermountain lowlands. High-energy rivers like the Mat, Vjosa, Dukat and Bistrica have created larger deltas filled with thick heterogeneous coarse deposits. Other rivers like the Buna, Shkumbin, Seman and Pavlla have deposited only fine materials in the coastal area after depositing the coarse materials inland. In the biggest delta, that of the Mat River, the maximal thickness of the gravelly alluvial deposits is about 270 m. In the Korça intermountain plain the gravelly deposits are of lake and alluvial genesis and the maximal thickness is more than 300 m.

Detailed interpretation of many borehole logs reveals the great variation in thickness of alluvial deposits and their hydraulic characteristics. In the Shkoder, Elbasan and Drino basins they mostly form a single thick unconfined aquifer, while in the Lushnje, Berat and Vjose basins they form a single confined aquifer. There are also multilayered confined aquifers, as in the plains of Lezha, Fushe Kuqe, Korça and Vurgu whose maximal gravelly aquifer thickness varies from 100 to 150 m. As regards the hydraulic properties of the aquifer and the well capacities, the results largely differ according to the well-drilling method applied. The capacity of the percussion-drilled wells and the calculated aquifer characteristics are usually five to ten times higher than those obtained from small diameter rotary wells (Eftimi 1982a, 2006). The hydraulic parameters of the most important gravelly aquifers of Albania have high values and hence the specific capacity and total capacity of wells are also large (Tab. 1). The maps of hydraulic parameters for the main gravelly basins of Albania (R. Eftimi 1983a) show that the areas with higher hydraulic parameter values usually overlap those of deeper valley bottoms. Fig. 3 shows the map of transmissivity of the Vjose alluvial basin.

Due to the coarseness of the material and the excellent hydraulic connection of the aquifers with the rivers, the gravelly deposits can produce large amounts of groundwater. In Albania the limits of pumpage from a groundwater basin were long identified with natural groundwater flow, which was considered a so-called safe yield. While the limitation of groundwater pumpage to the safe yield diminishes the exploitation capacity of the aquifer, going beyond the safe yield may lead to some negative consequences like the drying-up of streams, springs and wetlands (Sakiyan et al. 2004). So, the concept of safe yield is not in fact safe for the aquifer development (Sophocleus 2000).

The experience of aquifer development in Albania has shown that groundwater pumpage in most gravelly basins could be appreciably increased without severe consequences with pumping wells located near the recharge areas (rivers). Pumpage capacity could be increased by induced recharge and by removal of water from storage (Theis 1941, Rorabaugh 1956, Bochever 1968, Noris et al. 1969, Walton 1970, Eftimi 1982b). In contrast, in the alluvial basins with restricted recharge capacity, like the Korçe intermountain basin, intensification of groundwater pumpage in the last three decades has resulted in persistent groundwater decline by about 20 m.

The chemistry of the water is controlled mainly by the quality of recharging water (usually that of nearby rivers), by aquifer rock types, ion-exchange and mixing with saline water. As a rule, groundwater quality near the recharge area is good, as the water has a low mineral content (the total dissolved solids is usually less than 500 mg/l), and

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Table 1: *Summarized hydraulic parameters of the main gravelly aquifers in Albania*

M-maximal thickness; K-permeability, T-Transmissivity, S-storage coefficient, q-specific capacity of wells, Q-total capacity of wells.

Gravelly basin	M	K	T	S	q	Q
	m	m/day	m^2/day	fraction	l/s/day	l/s
Shkoder	60	100 – 800	2,000 – 15,000	0.18 - 0.24	10 – 80	10 – 150
Zadrime	50	20 – 200	300 – 10,000	-	5 – 70	5 – 120
Mat (Lezhe - Fushe Kuqe)	150	90 – 260	2,000 – 10,000	$1x10^{-3}$	5 – >50	5 – 150
Tirana - Adriatic	25	20 – 300	200 – 3,000	$1.5\text{-}4..5x10^{-4}$	2 – 30	5 – 60
Erzen	15	10 – 50	100 – 700	-	2 – 10	2 – 10
Elbasan	100	100 – 750	2,000 – 8,000	0.17 - 0.25	20 – 100	10 - 200
Lushnje	25	20 – 250	250 – 4,000	$3x10^{-4}$	5 – 30	5 - 100
Berat	70	10 – 400	200 – 4,500	-	3 – 40	10 -100
Vjose	30	50 – 500	2000 – 9,000	-	5 – >100	5 - 150
Dukat	> 100	50-350	1000 – 5,000	0.20-0.22	10 - 45	5 - 100
Korçe	50*	5 – 70	100 – 2,100	$4\text{-}7x10^{-4}$	2 – 20	5 - 150
Gjirokaster	50	50 – 600	20 – 15,000	0.15-0.25	2 – 130	10 - 150
Vurg and Murasia	100	10 – 300	300 – 3000	-	1 – 50	1 – 70

the water is soft to averagely hard, mainly of the HCO_3-Ca or HCO_3-Mg type.

Natural softening of the groundwater (Hem 1985, Appelo et al. 1999) due to the precipitation of carbonates and ion exchanges is observed in some gravelly aquifers of the Adriatic Depression. The phenomenon seems to be related mostly to ion-exchange reactions; fresh water entering the aquifer makes contact with the clayey layer saturated with adsorbed sodium ions during the last Holocene sea intrusion. Natural softening is particularly developed in the alluvial basins of the Vjose (Mitro 1966), Mat (Eftimi 1966), Lushnje (Eftimi 1975) and Berat (Tartari 1982). In the Lezha plain (the northern part of the Mat basin) the total hardness of the water recharged by the Mat River is about 8-10 meq/l, decreasing to about 1-2 meq/l at the distance of about 8 km (Fig. 4).

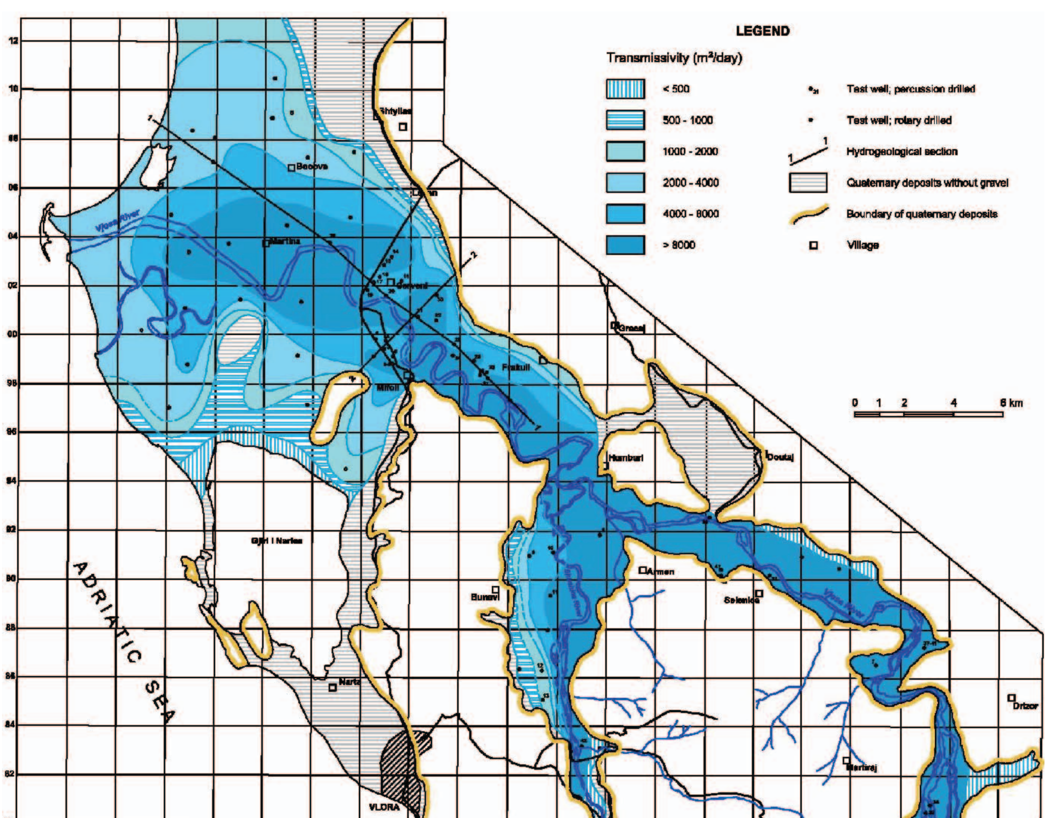

Fig. 3: *Transmissivity map of the Vjose gravelly basin, southwest Albania*

In peripheral areas the coastal gravelly basins still contain some remnant saline water since they were deposited in a marine dominant environment during the last Holocene transgression maximum (Custodio 2010). Using the molar Na/Cl ratio for assessing the origins of groundwater salinity (Kimblin 1995, Appelo et al. 1999, Edmunds et al. 2002) it was found that extensive areas of the gravelly coastal aquifers of Albania are affected by intrusion (Eftimi 2003a).

The chemistry of groundwater is an important tool for assessing the groundwater regional hydrodynamic scheme (Back 1960, Charon 1969, Plumer at al. 2004, Glynn and Plummer 2005). This conclusion is also supported by hydrochemical maps of the alluvial basins of the Fushe Kuqe (Gjata et al. 1964, Eftimi 1966), Vjose (Mitro 1966), Shkumbin (Lako 1973), Lushnje (Eftimi 1975), Lezhe (Bisha at al. 1978) and Berat (Tartari, 1982) which accurately indicate the general hydrodynamic conditions of their respective basins.

Particularly informative is groundwater chemistry when applied together with environmental isotopes (Payne 1983, Rosenthal et al. 1990, Königer at al. 2001, Salem et al. 2004). A regional environmental isotopic ($\delta^{18}O$, $\delta^{2}H$ and $\delta^{3}H$) and hydrochemical study (conductivity and chloride) was successfully applied to highlight the regional recharge conditions of the Tirana-Mat alluvial basin (Eftimi at al. 2006a). In the northern part of the basin the Mat River is indicated as a very important recharge source, while the Droja River has less recharge capacity. In the southern part of the basin, small-capacity recharge mainly occurs from the rivers from the eastern mountain range, and from irrigation and wastewater infiltration.

The gravelly aquifers in the lowlands show a curve of falling groundwater levels throughout the summer and autumn to a minimum in October or November and then a shorter period of rapidly rising levels to a maximum in March or April. The seasonal amplitude of groundwater level fluctuation usually is about 1.5 to 3.0 m, but increases to 5 m in areas of intensive groundwater pumping. The exceptionally maximal seasonal amplitude of 25 m is registered in the Drinos River alluvial basin of southern Albania, but this is related to the drainage of the Drinos River alluvial basin through the neighbouring Mali i Gjere karst massif (Eftimi et al. 2009).

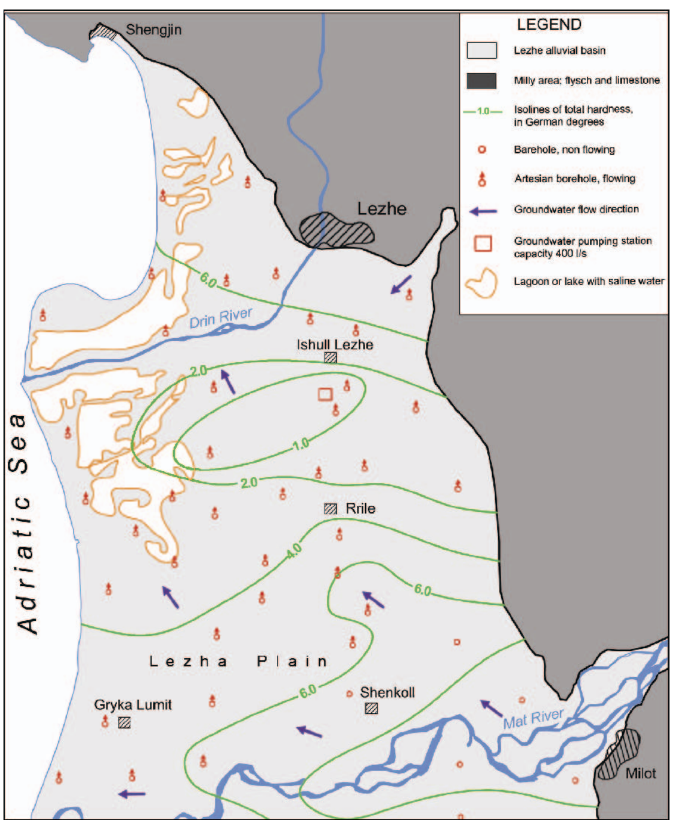

Fig. 4: *Map of groundwater total hardness of the Lezhe alluvial basin, northwest Albania*

Groundwater resources in the gravelly aquifers are intensively used for domestic and industrial water supply. The depth of the exploitable wells usually varies from about 30 m to over 100 m, and their maximal capacities vary from about 100 to more than 200 l/s. The water supply of Albania's largest cities, namely Shkoder (1000 l/s), Durres (900 l/s), Elbasan (1000 l/s), Korçe (400 l/s), Lushnje (250 l/s), Fier (750 l/s), Gjirokaster (150 l/s) and Saranda (150 l/s), is totally based on groundwater wells, while the capital Tirana is partially supplied by wells.

Due to large demographic movements in the past two decades, illegal building has occurred upflow in the immediate vicinity of the urban water supply wells, posing a serious threat to groundwater quality. This is the case, for example, with the well fields of Berxulle-Laknas in Tirana, Dobraç in Shkodra and Krasta in Elbasan.

Low productive porous aquifers are found mainly in rocks of different genesis like alluvial fan deposits, slope debris breccias and moraine deposits.

Alluvial fan deposits are mainly developed in some inland basins of Albania, such as Tropoje, Peshkopi, Pogradec, Korçe and Kolonje. Their maximal thickness varies from about 100 m to more than 250 m. They have lateral and vertical transitions to the alluvial fill deposits in the plain basins, and are hydraulically interconnected with them. The coarse alluvial fan deposits are filled with fine material, appreciably reducing their permeability. As testified by findings from dozens of groundwater wells in the Korça basin, the mean permeability of alluvial fan deposits is usually about 15 times lower than that of adjacent alluvial gravelly aquifers. The permeability of the fan deposits is usually lower than 5 m/day, and well productivity is less than 2 l/s.

The slope debris breccias are mainly developed at the foot of carbonate structures in southern Albania and moraine deposits occur mainly in North Albania. They usually have high permeability, but due to their restricted outcrop their groundwater resources are small. However, there are also large springs issuing from these deposits, discharging about 20 to about 100 l/s. This usually happens when slope debris breccias and moraine deposits serve as transit for the abundant groundwater of underlying rocks.

Fissured and karst aquifers

To this group belong (a) highly productive karst aquifers, and (b) moderately productive fissured (or fissured and porous) aquifers.

Highly productive karst aquifers crop out over an area of about 6,500 km², about ¼ of Albania's total surface area. They usually comprise mostly Mesozoic carbonate rocks such as limestones and, to a lesser extent, dolomites. There are some 25 karst massifs outcropping in the country, while over large areas of the Ionian and Kruja Zones and in the Adriatic basin, the carbonate rocks are covered by flysch and molasses deposits.

The karst rocks have a well-developed karstic morphology both on the surface and at depth. Karst phenomena are primarily developed over extensive carbonate structures of the Albanian Alps, and in the Mirdita and Ionian Zones. Wide areas of karst basins are occupied by well-developed high elevation karst plateaus; among them, very attractive is the karst plateau of the Mali me Gropa massif, extending about 40 km² and representing the recharge area for the well-known

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karst springs of Selita and Shemria used for the Tirana City water supply (Fig. 5).

The surface hydrographic network of karst zones is not well developed, or is even totally lacking. In contrast, the subsurface hydrographic network is intensively developed. Most of the karst areas of Albania have suffered an intense tectonic uplift resulting in formation of vertical conduits which discharge the infiltrated water to quasi-horizontal collecting conduits ending in large karst springs located in low-elevation outcropping points of the carbonate aquifer, as is the case of the Selita spring (Fig. 5). Karst areas of Albania coincide with high-elevation mountains with high hydraulic gradients, which are the preconditions for the conduits being developed more linearly (Bakalowicz 2005).

The karst networks in Albania clearly appear different from the fracture pattern of respective karst structures and, as Mandel (1963) and Bakalowicz (2005) have evidenced, they are organised like fluvial systems. This happens even when the direction of bedding plains is perpendicular to that of the hydraulic gradient, as is the case of the Blue Eye Spring (Fig. 6).

Environmental isotope and hydrochemical methods have been applied in some karst areas of Albania in order to better understand their water circulation patterns. In some areas "underground piracy" has been observed, a term used by Stevanovic et al. (1994) when a karst aquifer with a lower hydraulic head is recharged by another with a higher hydraulic head. With environmental isotopes it has been established that Prespa Lake recharges the Ohrid Lake through the Mali Thate karst massif (Fig. 7) and about 50% of the discharge of the common discharge of Tushemisht and St Naum springs represents the Prespa Lake water (Anovski 1991, Eftimi et al. 1996, 2007). An artificial tracer experiment carried out in 2002 physically demonstrated the underground connection between both lakes, and maximum karst underground flow velocity was about 700 to 2900 m/h (Amataj et al. 2005), which is much higher than reported velocities for other karst areas (Garašic 1997, Kogovšek et al. 1997). By a similar combined study it was established that the Poçem karst spring is replenished by the Vjosa River by about 80% (Akiti et al. 1989, Eftimi at al. 2006b). Through another environmental isotope and hydrochemical study it has been established that the Blue Eye Spring is replenished by the Drinos River gravelly aquifer (Fig. 6) by about 30 t0 35%, and the remaining quantity is replenished by the precipitation infiltrating into the Mali Gjere karst massif (Eftimi et al. 2007, 2009). Fig. 6 gives the recharge scheme of the Blue Eye spring. From both surveys, that of the Poçem Spring and the Blue Eye Spring, the sulphate ion is used as an environmental hydrochemical tracer.

Fig 5: *The karst plateau of Mali me Gropa at about 1600 m a.s.l., and Selita Spring, 981 m a.s.l*

The findings in many groundwater wells of karstic rocks testify that the filtration coefficient varies from less than 1 m/day to more than 100 m/day, and transmissibility varies from about 10 to more than 5,000 m²/day. The specific capacities of wells vary from 0.1 to over 20 l/s/m, with the maximal capacity of wells more than 70 l/s.

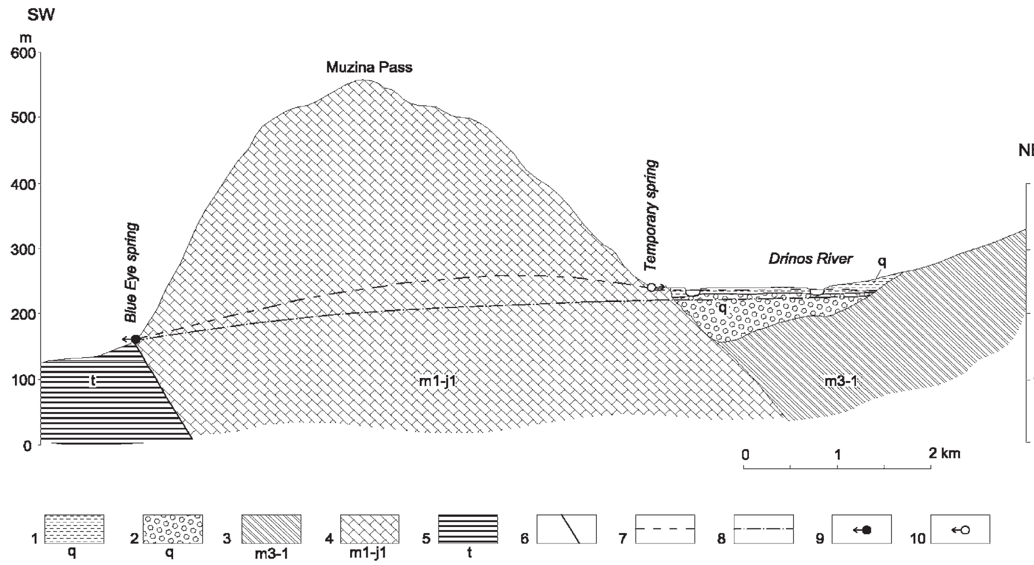
Effective infiltration, the part of precipitation recharging the karst groundwater, calculated by the Kessler method (Kessler 1967), accounts for about 40 to 55% of mean yearly precipitation. The average yearly efficient infiltration in the Albanian Alps is about 1,500 to 2,000 mm, in Mali me Gropa 1,100 mm, in Mali Thatë 450-500 mm and in Mali Gjerë about 1,175 mm.

Karst waters discharge mainly as large karst springs with greatly varying productivity. There are roughly 110 karst springs with average discharges exceeding 100 l/s. Of these, 17 have discharges exceeding 1,000 l/s. The average yearly discharge of the Blue Eye Spring, the biggest karst spring in Albania, is about 18.4 m^3/s (Fig. 3). Karst springs occur mainly at the lower outcrop of karst rocks, on the fringe of mountain massifs or in deep river gorges cutting the karst massifs. In the Ionian coast karst, where local impermeable barriers develop along the coastline, there are good quality springs like that of Uji Ftohte with an average discharge of 2.5 m^3/s. Along most of the coastline there is no impermeable barrier, and saline coastal or submarine springs occur. Estimated total karst water resources drained along the Ionian Sea by the coastal carbonate aquifers amount to about 15 to 20 m^3/s (Eftimi 2003a).

The discharge curves of karst springs show two maxima and two minima: the main maxima are in April/May in connection with snowmelt, and the second in December is in connection with rainfall. During the summer the karst spring discharges subsequently diminish (recession period), in connection with low precipitation and high evapotranspiration, and the minimum is mainly in October. The second smaller minimum of February is caused by the freezing of the ground in high elevation karst water recharge areas. Usually the recession period is characterised by two laminar flow micro regimes (Eftimi 1971).

Karst water differs significantly in physic-chemical characteristics. A study of 25 springs in four karst areas of Albania with different lithology showed a very clear relation of karst water quality to the lithology concerned (Eftimi 1998, 2005). The most indicative parameters characterizing the chemistry of karst springs are water conductivity and temperature, total hardness, r/Ca/rMg, rSO_4/rMg ionic ratios, CO_2 pressure and saturation indexes with calcite (SIc) and dolomite (SId). Of great use for the relation between water chemistry and specific lithologic units, and additionally for the identification of the recharge areas of the springs, are the graphics of rCa/rMg versus rCa+rMg (Fig. 8) combined with SO_4 content, as well as the graphic of Sic and SId (Figure 9).

It is already known that the rCa/rMg ratio in groundwater has a clear geochemical implication (Langmuir 1971, Zötl 1974, Zojer et al. 1988), or as Hem (1985) wrote "the proportion of magnesium to calcium reflects the composition of the limestone". For the investigated dolomite and limestone waters there is an indirect correlation between the rCa/rMg ratios and the sums of rCa+rMg, while the sulphate waters are "displaced" from the "correlation" curve (Fig. 8). Limestone springs have higher rCa/rMg ratios and smaller sums of rCa+rMg, and dolomite springs have the opposite values. Although most limestone springs are undersaturated with respect to calcite and dolomite, the degree of undersaturation with respect to dolomite is much greater than that with respect to calcite (Fig. 9). This is explained by the higher solution kinetics of calcite in comparison with



1 Silt; 2 Sands and gravels; 3 Flysch; 4 Limestones and siliceous rocks; 5 Clays and gypsum; 5 Clays and gypsum; 6 Major fault; 7 Maximal groundwater level; 8 Minimal groundwater level; 9 Perennial spring; 10 Temporary spring

Fig. 6: *Hydrogeological cross section through Mali Gjere karst basin and Blue Eye Spring*

dolomite (Thrailkill 1977, Appelo et al. 1999). The variation in the physical and chemical properties of the springs is used to characterize the physical behaviour of karst aquifers (Shuster et al. 1971, Jacobson et al. 1974). The Blue Eye Spring is mainly a conduit flow spring, while the Pellumbas Spring, issuing from dolomites, is a diffuse flow spring (Eftimi 1998, 2005).

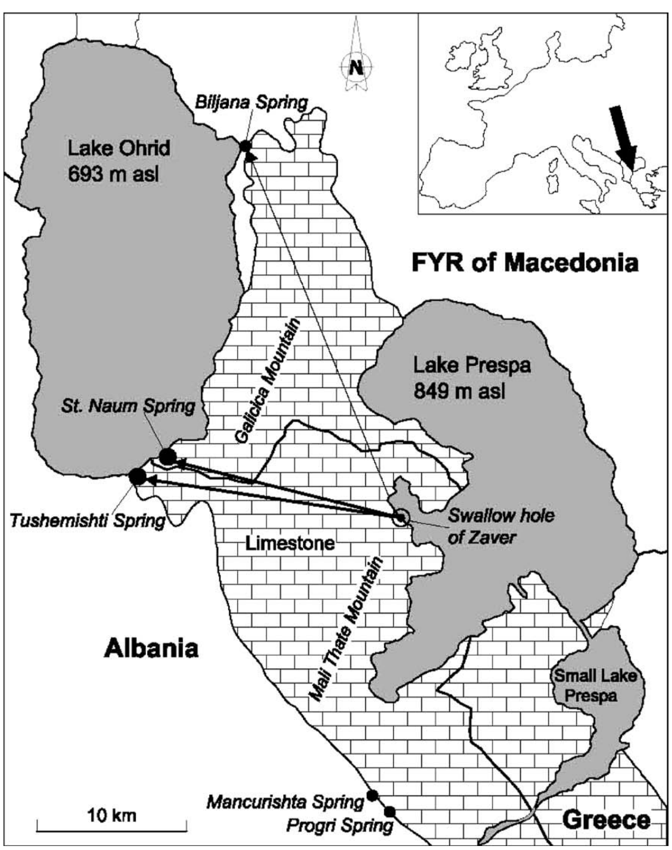


Fig. 7: *Recharge of Ohrid Lake from Prespa Lake. The black arrows show the proven underground connection.*

Along the southern Ionian carbonate rocky coast, mixing with seawater takes place and there are some large mineralized karst springs of the chlorine-sodium type; the chloride concentration varies from about 400 mg/l to about 5,000 mg/ l (Eftimi 2003a). As in many countries in South-eastern Europe, in the coastal area of Albania many underground flows towards the sea are still waiting to be identified (Stevanovic et al. 2010).

The utilization of karst water is related mainly to (a) successful results of drilling wells, and (b) the high vulnerability of the karst medium to pollution (Bakalowicz 2005). Several approaches are known for tapping karst water (Milanović 2000), but those most widely used in Albania are drilling wells and pumping from siphons or galleries. Determination of the conduit locations is certainly the main difficulty when intending to drill in karst limestone. Experience in Albania has shown that the most appropriate location for productive wells is close to springs. For example, a well 50 m deep near a karst spring with a maximal discharge of about 20 l/s has a constant discharge of more than 50 l/s and is currently used to supply the town of Mamurras. Generally speaking, location of the wells in low topographic settings, even small valleys, appreciably affects the yield of wells, as emerges from experience with village water supplies. The results of many wells testify that permeability of the carbonate rocks is higher at a depth down to 100 m b.g.s. (below ground surface); at greater depths it usually diminishes. A common experience in Albania is intensive pumping directly into the siphon of intermittent karst springs, or into karst caves crossing the karst water level. There are two well-known large pumping stations in the eastern Mali Gjere karst basin, one situated in the siphon of the Viroi spring (Fig. 10) and the other in the Goranzi karst cave. In both cases the groundwater exploitation is enabled by the large storage capacity of the karst basin.

The difficulties in protecting karst water are related not only to its high vulnerability, but also to the fact that most people are unaware of the special properties of karst aquifers. A typically regrettable example is the pollution of the Cold Water springs, average capacity 2.5 m^3/s, the biggest good quality spring issuing on the shoreline of Adriatic Sea, and used for the water supply of Vlore City. After 1992

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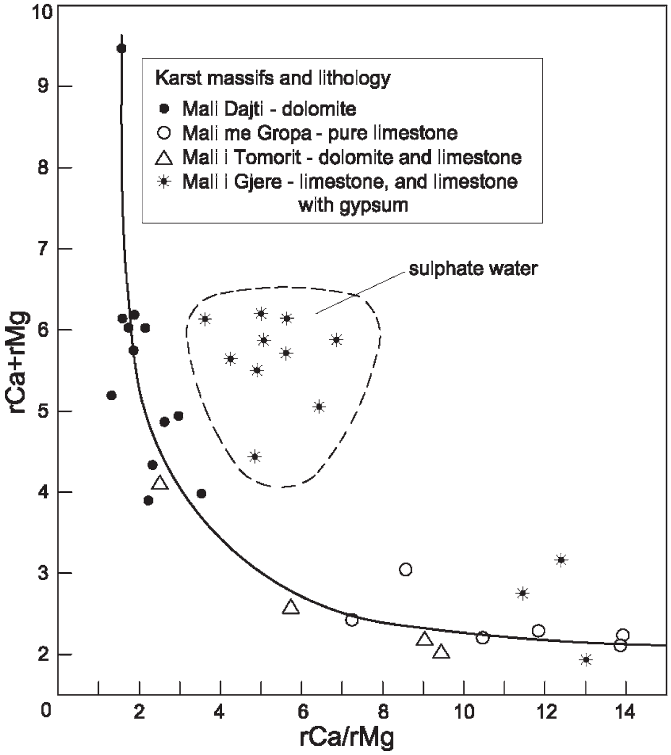

Fig. 8: *rCa/rMg versus rCa+rMg for some karst springs.*

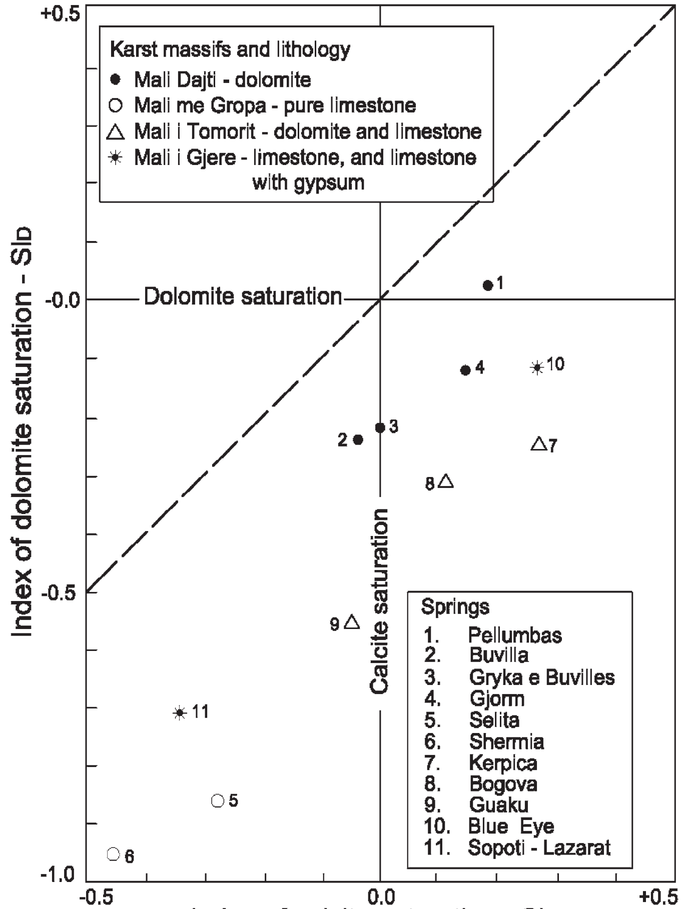

Fig. 9: *Sic versus Sid for some karst springs.*

an uncontrolled urban area developed immediately upstream of the springs. The thin terra rossa covering the upstream area only reduces its vulnerability but is not enough for definitive protection.

Moderately productive fissured (or fissured and porous) aquifers are associated to some major basins filled with sedimentary molasses of different lithology and representing a hardrock environment. The total outcrop surface of sedimentary hardrocks in Albania is about 4,000 km².

The Mati and Mokra (part of Albanian-Thessaly) basins are the most important sedimentary basins of the interior; the former is filled by Low Neogene-Tortonian sandstone deposits, while the second is filled by very different Palaeogene and Low Neogene-Akuitanian sediments. The Adriatic basin is the largest of the outer zones and consists of some chains of anticlines and synclines constituted by Neogene, Pliocene and Quaternary sediments (Meço & Aliaj 2000, Xhomo et al. 2002). The Tortonian sandstone deposits are different: the Tirana syncline consists of a lower section with thick-bedded sandstone, and an upper section with thin-bedded sandstone; in most of the Adriatic basin the sandstone deposits are well cemented and only in the Kraps area the sandstones are friable. Lithologically, the Pliocene sediments are divisible into two formations; the lower sec-

Tab. 2: *Characteristic values of T, K and q for the molasses sediments.*

Zone	Age of rocks	Rocks	Number of wells	Mean depth m	T, m²/d		K, m/d		q, l/s/m	
					50%	Average	50%	Average	50%	Average
Rrogozhina Formation Adriatic basin	Pliocene	Sandstone, conglomerate	212	211	54	80	1.52	2.74	0,42	0.61
Tirana Syncline Adriatic basin	Tortonian, Upper Section	Thin-bedded sandstones	46	226	2.5	3.1	0.067	0.09	0.025	0.03
Tirana Syncline Adriatic basin	Tortonian, Low Section	Thick-bedded sandstones	13	300	4.4	5.3	0.077	0.095	0.048	0.056
Adriatic basin	Tortonian	Sandstone	10	189	-	5.2	-	0.23	-	0.05
Kraps area Adriatic basin	Tortonian	Friable sandstone	5	298	-	30.0	-	0.48	-	0.27
Mat Depression	Tortonian	Clayey sandstone	6	176	-	4.5	-	0.15	-	0.04
Mokra Depression	Aquitaine	Conglomerate, sandstone	6	194	-	14.0	-	0.25	-	0.12

Fig. 10: *Intermittent spring of Viroi, Qmax > 50 m³/s, near Gjirokaster City in southern Albania. A pumping station of 2 m³/s capacity is situated near the siphon; the water is used for irrigation.*

tion known as the Helmesi Formation is represented mainly by clay, while the upper section known as the Rrogozhina Formation consists of conglomerate and sandstone intercalated with clay and claystone. The thickness of the conglomerate and sandstone layers usually varies within 30 to 50% of the total thickness of the Rrogozhina Formation, which covers an area of about 2.300 km².

Short-term tests of about 300 pumped wells are used to calculate transmissivity (T) and permeability (K) based on specific capacity (q) data corrected for selected well diameters and for a pumping period (Eftimi 2003b, 2003c). Most of the wells have a depth of about 200 to 300 m and have been drilled over a large span of years, from 1960 to 1995. The drilled diameters are to some extent comparable, the minimum being 110 mm and maximum 200 mm. Specific capacity data to calculate transmissivity of hardrocks are widely used (Theis et al. 1963, Csallany 1967, Walton 1970, Carlson et al. 1977). The results of the statistical treatment of data of segregated groups of wells are summarised in Tab. 2 and are represented as frequency graphs (Fig. 11 and 12). For the segregated groups with up to 10 wells, only the averages of the same parameters are estimated, excluding the values lying completely outside the range of all other wells of the same group.

Considerable variation in apparent values of the considered parameters of wells may be noted within Neogene deposits. The difference between the lowest and highest median and average values of investigated parameters is about five-fold. The maximal discharge of wells is variable: in the Mati basin it is about 1-2 l/s, in the Mokra basin it exceeds 5 l/s, in Tirana basin it is about 0.5 to 1 l/s and in the Kraps area it is about 3 l/s. The controlling factor seems to be the degree of cementation and compaction of sandstones ranging from hard and well-cemented sandstones of the Tirana syncline, to the fireable sandstone of the Kraps area. The graphs (Fig. 11) indicate that the Upper and Lower Tortonian aquifers in Tirana syncline have practically the same permeability but different transmissivity and different specific capacity of wells. It seems that the higher transmissivity of the Lower Tortonian aquifer is related to the greater thickness of sandstone layers rather than their higher fracturing or porosity.

It may be easily ascertained that the wells of the Rrogozhina formation aquifer are more productive than those found in other sedimentary hardrocks of Albania. Indeed, from detailed statistical treatment, the yield of wells in the Durres area (33 wells) is at least double the average of all wells (Eftimi 2003b, 2003c). This may be explained by the solution of carbonate cement of the conglomerate-sandstone of the Rrogozhina formation aquifer, recalling karstification processes, which is clearly observed on carrots. The widened by the solution of carbonate cement canals in conglomerate are covered by calcite deposits like the karst canals of carbonate rocks. Other major control-

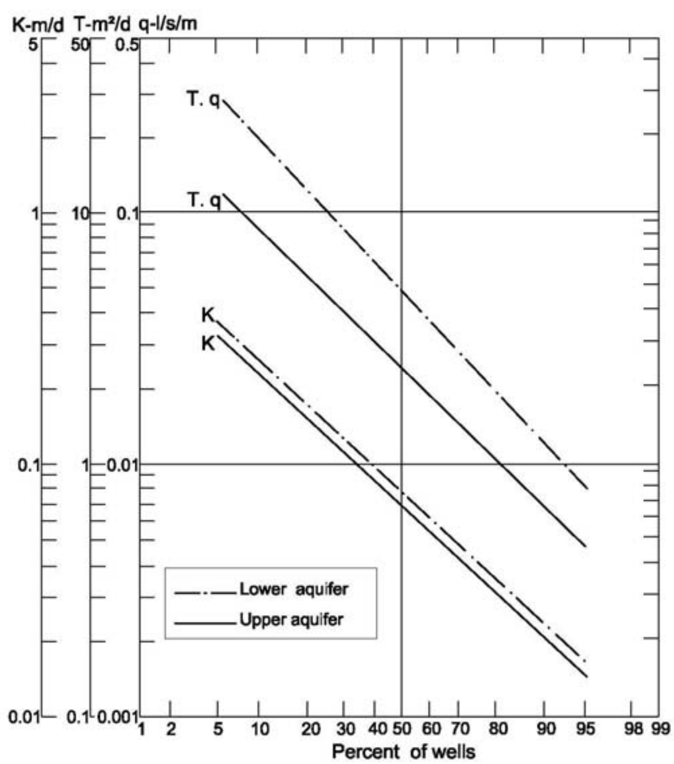

Fig. 11: *T, K and q frequency graphs of wells of Tortonian deposits, Tirana syncline.*

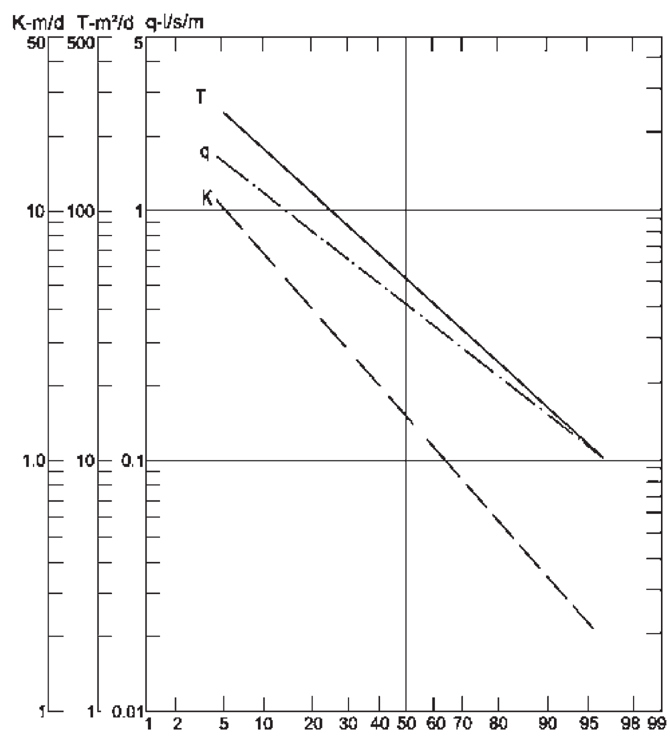

Fig.12 *T, K and q frequency graphs of wells of the Rrogozhina formations, Adriatic basin.*

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ling factors of local importance are the structural-tectonic position of wells, the topography as well as technology of drilling wells. The yields of wells along the uplifted sides of some Pliocene anticline structures, which are accompanied by vertical rupture faults, are usually 3 to 8 times smaller than those of wells on normally sloping flanks of the same structures (Eftimi 2003c). The wells located at the bottom of even small valleys have yields that may be double or triple. Hence three wells, used to supply the town of Kavaje, each located at the bottom of some small valleys, have capacities of 10 to 15 l/s. From the evidence of wells drilled in the last 15-20 years in Albania, new drilling technologies that ensure larger well diameters and applying high pressure forcing air for the development, greatly affect well yield, doubling or tripling it.

The groundwater in Neogene deposits of the Mat and Mokra basins is averagely hard, the TDS vary from 300 to 700 mg/l, and water chemical type is bicarbonate-calcium or magnesium. In the Adriatic basin the groundwater of Neogene deposits down to about 300 m b.g.s. has TDS smaller than 1 l/s. TDS subsequently increases with depth with chloride-sodium water prevailing.

The groundwater of the Rrogozhna formation aquifer is hard, with TDS varying from about 400 to 650 mg/l and with increased iron concentrations between about 0.3 and 3.0 mg/l. The Rrogozhina formation aquifer is widely used to supply water to villages and small towns like Kavaja, Rroskovec and Patos.

Local productive and non-aquiferous rocks

Local productive rocks are associated to Jurassic magmatic intrusive rocks which are found in inner Albania; the total outcropping surface is about 4,200 km². These rocks consist mainly of ultrabasic ones like dunite, harcburgite and serpentines, and of basic rocks, mainly gabbros and less of acid rocks. Hydrogeological information in most cases concerns data from mining test wells and chromium mine dewatering (Tafilaj 1963).

Two types of fracture zones are distinguishable here. The first, occurring close to the surface is represented by weathered joints, and to a lesser degree, by tectonic faults. The first zone usually contains non-captive groundwater recharging small springs with widely variable discharge. The second type, associated with faults, extends to a considerable depth and contains captive groundwater with a relatively stationary regimen. The wells indicate a great diversity in output, reflecting the importance of the distribution of fracture systems and their frequency. According to the results of 15 wells tapping deep tectonic fractures, the productivity of the ultrabasic intrusive rocks ranges from low to high (Tab. 3). The free flows of wells tapping strongly fractured intrusive rocks and placed at favourable locations (like the valley bottom) vary from 1 to 8 l/s. As for springs, when they are related to well-developed fracture and fault zones the maximal discharge is about 20 to 30 l/s.

Hydrogeological observations on numerous chromium mines in Albania testify that fracture zones with maximal width of about 70 m are observed even at depths exceeding 500 m. Open fractures act as highly permeable conduits and may have inflows up to about 50-60 l/s. The Bulqiza chromium mine at an elevation from 450 to 1,200 m drains on average about 250 l/s. At Klosi, a 6.5 km tunnel hollowed into the Bulqiza ultrabasic rock massif discharges about 300 l/s, and the pressure changes are transmitted to a surface area of about 40 km². This has caused the lowering of the ground surface of Vajkani valley to a maximum of 3.6 m, as a result of the dewatering of the clayey layer about 150 m thick filling the valley (Tafilaj et al. 2001).

Groundwater in magmatic intrusive rocks is generally fresh and of low hardness; conductivity varies from 130 to 300 µS/cm, total hardness from about 4.0 to 10.0° German and the prevailing chemical type is that of bicarbonate-magnesium.

Practically non-aquiferous rocks include a variety of deposits in terms of genesis and age. This group includes volcanic and volcanic-sedimentary rocks, metamorphic such as slate, clayey and flysch sedimentary rocks, as well as gypsum with a low permeable silty clay covering layer. These rocks crop out on about 40% of Albania's total surface area. All comprise very poor aquiferous layers and are considered almost devoid of groundwater.

Relatively more aquiferous are volcanic-sedimentary complexes of rocks which are found mostly in the north-central part of Albania. They consist of Triassic and Jurassic flysch-like formations with different volcanic rocks like diabase, andesite and spilite, and of partially metamorphosed sedimentary rocks like schists and subordinate sandstones, conglomerates and quartzite. These rocks have lost much of their original porosity due to metamorphisation and growth of minerals in the fissures. The fissures and fractures, which could act as conduits for water, at least near the ground surface, are often closed

Tab. 3: *Hydraulic data for wells tapping fault zones in ultrabasic intrusive rocks*

Number of wells	Depth of wells – m			Specific capacity, l/s/m			Transmissibility, m²/day		
	Minimal	Mean	Maximal	Minimal	Mean	Maximal	Minimal	Mean	Maximal
15	60	225	350	0.06	0.36	1.1	6.5	35	110

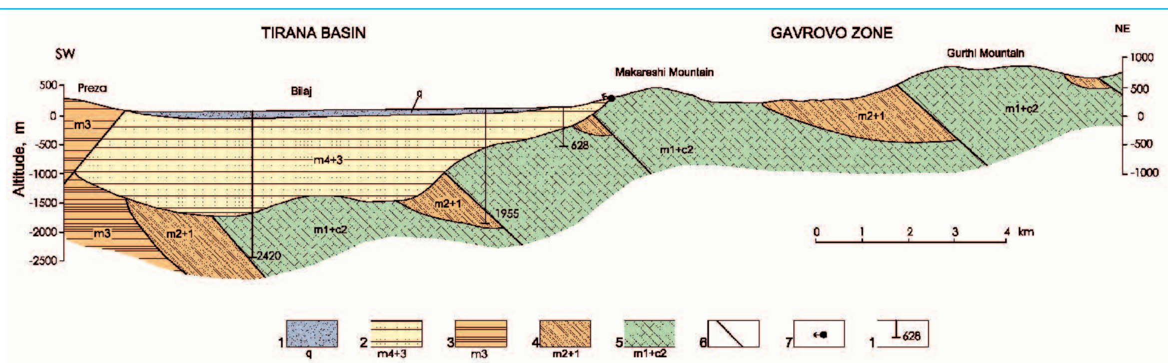

Fig. 13: *Hydrogeological cross-section in the central part of the Tirana Basin*

by clay formation caused by weathering. Their water-bearing capacity is generally low; the yield of wells and springs is less than 0.3 l/s. Most waters have a rather low salinity in the range of 30-150 mg/l, and around copper mines the waters are often acid.

Flysch deposits fill much of the outer tectonic zone, like the Krasta flysch zone, the Kruja zone and Ionian zone. In Krasta flysch there are some small Cretaceous-Palaeogene limestone structures which contain relatively important groundwater resources; some springs have discharges of about 10 to 20 l/s. The Palaeogene-Neogene flysch deposits of the Kruja and Ionian zones generally contain scant groundwater resources. Only in some relatively thick sandstone or limestone layers of the large syncline structures in southern Albania like that of Shushica, Memaliaj and Delvina are there locally important resources.

Mineral waters

There are both thermal and cold mineral waters in Albania. Thermal waters fall into two hydrochemical groups, namely sulphurous and methane waters.

Sulphur mineral water is considered the groundwater with increased concentrations of sulphur gas (H_2S), usually more than 10 mg/l. This type of water occurs primarily in syncline structures of the Ionian and Kruja zones where some major mineral springs are known. Deep wells have revealed thermomineral waters in some buried Mesozoic carbonate structures of these zones which are covered by flysch or molasses (Fig. 13). In the Korabi zone, deep circulating groundwater in contact with gypsum deposits produces the famous sulphur thermomineral springs of Peshkopi. There is a wide range of temperatures, hydrogen sulphur content, total mineralization and chemical types of sulphur waters (Tab. 4).

Methane mineral waters were detected in numerous deep oil and gas exploratory wells in the Neogene aquifers of the Adriatic basin at depths ranging from 1,000 to 3,500 m. The water temperatures range from 25 and 80° C. The waters have increased total mineralization, which varies from 10 to 60 gr/l, and with chlorine-sodium composition; the water has also high hydrogen sulphide and iodine and bromine contents (Tab. 4). Such waters have been recorded from some Adriatic basin structures such as the Ardenice, Frakull, Patos and Seman.

Cold mineral waters is the term assigned to groundwaters whose temperature is less than 20° C or is approximately the same as the mean annual air temperature of the spring location area. To this group belong some springs issuing from the carbonate structures of the Ionian Zone in contact with gypsum and anhydride - evaporate deposits. The waters have a high concentration of sulphates and chlorides. The springs in this group include the Glina and Kolonja near Gjirokastra, and the Bashaj spring in Smokthina (Tab. 5).

Groundwater resources

The total natural groundwater resources of Albania are calculated separately for the main aquifers (Tab. 6). For the calculation the following are taken into the consideration: the outcropping areas of the aquifers, the mean yearly precipitations and their area distribution, as well as infiltration values. The exploitable groundwater resources of Albania consist of about 50% of the total calculated natural groundwater resources. In gravelly aquifers the exploitable groundwater resources could be increased by induced infiltration wells located near recharge sources, which are mostly rivers.

According to approximate estimations in Albania, centralized urban and industrial water supply currently account for about 11 m3/s, while rural water supply uses about 2.0 m^3/s, amounting to a total of about 13 m3/s. This quantity represents only about 9.0 % of the total exploitable groundwater resources in the country.

Groundwater is a vital resource in Albania; it covers about 93% of the total drinking and industrial water consumption of the country. Besides, groundwater has important ecological implications for maintaining ecosystem services. This "unknown" treasure should be

Tab. 4: Synoptic data of sulphur thermomineral groundwater

No	Test point	Dischargel/s	Temperature °C	H_2S mg/l	Mineralization mg/l	Br mg/l	J mg/l	Chemical type
1	Llixha springs. Peshkopi	23	35.5-43.5	49.5	3.8-4.4	2.1	0.6	SO_4–Ca
2	Uji Bardhë springs. Përmet	70.0	18.5-22.5	326-358	5.4-5.6	-	-	Cl–Na
3	Deep well – Mamurras	3.8	17.1	170.0	5.1	-	-	Cl–Na
4	Deep well. Ishmi -1	6.6	59.0	1220	13.5	27.3	4.0	Cl–Na
5	Deep well. Kozan – 8	4.4	54.3	about 400	5.2	6.75	1.8	Cl–SO_4–Na–Ca
6	Llixha springs. Elbasan	15	48-58	335-408	7.0	-	-	Cl–SO_4–Na–Ca
7	Holta spring	20-50	24.0	-	2.4	-	-	SO_4–Mg–Ca (?)
8	Banjo Kapaj springs – 3	3-5	17.7	-	-	-	-	HCO_3–Ca
10	Leskovikut spring	15.0	26.7	7.0	1.2	-	-	Cl–HCO_3–Na–Ca

Tab. 5: *Summary of data of methane thermomineral groundwater and of cold sulphate springs*

No	Investigation point	Discharge/s	Temperature °C	CH_4 %	Mineralization gr/l	Br mg/l	J mg/l	Chemical type
1	Ardenica well– 11	18.0	?	53.5	53.8	109.7	21.2	Cl–Na
2	Kuman well – 1	?	?	-	42.3	100.2	12.9	Cl–Na
3	Seman well – 7	30.0	67.0	-	24.0	25.0	30.0	Cl–Na
4	Bashaj spring	20 - 25	12.0	-	17.18	-	-	Cl–Na
5	Glina spring	1.8–4.0	13.7–16.0	-	1.17	-	-	SO_4–Ca

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better evaluated; investigated, monitored, protected and intelligently exploited. As a country aspiring to join the EU, European Water Directives should really be publicised, incorporated into the country's legislation and enforced. According to such Directives, a considerable research effort needs to be made to identify the Groundwater Bodies of Albania (this concept does not overlap with the already known concept of the aquifer); on this basis the investigation, monitoring and management of groundwater resources should be later organised.

During the past decade, tourist expansion and population density have been particularly evident in Albania, and the problem of water availability has become the main obstacle to further development. Comprehensive research programmes should be undertaken, particularly in coastal areas where many underground flows towards the sea are still waiting to be identified.

Tab.6: Natural and exploitable groundwater resources of Albania

Aquifers related to	Natural resource		Exploitable resources	
	m^3/year	m^3/s	m^3year	m^3/s
Carbonate (karst) rocks	$7.15*10^9$	227	$2.84*10^9$	90
Magmatic intrusive rocks	$1.00*10^9$	32	$0.41*10^9$	13
Molasse deposits	$0.45*10^9$	14	$0.22*10^9$	7
Gravely deposits	$0.47*10^9$	15	$0.945*10^9$	30
Total groundwater resources	$9.07*10^9$	288	$4.4*10^9$	140

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